

# Geopolitical Shock and Corporate Carbon Emissions: A Difference-in-Differences Analysis of the 2022 Russian Invasion of Ukraine

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## Abstract

This paper aims to examine whether the Russian invasion of Ukraine on 24 February 2022 led to changes in greenhouse gas (GHG) emissions of exposed firms to these markets from a dataset of 17,985 publicly listed firms from 104 different countries. Using the invasion as a quasi-exogenous geopolitical shock, a two-way fixed-effects difference-in-differences (DiD) design is applied to the dataset made up of the above-mentioned firms, each observed annually between 2018 and 2025. The treatment group is composed by the firms with pre-war (2018–2021) revenues originating from Russia and Ukraine. The empirical evidence indicates that, under a binary specification, a statistically significant change in Scope 1 emissions is detected. The estimates indicate a statistically significant reduction in Scope 1 emissions of approximately 4.9% ( $\beta = -0.0488$ ,  $p = 0.003$ ). The estimated coefficients are negative across specifications, varying slightly across the different ones, suggesting a pattern consistent with a reduction in Scope 1 emissions among exposed firms. These findings provide firm-level causal evidence that a major geopolitical shock can produce measurable reductions in corporate direct emissions.

*Keywords:* Difference-in-differences, Geopolitical risk, ESG, Scope 1 emissions, Russia–Ukraine war

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## 1. Introduction

The environment in which businesses operate has changed, with geopolitical risk becoming a major determinant in corporate decision-making. In contrast with earlier periods marked by relative stability, the current geopolitical environment is characterised by greater complexity, unpredictability and speed, making political developments a crucial component of corporate strategy (Dhawan and West, 2019). The Russian invasion of Ukraine in February 2022 has made this shift widely visible.

The war had immediate and substantial consequences for multinational firms. Due to their exposure to Russia, many companies faced forced divestitures, asset write-downs, and operational disruptions. High-profile cases such as BP and ExxonMobil reported losses of billions of dollars after leaving the Russian market (Braw, 2023). More broadly, survey evidence highlighted the increasing importance of geopolitical risk for business performance in the context of political unrest (Braw, 2023).

Beyond these direct financial losses, geopolitical shocks generate uncertainty and additional costs. The Russian invasion of Ukraine has altered risk perceptions and reduced the range of actions of companies, with real effects on investment resources and economic activity (Avril et al., 2024). In particular, the conflict caused severe disruptions in global energy markets, leading to significant increases in energy prices and volatility. Given that energy is a fundamental production input, these developments directly affected firms' costs, profitability and operational decisions. Heightened uncertainty may lead firms to postpone or scale back long-term investments, particularly when these involve high sunk costs or limited reversibility (Bloom et al., 2022). Disruptions in trade routes, input sourcing and supply chain relationships can also require firms to reorganise production and adjust their sourcing strategies (Baldwin and Freeman, 2021).

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These mechanisms are directly relevant for environmental performance. Corporate carbon emissions, especially Scope 1 and Scope 2, are closely tied to production processes, energy consumption and the composition of energy use. This creates a tension between short-term economic pressures and sustainability goals, particularly regarding the reduction of carbon footprints. Geopolitical shocks may affect emissions through multiple channels. Among others, rising energy prices and concerns about energy sources can cause firms to reduce energy dependence, improve efficiency or accelerate diversification from fossil fuels. In contrast, uncertainty and financial pressure may drive firms to delay green investment and undertake short-term production adjustments that increase emissions. Taken together, these effects imply that geopolitical shocks can create a trade-off between short-term operational adjustment and longer-term decarbonisation objectives.

Importantly, the impact of such shocks is unlikely to be uniform across firms, as they differ in their exposure to the conflict. Exposure depends on firms' investments, operations, customer base, energy dependency and supply chain linkages in the affected regions. As shown in the ECB framework, agents with higher exposure to geopolitical conflicts respond more strongly to such shocks (Avril et al., 2024). This heterogeneity provides a natural setting to analyse how firms adjust their environmental performance in response to geopolitical events. It raises the question of whether more exposed firms to the Russia–Ukraine shock changed their actual emissions differently from those that were less exposed.

The Russian invasion of Ukraine is particularly relevant for such an analysis as it constitutes an unexpected and exogenous shock. Its timing was abrupt, its economic consequences were broad, and its effects varied across firms depending on their existing exposure to the affected region.

A key unanswered question in the literature is whether geopolitical disruptions translate into improvements in corporate environmental performance, or simply mechanically reduce emissions due to disruption. This distinction is crucial. While much research has focused on geopolitical shocks' influence on changes in ESG scores, financial results, and investor behaviour, very little work has addressed the issue of how corporate carbon emissions actually respond to such shocks. ESG indicators often capture increased transparency, corporate image and policy rather than operational outcomes. Therefore, there is currently limited evidence concerning the relationship between a firm's environmental impact and geopolitical disruption events. By focusing specifically on firms' emissions in Scopes 1 and 2, this paper directly addresses the extent to which firms alter their actual emissions following geopolitical disruptions.

Knowledge on the nature of the response of firms' emissions to geopolitical disruptions is essential when trying to understand the reasons behind changes in firms' carbon footprints. A decrease in emissions could stem from multiple factors including firm contraction, changes in supply chain or adjustments in energy consumption. Separating these effects might be difficult, however, establishing the existence of a reaction to a shock and its variability by firms' sensitivity is a starting point.

Against this background, this paper examines the effect of the Russia–Ukraine war on international firms' Scope 1 and Scope 2 emissions. Using firm-level emissions data (2018–2025) and cross-sectional variation in exposure to the conflict, the paper studies whether the onset of the war led to a significant change in firms' actual carbon emissions and whether this effect was stronger for firms with higher exposure to Russia and Ukraine.

This contribution is threefold. First, the paper moves beyond ESG scores by focusing on realised emissions, thereby capturing firms' actual environmental performance. Second, by relying on a clearly identified geopolitical shock rather than on a continuously evolving risk index, the analysis can move closer to identifying the causal effect of geopolitical risk on firm-level emissions. Third, it provides new evidence on how emissions respond to geopolitical shocks, giving a new perspective on the mechanisms at work.

## **2. Hypotheses Development**

Despite the growing interest in understanding the relationship between geopolitical risk and corporate sustainability, several gaps remain in the existing research.

Most of the literature relies mainly on employing broad sustainability proxies such as firms' ESG scores assigned to companies, rather than on firms' actual environmental measures. While these composite indicators are useful in capturing general corporate sustainability practices, they do not directly measure environmental performance. In particular, such measures may not capture firms' actual carbon emissions, which are more closely tied to firms' production technologies, energy consumption and operational choices. For a study interested in how firms respond

to an external shock through concrete environmental adjustment, Scope 1 and Scope 2 emissions represent a more precise measure regarding environmental performance than aggregate ESG ratings.

An important strand of literature measures firm-level exposure to political or climate risk using word-based indicators derived from earnings calls or corporate disclosures. Although these approaches provide valuable insights into firms' perception of risk, they capture attention to such uncertainties rather than realised environmental outcomes.

While some studies analyse the relationship between political risk and emissions, they rely on constructed risk indices rather than exploiting a clearly defined geopolitical shock. As a result, isolating the causal impact of a specific event on firms' environmental performance remains difficult. This limitation is important, as it constrains the possible interpretation of whether observed changes in corporate carbon footprints reflect genuine environmental adjustment or are simply driven by broader macroeconomic conditions and evolving risk perceptions.

Although recent research increasingly uses exogenous geopolitical shocks and difference-in-differences strategies to study firm behaviour, the outcomes analysed are typically financial or operational, such as profitability, investment, firm risk, supply chain restructuring or ESG engagement. There remains limited causal evidence on how firms' actual carbon emissions respond to a major geopolitical shock.

Taken together, the literature offers useful insights into the connections between geopolitical risk and corporate sustainability, but it still lacks direct evidence on the adjustment of actual firm-level emissions in response to a large geopolitical shock. It remains unclear whether firms exposed to the Russia–Ukraine conflict, due to commercial, operational or supply chain ties, changed their Scope 1 and Scope 2 emissions differently from less exposed firms.

This paper addresses this gap by examining the impact of the Russian invasion of Ukraine on firms' Scope 1 and Scope 2 emissions, conditional on their exposure to the conflict. By focusing on actual emissions and exploiting variation in exposure to a specific geopolitical event, this paper contributes to understanding the environmental consequences of geopolitical shocks at the firm level.

The empirical analysis is guided by the following research question:

*RQ. Do firms with pre-war exposure to Russia and Ukraine exhibit a different emissions adjustment after the onset of the war compared to non-exposed firms?*

The main hypotheses are:

*Hypothesis 1. Pre-war commercially exposed firms to Russia and Ukraine experienced a different adjustment in Scope 1 GHG emissions after the onset of the Russia–Ukraine war compared to non-exposed companies.*

*Hypothesis 2. Pre-war commercially exposed firms to Russia and Ukraine experienced a different adjustment in Scope 2 GHG emissions after the onset of the Russia–Ukraine war compared to non-exposed companies.*

### **3. Literature Review**

#### *3.1. Geopolitical risk and corporate environmental performance*

Recent academic interest has increasingly examined how changes in the global political situation shapes businesses operations in terms of sustainability. However, most of the research conducted on the potential effects of geopolitical risk has focused on the stock market or investment outcomes rather than on environmental performance. More recent work, instead, increasingly treats geopolitical risk as an external force that shapes firms' environmental practices.

Geopolitical risk has been shown to affect firms' ESG performance across countries. Abdullah et al. (2024) provide a large cross-country study using 65,354 firm-year observations across 41 countries over the period 2002–2021, documenting a negative relationship between geopolitical risk, measured using the Caldara and Iacoviello (2022) index, and the Thomson Reuters ESG score. The results indicate that geopolitical risk weakens ESG performance through

channels such as higher cost of capital, lower levels of corporate investment and reduced cash holdings. Nonetheless, firms operating in lower-risk environments may strategically strengthen sustainability policies in response to geopolitical tension, mainly to improve reputation.

However, the literature is not unanimous. Erzurumlu et al. (2025) use the same Caldara and Iacoviello (2022) index to examine geopolitical risk and Economist Intelligence Unit data to measure domestic political risk, and find that firm responses are heterogeneous. Based on a sample of 42,587 firm-year observations from 37 countries over 2002–2022 and employing a lead–lag autoregressive panel methodology, the study finds that higher risk is associated with increased ESG engagement, with heterogeneous effects across firms depending on their initial ESG maturity. Firms with lower ESG scores react more strongly to domestic political instability, while firms with higher ESG maturity respond more acutely to geopolitical shocks.

Alternative identification strategies further support the adverse effects of geopolitical instability on ESG outcomes. Saharti et al. (2024) provide evidence based on a binary treatment methodology, using a dichotomous geopolitical variable from the Uppsala Conflict Data Program (UCDP/PRIO) for 79 countries over 2002–2021, showing the effect of firms’ nationality on the matter. The fixed-effects regressions find that firms based in countries experiencing geopolitical conflict exhibit lower Refinitiv ESG scores than those in non-conflict countries. The effect is greater in developed nations than in developing ones. The findings for the environment pillar are particularly relevant: uncertainty appears to discourage long-term capital investments aimed at reducing greenhouse gas emissions.

Furthermore, recent research highlights how firms’ climate change risk is affected by geopolitical uncertainties (Rahim et al., 2025). Using data from 40 countries over 2004–2022 (56,601 observations) and climate risk measures based on text-based analysis of corporate disclosures (Sautner et al., 2023), the results find that climate vulnerability rises as a firm’s geopolitical risk (Caldara and Iacoviello, 2022) increases.

Firm-level evidence from China further supports these results. Focusing on Chinese A-share companies, Jiang et al. (2024) show that global geopolitical risks negatively affect performance on the Bloomberg ESG score, with stronger effects among non-state-owned and politically unconnected firms. The study highlights that the most likely channel is the reduced ability to access the financial capital needed for environmental investments under geopolitical risk. Although focused on Chinese firms, this study provides useful evidence on the channels through which geopolitical uncertainty translates into weaker environmental performance.

Evidence from global event studies further confirms the heterogeneous impact of geopolitical shocks across firms and countries. Boccaletti et al. (2026), using a sample of more than 17,000 firms worldwide, show that the Russia–Ukraine invasion generated significant negative stock market reactions, with substantial variation across countries and sectors. Importantly, firms with stronger ESG performance experienced less negative market reactions, suggesting that sustainability characteristics can partially buffer geopolitical shocks.

In Europe, a more nuanced analysis reveals differences in the influence of geopolitical shock on ESG categories (Kovács et al., 2024). Governance attributes became highly valuable for shareholders during the invasion, whereas environmental and social factors were less influential in determining stock prices.

As one can conclude from the discussed literature, the effect of geopolitical risks on the sustainability of firms may differ widely among countries, firms, industries and ESG attributes.

### *3.2. Geopolitical risk and carbon emissions*

A small but growing body of work focuses more directly on emissions and carbon intensity. This literature is closer to the present study as it moves from broad ESG assessments to realised environmental outcomes.

Firm-level evidence provides more direct insights into how political uncertainty affects carbon emissions. Banerjee et al. (2025) provide the closest study to ours within this literature. Using the firm-level political risk measure constructed from quarterly text analysis of earnings conference call transcripts devoted to political risks (Hassan et al., 2019), the findings suggest that heightened political risk leads US firms to reduce their total Scope 1 and Scope 2 carbon emissions. The findings suggest that firms reduce emissions in response to greater political scrutiny and that environmental innovation plays an important role in enabling this adjustment. This reduction is achieved mainly through environmental innovation investments.

According to Shu et al. (2022), geopolitical risk is a driver of carbon intensity and CO<sub>2</sub> emissions at the national level. Examining several high-geopolitical-risk countries, evidence indicates that geopolitical instability interacts with financial developments and renewable energy insertion in shaping a country’s carbon intensity.

Focusing specifically on EU member states between 1990 and 2021, Borozan (2024) suggests that the relationship between geopolitical risk and emissions is time-dependent. While a short-run mitigating impact of geopolitical risk on carbon emissions is observed, this effect is statistically insignificant in the long run. However, when energy security and geopolitical risk are considered jointly, the result observes an increase in emissions.

Li et al. (2025) provide evidence of a threshold effect: rising geopolitical risk increases carbon emissions in higher-income countries via strategic reallocation of energy resources, while reducing them in lower-income countries through demand compression. These macro-level findings are not directly transferable to the firm level but offer a useful reference point for assessing how disruptions to energy markets caused by the Russia–Ukraine conflict propagate through the economy.

Recent research findings from around the world have further underscored the intricate nature of the association between geopolitical risk and carbon emissions. Using the technique of panel regression for 31 nations, Feng et al. (2024) have shown that geopolitical risk and energy resilience exhibit an interaction with carbon emissions. Specifically, they establish that geopolitical risks can have a negative effect on carbon emission.

Taken together, the international literature provides strong evidence that geopolitical shocks affect corporate behaviour, financial performance, and ESG-related outcomes across countries. However, most existing studies focus on stock market reactions, ESG scores, or macro-level emissions, rather than firms' realised carbon emissions. This leaves limited international evidence on how firm-level Scope 1 and Scope 2 emissions adjust in response to a major geopolitical shock.

### *3.3. Geopolitical shocks and corporate behaviour: difference-in-differences antecedents*

The causal identification of geopolitical effects on corporate outcomes has also been studied through difference-in-differences (DiD) experiments that exploit exogenous shocks as sources of variation. This literature is important as it shows that geopolitical events can be studied with such causal framework when firms differ in their ex-ante exposure to the shock. The Russia–Ukraine war, as a singular and significant event, has provided an attractive setting for the application of this methodology.

Wang et al. (2024) examine how exit decisions from Russia after the invasion affect firms' idiosyncratic risks, comparing US firms that announced their withdrawal from Russia between February and May 2022 with a set of matched control firms. The findings reveal that companies exiting Russia experience an overall decrease in idiosyncratic risk, with significantly larger reductions for firms that withdraw completely rather than for those that only suspend their operations. The study indicates that firms with geographically diversified supply chains experience significantly larger decreases relative to those without such diversification, suggesting that supply chain structure moderates a firm's sensitivity to global shocks.

Shu et al. (2024) provide complementary evidence by examining firms that remained in Russia following the invasion. Using propensity score matching combined with DiD, the results show that firms maintaining operations experienced significant profitability deterioration, with stronger effects for firms having subsidiaries and suppliers in Russia and attenuated effects for those with only customers exposure. While not focused on environmental outcomes, these studies demonstrate the validity of the Russia–Ukraine war as a DiD setting.

The US–China trade war has generated a parallel stream of evidence on how geopolitical frictions affect corporate sustainability. Zhang et al. (2025) use evidence from the 2018 tariff escalation to investigate in a DiD design how US–China trade tariffs affect the environmental performance of US semiconductor firms. The treatment group consists of US semiconductor firms with direct suppliers in mainland China, while the control group comprises high-tech firms without such supplier relationships. The study finds that heightened bilateral tensions significantly affect firms' environmental performance through increased operational uncertainty and supply chain disruptions, reducing investment in environmental initiatives.

Some studies examine firms' strategic responses by firms. Xu and Wu (2023) analyse how import competition from China affects the ESG performance of US firms, finding that greater import competition leads to improved ESG scores, with the improvement driven by differentiation strategies. Similarly, Xu et al. (2024) document that Chinese exporters responded to the escalation of US import tariffs by strengthening their ESG engagement as a competitive positioning strategy, with the effect stronger for firms with green innovation capabilities. Long and Jia (2022) provide complementary evidence by examining CSR disclosure readability among Chinese listed firms during the trade war, documenting that firms released more readable CSR reports in response to the geopolitical shock, interpreted as

reputation management under adversity. Collectively, this US–China trade war literature establishes several important methodological and conceptual precedents for the present study: the validity of the DiD approach for geopolitical shocks, the importance of differential firm exposure and the role of strategic environmental signalling as a corporate response to geopolitical pressure. Together, these studies show that geopolitical shocks can be studied using quasi-experimental methods, but direct evidence on firm-level carbon emissions under the Russia–Ukraine shock is still missing.

#### *3.4. Measuring geopolitical risk exposure at the firm level*

A central challenge in studying the effect of geopolitical risk at the firm level is constructing a measure of exposure that captures firm-specific exposure to a given geopolitical event, rather than the national one. Importantly, the concept of firm-level exposure is not uniquely defined in the literature. It rather depends on the channels through which a geopolitical shock affects companies. Different studies analyse exposure using specific dimensions such as reliance on Russian energy, supply-chain linkages or commercial ties with the affected regions. These alternative measures capture distinct but related aspects of firms' vulnerability to the shock. As a result, differences in exposure definitions across studies should not be interpreted as inconsistencies, but rather as reflecting different underlying transmission channels. Within this broader framework, the existing literature has relied on three broad approaches to measuring firm-level exposure.

The first uses country-level GPR indices (Caldara and Iacoviello, 2022) and assigns each firm the GPR of its country of domicile. This approach is, however, US-centric in its construction and does not take into consideration the fact that a company may also be exposed to other countries' risk through its supply chain, for example.

The second approach uses text-based measures, such as the firm-level political risk index of Hassan et al. (2019), which exploits textual analysis of earnings call transcripts to measure idiosyncratic political risk exposure.

The third approach, most relevant for event-study or DiD designs, constructs ex-ante firm-level exposure measures based on observable firm characteristics that predict sensitivity to the specific geopolitical event under study. In the context of the Russia–Ukraine war, relevant exposure dimensions include, among others, revenue derived from Russian and Ukrainian markets, reliance on Russian-origin energy inputs (particularly natural gas) and supply-chain ties with Russian counterparties. While some studies focus on energy dependence as the primary channel of exposure, this paper adopts a commercial exposure measure based on pre-war revenues from Russia and Ukraine, thereby capturing firms' economic dependence on the affected markets. This third approach is particularly attractive as it aligns measurement with causal identification: by relying on pre-war exposure, it becomes possible to compare how firms with different initial ties to the affected region adjusted after the shock.

#### *3.5. The Russia–Ukraine war as a corporate sustainability shock*

The Russian invasion of Ukraine in February 2022 represents an unusually sharp and exogenous geopolitical shock. Several mechanisms link the war to firm-level environmental outcomes.

One immediate effect of the war was the disruption of global energy markets. The conflict triggered an acute energy crisis, particularly in Europe, as Russian natural gas supplies were curtailed or became politically unsustainable. Firms dependent on Russian sourced energy faced a sudden increase in input costs and supply uncertainty. This created incentives to reduce energy consumption, diversify energy sources or adjust supply chains, which may have affected carbon intensity. The crisis raised production costs for firms, especially in energy-intensive activities. Since emissions depend on energy use, these changes are likely to have affected firms' carbon emissions (Shu et al., 2022; Borozan, 2024).

At the same time, the war led to an increase in macroeconomic and geopolitical uncertainty, which has been shown to affect firms' investment decisions (Caldara and Iacoviello, 2022). This is particularly relevant for environmental performance, as investments aimed at reducing emissions are typically long-term and costly and may therefore be delayed.

Recent research also highlights the role of financial constraints. Evidence based on the Russia–Ukraine shock shows that banks more exposed to geopolitical risk reduced their lending, leading to declines in investment and employment in relying firms (Avril et al., 2024). To the extent that environmental investments depend on external financing, this channel may also affect firms' ability to reduce emissions.

The effects of the war are unlikely to be uniform across firms. Exposure to Russia and Ukraine varies depending on firms' operations, energy sourcing and supply chains. Firms with stronger links to the region appear to have

experienced more severe disruptions after the invasion (Shu et al., 2024; Wang et al., 2024), which suggests that their adjustment may also differ. Firm-level evidence from Europe confirms the central role of energy exposure during the war. Ferriani and Gazzani (2023) show that European firms with higher energy and carbon intensity experienced significantly worse financial performance following the invasion, as rising energy prices disproportionately affected their cost structures and risk profiles.

Finally, the reputational and regulatory environment shifted sharply following the invasion. European governments accelerated their renewable energy targets and imposed pressure on firms to reduce dependence on fossil fuels, while investors and stakeholders intensified scrutiny of firms' geopolitical and environmental exposure simultaneously. The coincidence of the war with a phase of heightened climate policy ambition in Europe, including the implementation of the EU Taxonomy and evolving corporate sustainability reporting requirements, creates both a challenge and an opportunity for identification: firms' carbon responses to the war are confounded by concurrent regulatory developments, but also amplified by the institutional context.

Taken together, an ambiguous overall effect of the Russia–Ukraine war on firm-level emissions may be expected. While higher energy costs may encourage efficiency improvements, increased uncertainty and tighter financing conditions may work in the opposite direction. This makes the conflict a relevant setting to examine how firms adjust their environmental performance following a major geopolitical shock.

Against this background, this study contributes to the literature in three main ways.

First, it provides causal evidence on the effect of the Russia–Ukraine war on firm-level carbon emissions, exploiting the war as a quasi-natural experiment and using a difference-in-differences design with pre-event measures of geopolitical risk exposure to identify heterogeneous treatment effects. This approach extends the quasi-experimental literature on the war (Wang et al., 2024; Shu et al., 2024) to the environmental domain and complements macro-level evidence on geopolitical risk and carbon emissions (Shu et al., 2022; Borozan, 2024; Li et al., 2025).

Second, the study contributes to the geopolitical-risk and ESG literature (Abdullah et al., 2024; Erzurumlu et al., 2025; Saharti et al., 2024; Jiang et al., 2024) by focusing specifically on Scope 1 and Scope 2 emissions as a direct dimension of environmental performance. Realised emissions capture the operational dimension of decarbonisation and are less susceptible to aggregation and rating transparency issues documented for composite ESG scores.

Third, while the political-risk and carbon-emissions literature (Banerjee et al., 2025) focuses on US firms and on general political risk rather than on a specific geopolitical shock such as the Russia–Ukraine war, this study addresses that gap. It allows us to identify whether the environmental effects of the war scale systematically with pre-war firm exposure to the affected region.

## **4. Data and Method**

### *4.1. Data and sample*

The empirical analysis is conducted on a firm-year panel covering 17,985 publicly listed firms from 104 countries, representing 71 industries, and over the period 2018–2025, for a total of 143,880 observations. The dataset is made up of accounting information (total revenues), geographic revenue decomposition (turnovers originating from Russia and Ukraine) and environmental measures (Scope 1 and Scope 2 location-based GHG emissions, expressed in metric tonnes of CO<sub>2</sub>-equivalent).

The environmental data were extracted from the Trucost Environmental Dataset by S&P Global Sustainable1. Only public firms with at least 4 observations for each measure were retained and the few missing GHG emissions values were estimated using the arithmetic average of the available data for the same company. Revenues originating from Russia and Ukraine were, instead, collected from FactSet using the site's estimates for each company and year through an API established between code and website.

The sample is broadly diversified across industries and countries. No single sector or country of origin dominates the composition. A large residual category ("Other") accounts for about 65% of firms, while the remaining observations are spread across industries such as chemicals, machinery, and electronic equipment, each representing a relatively small share of the total observations. Similarly, firms originate from a wide range of countries, with no single country accounting for a disproportionate share of the sample. However, at the regional level, Asia and the United States jointly account for about 70% of the observations, indicating an expected degree of concentration across broader geographic areas.

Table 1 reports descriptive statistics for the main variables. Two features of the sample deserve specific emphasis. First, the average pre-war exposure to Russia and Ukraine is modest: across firms, the mean combined exposure is approximately 0.5% of total revenues. Even the most exposed firms in the sample (excluding Russian or Ukraine companies) rarely derive more than 15–20% of their turnovers from the two belligerent economies. Second, the distribution of GHG emissions is highly right-skewed, as is typical for such data. For instance, Scope 1 emissions have a mean of 844,049 tCO<sub>2</sub>e but a median of only 6,503, and Scope 2 emissions show a similar pattern (mean 140,436 vs. median 8,514), motivating the use of a logarithmic transformation in the empirical specifications.

Table 1: Descriptive Statistics.

Variable	Mean	SD	p25	Median	p75
Revenues (USD mn)	3,237	14,698	128	440	1,601
% Revenues Russia	0.438	2.992	0.000	0.000	0.266
% Revenues Ukraine	0.064	1.209	0.000	0.000	0.025
Scope 1 (tCO <sub>2</sub> e)	844,049	7,927,750	1,008	6,503	44,842
Scope 2 (tCO <sub>2</sub> e)	140,436	1,134,568	1,533	8,514	42,683

Notes:  $N = 143,880$  firm-year observations on 17,985 firms over 2018–2025. Pooled across years.

Table 2: Variable Description.

Variable	Measure
Ticker	FactSet company ticker
Company_id	Trucost Environment database company id
company_name	Company's full name
industry	Trucost Environment assigned sector
country	Country of headquarter
fiscal year	Fiscal year of the observation
ghg_scope1	tCO <sub>2</sub> e GHG Scope 1 emissions
ghg_scope2_location	tCO <sub>2</sub> e GHG Scope 2 location-based emissions
revenue	Total company turnover
pct_rev_ukraine	FactSet estimated revenue % from Ukraine
pct_rev_russia	FactSet estimated revenue % from Russia

#### 4.2. Identification

The empirical strategy treats the 24 February 2022 invasion as a quasi-exogenous geopolitical shock and exploits cross-sectional variation in firms' pre-war economic exposure to Russia and Ukraine to identify differential causal effects. The identifying assumption is that, in the absence of the invasion, the trajectory of GHG emissions of treated firms (those with any positive pre-war exposure) would have evolved in parallel with that of control firms (those with zero pre-war exposure), conditional on the relevant fixed effects.

To minimise the risk of endogenous treatment classification, the war itself altered post-2022 exposure through divestment and operational withdrawal, this study defines treatment using the firm's average share of revenues originating from Russia and Ukraine over the pre-war period 2018–2021:

$$Exposure_i = \frac{1}{4} \sum_{t=2018}^{2021} \frac{Rev_{it}^{RU} + Rev_{it}^{UA}}{Rev_{it}} \quad (1)$$

This pre-war exposure measure is constant within firm by construction. The treatment indicator is then defined as a binary variable equal to one whenever pre-war exposure is strictly positive:

$$Treat_i = \mathbf{1}\{Exposure_i > 0\} \quad (2)$$

This any-exposure specification is preferred over a percentile-based cutoff for two reasons. First, given the highly skewed distribution of pre-war exposure documented in Section 4, with the median of the full sample at exactly zero, the natural and substantively meaningful threshold is the discontinuity between firms with and without any commercial presence in the affected economies. Second, the binary specification has a transparent interpretation: it compares firms that had something to lose, however modest, in Russia or Ukraine with firms that had no commercial stake in the affected region.

### 4.3. Specifications

The baseline two-way fixed effects DiD regression takes the form:

$$y_{it} = \alpha_i + \lambda_t + \beta(Treat_i \times Post_t) + \varepsilon_{it} \quad (3)$$

where  $y_{it}$  is  $\log(1 + Scope_{k_{it}})$  for firm  $i$  in year  $t$ ;  $\alpha_i$  are firm fixed effects;  $\lambda_t$  are the fixed effects (depending on the model);  $Post_t$  equals one for  $t \geq 2022$ ;  $\beta$  (the coefficient of interest) captures the differential change in the outcome experienced by treated firms relative to controls in the post-invasion period; and  $\varepsilon_{it}$  is the error for firm  $i$  in year  $t$ .

Three fixed-effects specifications are reported throughout the paper to assess the robustness of the estimates to alternative sources of confounding variation:

- *Firm FE + Year FE*: the baseline two-way fixed-effects model. Year fixed effects absorb common shocks that affect all firms in a given year (such as the global energy price shock or the pandemic-related distortions).
- *Firm FE + Country  $\times$  Year FE*: this specification absorbs all country-specific time-varying shocks. It is particularly important in a global panel: if firms headquartered in a given country face common regulatory, macroeconomic or political pressures that simultaneously affect both their exposure to Russia and Ukraine and their emissions, country-by-year fixed effects neutralise this confounder. Identification then comes from comparing firms within the same country in the same year, which differ in their pre-war exposure.
- *Firm FE + Industry  $\times$  Year FE*: this specification absorbs all industry-specific time-varying shocks. In particular, it absorbs sectoral energy-price shocks, which is essential given that the post-invasion period was characterised by very heterogeneous price dynamics across sectors. Identification comes from comparing firms within the same industry in the same year.

### 4.4. Outcomes and inference

Two outcomes are considered:  $\log(1 + Scope_{1_{it}})$  and  $\log(1 + Scope_{2_{it}})$ . The  $\log(1 + x)$  transformation accommodates the small share of zero observations and the heavy right-skewness of the emissions distributions. Standard errors are clustered at the firm level throughout, following the recommendation of Bertrand et al. (2004) for DiD designs with repeated dependence within units.

### 4.5. Event-study specification

To assess the parallel-trends assumption and to depict the dynamic profile of the effect, the event-study analogue of equation (3) is also estimated:

$$y_{it} = \alpha_i + \lambda_t + \sum_{k \neq 2021} \theta_k (Treat_i \times \mathbf{1}\{t = k\}) + \varepsilon_{it} \quad (4)$$

where 2021, the last year before the invasion, is taken as the omitted reference. The coefficients  $\theta_k$  for  $k < 2021$  test for pre-existing differential trends; the coefficients  $\theta_k$  for  $k \geq 2022$  trace the dynamic response to the shock. The same three fixed-effects specifications considered in Section 4.3 are applied to the event-study model. A joint Wald test on the pre-treatment coefficients (years 2018–2020) is used to formalise the parallel-trends assessment.

## 5. Results

### 5.1. Treated group composition

Table 3 reports descriptive statistics of the treated and control firms before the shock. Treated firms have, on average, substantially larger size, with pre-2022 revenues mean of USD 4,401 million compared to USD 2,002 million of the control group. The size difference suggests that firms with commercial exposure to Russia or Ukraine tend to have higher scale and be more internationally active. Consistent with this difference and with the general direct relationship between revenues and emissions, treated firms also display higher absolute pre-shock emissions: both Scope 1 and Scope 2 are higher for exposed firms. Furthermore, the table reveals compositional differences across regions, industries and countries. Non-treated firms are more represented in sectors such as Real Estate Management and Banks, which are typically more domestically oriented and more closely tied to local markets. As a result, these industries are less directly exposed to the disruptions generated by a war occurring outside the borders of their main country of operation. Considering the country level, treated firms are more concentrated in South Korea and Taiwan.

These descriptive differences reinforce the necessity of using firm fixed effects and demanding country-by-year and industry-by-year fixed effects in the empirical analysis to ensure that the estimated treatment effect is not driven by differences in sample composition.

Table 3: Treated Group Statistics.

Dimension	Variable / Category	Control	Treated
Sample	Number of firms	10,831	7,154
Firm size	Pre-2022 revenues mean, USD mn	2,002	4,401
Pre-shock emissions	Mean Scope 1 emissions, tCO <sub>2</sub> e	774,762	961,564
	Mean Scope 2 emissions, tCO <sub>2</sub> e	86,958	207,856
Region	European firms	12.8%	14.7%
Industry composition	Chemicals	2.9%	7.7%
	Machinery	2.8%	7.5%
	Real Estate Management	5.6%	0.9%
	Banks	5.1%	1.2%
Country composition	South Korea	5.5%	10.1%
	Taiwan	4.2%	8.7%

### 5.2. Parallel-trends diagnostics

Before estimating the post-treatment differential effect, the validity of the parallel-trends assumption is assessed jointly through a Wald test on the pre-treatment event-study coefficients ( $\theta_{2018} = \theta_{2019} = \theta_{2020} = 0$ ) and visually through the event-study plots in Figure 1 and Figure 2.

Table 4 reports the joint Wald-test results for the two outcomes and the three fixed-effects specifications.

For Scope 1, the null hypothesis of zero pre-trends cannot be rejected at the 10% level under any specification ( $p$ -values range from 0.148 to 0.672). The visual inspection in Figure 1 confirms this: the pre-treatment coefficients are economically small and statistically indistinguishable from zero across all three specifications. The parallel-trends assumption is therefore credible for Scope 1.

For Scope 2, by contrast, the joint Wald test rejects the null of zero pre-trends decisively in all three specifications ( $p < 0.01$ ). The event-study plot in Figure 2 reveals the source: treated firms exhibited a downward differential drift in log Scope 2 relative to controls in the years preceding the invasion, with pre-2021 coefficients in the range  $-0.04$  to  $-0.08$ . This systematic divergence violates the central identifying assumption of DiD for the Scope 2 outcome and implies that the post-2022 coefficient cannot be given a clean causal interpretation: at least part of the post-invasion differential reflects mean reversion rather than the effect of the shock.

This contrast between Scope 1 (parallel trends supported) and Scope 2 (parallel trends rejected) is methodologically important and conditions the interpretation of the main results in Section 6.

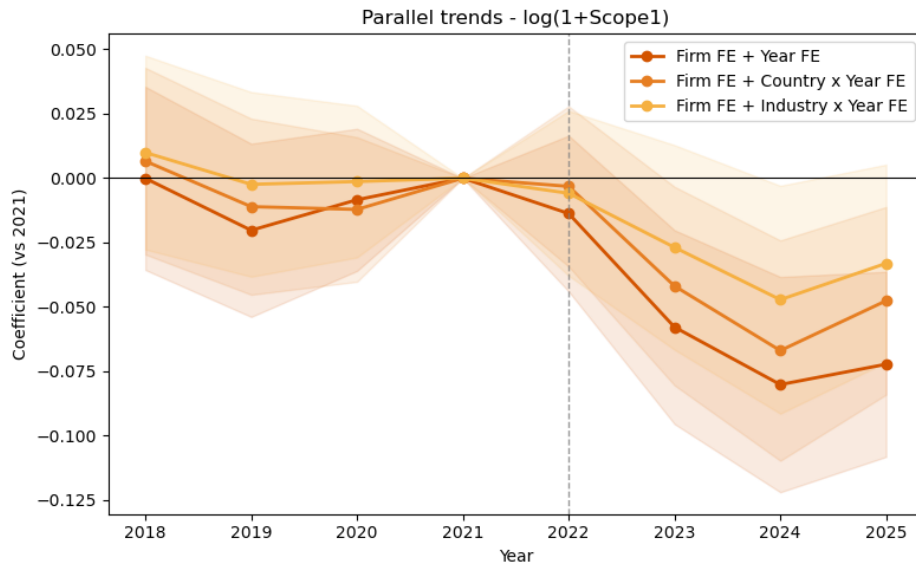


Figure 1: Event-study estimates —  $\log(1 + \text{Scope } 1)$ .

*Notes:* Event-study estimates of the differential effect of pre-war exposure (any vs. none) on  $\log(1 + \text{Scope } 1)$  emissions. Each line corresponds to a different fixed-effects specification. Year 2021 is the omitted reference. The vertical dashed line marks the February 2022 invasion. Shaded areas represent 95% confidence intervals based on firm-clustered standard errors.

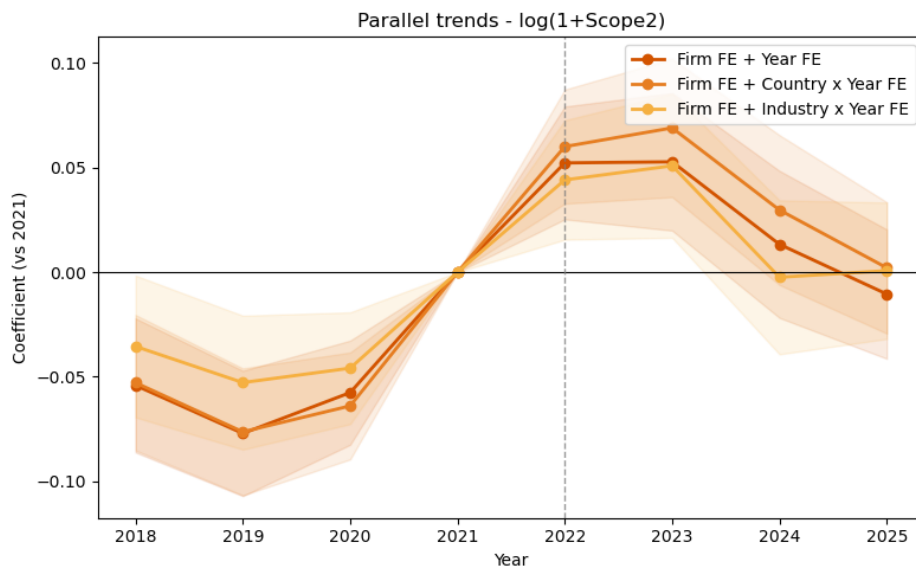


Figure 2: Event-study estimates —  $\log(1 + \text{Scope } 2)$ .

*Notes:* Event-study estimates of the differential effect of pre-war exposure (any vs. none) on  $\log(1 + \text{Scope } 2)$  emissions. Each line corresponds to a different fixed-effects specification. Year 2021 is the omitted reference. The vertical dashed line marks the February 2022 invasion. Shaded areas represent 95% confidence intervals based on firm-clustered standard errors.

Table 4: Joint Wald test on pre-treatment coefficients (2018–2020).

Specification	Outcome	Wald	$p$ -value	PT satisfied?
Firm FE + Year FE	log(1 + Scope 1)	5.349	0.148	Yes
Firm FE + Year FE	log(1 + Scope 2)	31.967	0.000	No
Firm FE + Country $\times$ Year FE	log(1 + Scope 1)	3.848	0.278	Yes
Firm FE + Country $\times$ Year FE	log(1 + Scope 2)	33.221	0.000	No
Firm FE + Industry $\times$ Year FE	log(1 + Scope 1)	1.544	0.672	Yes
Firm FE + Industry $\times$ Year FE	log(1 + Scope 2)	15.520	0.001	No

*Notes:* The Wald test is performed jointly on the pre-treatment event-study coefficients for years 2018, 2019 and 2020, with 2021 as the omitted reference year. All specifications include firm fixed effects and year fixed effects. Standard errors are clustered at the firm level. The null hypothesis is that all three pre-treatment coefficients are jointly equal to zero. The parallel-trends assumption is judged satisfied at the 10% significance level.

### 5.3. Baseline DiD estimates

Table 5 reports the baseline DiD estimates of equation (3) for the two outcomes and the three fixed-effects specifications. The coefficient of interest is  $\beta$ , the interaction between the binary exposure indicator and the post-invasion dummy.

Three patterns stand out from the table. First, the Scope 1 coefficient is negative and statistically significant in all three specifications, with magnitudes between  $-0.030$  and  $-0.049$  log-points. The Firm FE + Year FE estimate ( $-0.049$ ,  $p = 0.003$ ) implies that firms with any pre-war exposure to Russia and Ukraine experienced an approximately 4.9% reduction in (one plus) Scope 1 emissions in the post-invasion period relative to firms with no exposure. Considering the exposed firms over the period average Scope 1 emissions of 953,262 tCO<sub>2</sub>e, a 4.9% reduction equals 46,710 tCO<sub>2</sub>e. The estimate is attenuated but remains statistically significant when country-by-year ( $-0.036$ ,  $p = 0.031$ ) or industry-by-year ( $-0.030$ ,  $p = 0.077$ ) fixed effects are added. The fact that the negative effect survives the inclusion of these high-dimensional fixed effects is reassuring, as it indicates that the result is not driven by country, or industry, specific common shocks.

Second, the Scope 2 coefficient is positive and highly statistically significant in all three specifications, with magnitudes between  $+0.057$  and  $+0.089$ . Taken at face value, this would suggest that exposed firms experienced a relative increase in indirect (purchased electricity) emissions after the invasion. However, as documented in Section 5.2, the parallel-trends assumption is decisively rejected for the Scope 2 outcome. The event-study plot in Figure 2 makes clear that this positive coefficient reflects in large part a pre-existing downward drift in the Scope 2 emissions of treated firms relative to controls, which is mechanically translated into a positive post-invasion differential when treated and controls revert toward similar levels. The Scope 2 result is therefore reported for completeness but should not be interpreted as a causal effect of the invasion.

Third, the Scope 1 effect is robust across the three fixed-effects specifications: the point estimate decreases monotonically as more demanding fixed effects are added, suggesting that some, but not all, of the baseline effect is absorbed by country- or industry-by-year heterogeneity. The persistence of a negative and statistically significant coefficient under industry-by-year fixed effects, which absorbs sectoral energy-price shocks and any common sectoral response to the war, is the strongest evidence that the effect operates at the firm level.

Thanks to the event-study estimates (Figure 1 for Scope 1 and Figure 2 for Scope 2) from equation (4), it is possible to consider also the dynamic temporal evolution of the analysed phenomenon. For Scope 1, the dynamic profile is the most economically informative element of the analysis. The pre-treatment coefficients (2018, 2019, 2020) are economically small and statistically indistinguishable from zero across all three specifications. The 2022 coefficient is negative but small and not statistically significant: in the Firm FE + Year FE specification, it equals  $-0.014$  ( $p = 0.37$ ). The 2023 coefficient becomes substantially more negative ( $-0.058$ ,  $p = 0.003$ ) and the 2024 and 2025 coefficients reach  $-0.080$  ( $p < 0.001$ ) and  $-0.072$  ( $p < 0.001$ ), respectively. The same lagged pattern is visible, with attenuated magnitudes, in the Country  $\times$  Year and Industry  $\times$  Year specifications.

For Scope 2, the event-study profile is markedly different. The pre-treatment coefficients are large and significantly negative (around  $-0.05$  to  $-0.08$ ), reflecting a downward drift in treated firms' Scope 2 emissions relative to controls before the invasion. Post-2022, the coefficients jump up to approximately  $+0.05$  and decline back toward zero by

2024 and 2025. As already discussed, this pattern is not consistent with a clean causal interpretation: it most plausibly reflects a combination of mean reversion in pre-war differential trends and possibly substitution effects in electricity sourcing, but the failure of the parallel-trends assumption precludes any firm conclusion.

Table 5: Baseline DiD estimates.

<b>Outcome / Specification</b>	<b>Firm + Year FE</b>	<b>Firm + Country×Year FE</b>	<b>Firm + Industry×Year FE</b>
log(1 + Scope 1)	−0.049***	−0.036**	−0.030*
<i>Std. error</i>	(0.016)	(0.017)	(0.017)
<i>p-value</i>	0.003	0.031	0.077
log(1 + Scope 2)	+0.074***	+0.089***	+0.057***
<i>Std. error</i>	(0.014)	(0.014)	(0.014)
<i>p-value</i>	0.000	0.000	0.000
Firm FE	Yes	Yes	Yes
Year FE	Yes	(absorbed)	(absorbed)
Country × Year FE	No	Yes	No
Industry × Year FE	No	No	Yes
Observations	143,880	143,880	143,880
Firms	17,985	17,985	17,985

*Notes:* Coefficients on *Treat* × *Post* from equation (3). Treatment is a binary indicator equal to one for firms with any positive pre-war (2018–2021) average revenue exposure to Russia or Ukraine. Outcomes are log(1 + Scope *k*) emissions in metric tonnes of CO<sub>2</sub>-equivalent. Standard errors are clustered at the firm level. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

#### 5.4. Robustness

The credibility of the main Scope 1 finding is assessed against three sets of robustness exercises: stability across fixed-effects specifications; dynamic event-study consistency; revenues control.

*Stability across fixed-effects specifications.* The most demanding robustness check is, in fact, already incorporated in the main analysis: the Scope 1 result is presented under three nested fixed-effects specifications of increasing demands. The point estimate decreases from −0.049 in the baseline (Firm + Year FE) to −0.036 with country-by-year FE and to −0.030 with industry-by-year FE, while remaining statistically significant in all three cases, although the level of statistical significance declines slightly, as expected, with the inclusion of more stringent fixed effects. The pattern of attenuation is informative: country-by-year fixed effects absorb roughly 27% of the baseline coefficient, and industry-by-year fixed effects absorb roughly 39%. This implies that country and industry-specific time-varying shocks account for a meaningful but minority share of the headline effect and that a non-trivial share of the Scope 1 reduction operates within country-year and within industry-year cells.

As reported in Section 5.2, the joint Wald test on pre-treatment event-study coefficients does not reject parallel trends for Scope 1 in any of the three specifications, with  $p$ -values ranging from 0.148 (Firm + Year FE) to 0.672 (Industry × Year FE). As emphasised by Roth (2022), such tests have limited power against economically meaningful violations and should be read as necessary but not sufficient evidence. Nonetheless, the visual evidence in Figure 1 and the formal test together provide reassuring support for the parallel-trends assumption in the case of Scope 1.

*Dynamic event-study consistency.* The lagged emergence of the Scope 1 effect in 2023–2025 represents an additional, qualitative form of robustness. If the headline negative effect were driven by an idiosyncratic shock to the treated group in a single year, this should be visible as a discontinuous jump rather than as the smooth, monotonically intensifying pattern that emerges from Figure 1.

#### 5.5. Revenues control

As an additional form of robustness check, the baseline DiD specification is augmented with a time-varying control for firm revenues to verify whether the estimated post-invasion reduction in emissions is simply capturing a mechanical scale effect rather than a differential change in emissions behaviour. The new estimated model is:

$$y_{it} = \alpha_i + \lambda_t + \beta(Treat_i \times Post_t) + \gamma Revenue_{it} + \varepsilon_{it} \quad (5)$$

where  $Revenue_{it}$  denotes firm  $i$ 's total revenues in year  $t$ . The coefficient of interest remains  $\beta$ , which captures the differential post-invasion change in emissions for exposed firms relative to unexposed firms, conditional on firm revenues and the relevant fixed effects.

This test is of utmost importance and requires a different attention because firms exposed to Russia and Ukraine may have experienced stronger revenue contractions after the invasion due to market exit, sanctions, supply-chain disruption or the loss of commercial activity in the affected region. If the baseline Scope 1 result were entirely driven by lower firm size, revenues or lower production volumes, then controlling directly for revenues should substantially attenuate or eliminate the DiD coefficient.

The results, reported in Table 6, confirm our previous results. The coefficient on the treatment-post interaction remains negative, statistically significant and economically similar across all three fixed-effects structures. In the Firm FE + Year FE specification, the estimated effect is  $-0.055$  and statistically significant at the 1% level; when Country  $\times$  Year fixed effects are added, the coefficient remains negative and significant at  $-0.042$ ; under the Industry  $\times$  Year specification, the coefficient is still negative and significant at  $-0.039$ . The revenue coefficient itself is positive and highly statistically significant in all specifications, which is consistent with the intuitive direct relationship between firm revenues and absolute emissions.

Overall, Table 6 shows that the main Scope 1 result cannot be explained only by exposed firms becoming smaller or selling less after the invasion. The coefficient on revenues is positive across all three specifications, indicating that, holding other factors constant, higher firm revenues are associated with higher Scope 1 emissions. In other words, considering revenues alone, one would expect emissions to increase as firm scale increases. Despite this positive relationship between revenues and direct emissions, the DiD coefficient remains negative and statistically significant. This suggests that exposed firms reduced their Scope 1 emissions over and above what would be predicted by changes in firm scale.

The parallel-trends diagnostics are also unchanged in substance once revenues are included: for Scope 1, the joint Wald tests continue not to reject the null of parallel trends across the three specifications. This reinforces the causal credibility of the Scope 1 finding and supports the interpretation that the observed reduction reflects a genuine differential adjustment in direct emissions rather than a purely mechanical revenue effect.

Table 6: Robustness of Scope 1 DiD Estimates Controlling for Firm Revenues.

	<b>Firm + Year FE</b>	<b>Firm + Country<math>\times</math>Year FE</b>	<b>Firm + Industry<math>\times</math>Year FE</b>
log(1 + Scope 1)	$-0.055^{***}$	$-0.042^{**}$	$-0.039^{**}$
<i>p</i> -value	<i>0.001</i>	<i>0.010</i>	<i>0.021</i>
Parallel trends	Yes	Yes	Yes
Revenue	$0.000012^{***}$	$0.000011^{***}$	$0.000012^{***}$

Notes: Coefficients on  $Treat \times Post$  from equation (5) for log(1 + Scope 1). Standard errors are clustered at the firm level. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

For Scope 2, by contrast, the revenue-control robustness exercise leaves the interpretation of the results unchanged. As reported in Table 7, the DiD coefficients remain positive and statistically significant after controlling for firm revenues across all three fixed-effects specifications. The revenue coefficient is also positive and highly statistically significant in all models, confirming that firm scale is positively associated with indirect emissions.

However, the key issue for Scope 2 is not the statistical significance of the DiD coefficient, but the failure of the identifying assumption. As shown in Table 7, the parallel-trends condition is not satisfied in any of the three specifications. This is consistent with the baseline DiD analysis without the revenue control, where Scope 2 also failed the parallel-trends diagnostics. Therefore, the positive Scope 2 coefficients cannot be interpreted as causal evidence that the war increased exposed firms' indirect emissions. Instead, the Scope 2 estimates are reported for transparency and should be read with caution. Overall, Table 7 confirms that adding revenues does not solve the pre-trends problem for Scope 2, while the revenue-control robustness exercise mainly strengthens the credibility of the Scope 1 findings.

Table 7: Robustness of Scope 2 DiD Estimates Controlling for Firm Revenues.

	Firm + Year FE	Firm + Country×Year FE	Firm + Industry×Year FE
log(1 + Scope 2)	+0.068***	+0.082***	+0.048***
<i>p</i> -value	0.000	0.000	0.001
Parallel trends	No	No	No
Revenue	0.000011***	0.000011***	0.000012***

Notes: Coefficients on *Treat* × *Post* from equation (5) for log(1 + Scope 2). Standard errors are clustered at the firm level. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

The results discussed above are further supported by Figure 3, which shows that the average revenues of exposed firms did not decline after the invasion of Ukraine. On the contrary, revenues increased after 2021 and then remained broadly stable at a higher level in the following years. This pattern explains the positive coefficient of the revenue variable across the different specifications. A possible explanation is that, although some firms may have downsized or reduced their operations in the countries directly affected by the conflict, the impact on their total average revenues was limited. Revenue losses in affected markets may have been offset by operations in other countries or by the overall scale and diversification of these firms.

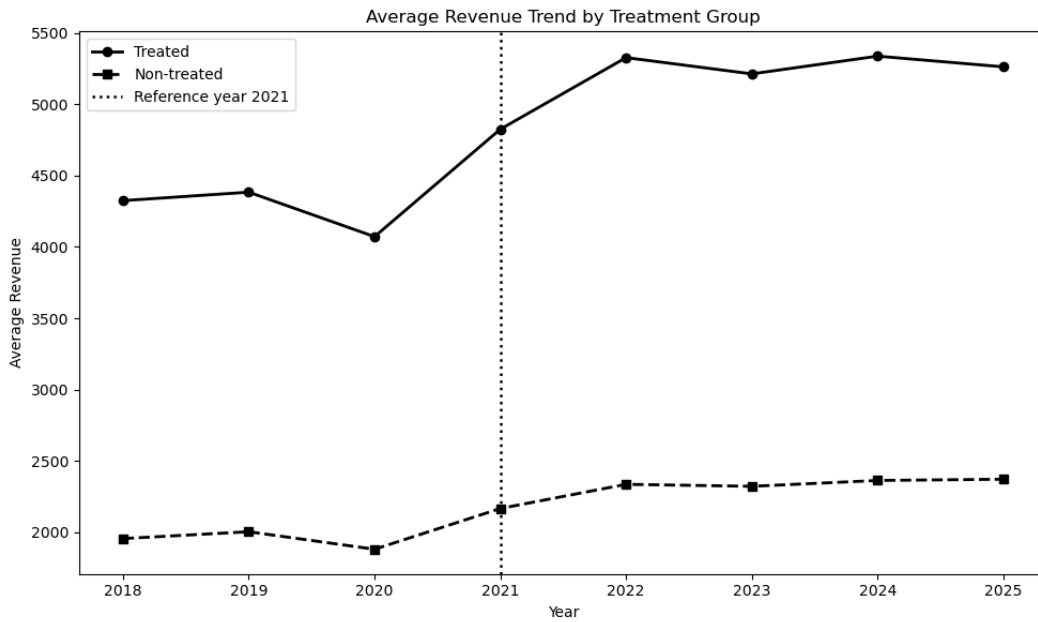


Figure 3: Average revenue trend by treatment group.

Notes: Average annual revenues of exposed (treated) and non-exposed (control) firms over the sample period. The vertical dashed line marks the February 2022 invasion.

### 5.6. Placebo test

As an additional robustness check, placebo DiD regressions are estimated by assigning fake treatment years before the actual Ukraine invasion. Specifically, the treatment is artificially assumed to start in 2020 and 2021, while keeping the same binary exposure definition based on pre-war revenues from Russia and Ukraine. The results show that the placebo coefficients are small in magnitude and statistically insignificant across all fixed-effects specifications. This indicates that exposed firms did not experience systematic differential changes in Scope 1 emissions relative to unexposed firms before the actual shock. Therefore, the placebo evidence supports the validity of the main Scope 1

results and reduces the concern that the post-2022 negative effect is driven by pre-existing differential trends rather than by the invasion.

Table 8: Placebo DiD estimates with fake treatment years.

Fake treatment year	Specification	$\beta$	$p$ -value
2020	Firm FE + Year FE	0.0060	0.682
	Firm FE + Country $\times$ Year FE	-0.0039	0.795
	Firm FE + Industry $\times$ Year FE	-0.0044	0.773
2021	Firm FE + Year FE	0.0096	0.552
	Firm FE + Country $\times$ Year FE	0.0055	0.735
	Firm FE + Industry $\times$ Year FE	-0.0021	0.903

Notes: Placebo DiD regressions for  $\log(1 + \text{Scope 1})$  emissions, with fake treatment years 2020 and 2021. Treatment is the binary exposure indicator based on pre-war revenues from Russia and Ukraine. Standard errors are clustered at the firm level.

## 6. Conclusion and Discussion

### 6.1. Interpreting the pattern of results: disengagement and energy mix effects

This section brings together the empirical findings and discusses their interpretation, limitations and broader implications. The central research question of this paper is whether firms with pre-war commercial exposure to Russia and Ukraine experienced a different change in greenhouse gas emissions after the 2022 Russian invasion of Ukraine compared to firms without such exposure. More specifically, the analysis asks whether exposed firms changed their direct emissions, measured by Scope 1 GHG emissions, and their indirect emissions from purchased electricity, measured by Scope 2 GHG emissions, with respect to non-exposed firms in the post-invasion period. By answering this question, the paper aims to understand whether a major geopolitical shock can translate into measurable changes in firms' actual environmental performance. The discussion therefore focuses on two key issues: first, whether the estimated effects can be interpreted causally considering the parallel-trends evidence and, second, what the observed pattern of results might suggest about the mechanisms through which geopolitical disruption may affect corporate emissions.

A first interpretation of the Scope 1 result is that the observed reduction reflects the environmental footprint of corporate disengagement. Firms with pre-war commercial ties to Russia or Ukraine reduced their direct emissions more than unexposed firms not necessarily because they adopted greener production strategies but because the shock forced or encouraged them to scale down, suspend or terminate carbon-emitting activities linked to the affected region. When a firm closes a facility, interrupts a fuel-intensive operation, terminates a supply contract or shuts down a regional distribution network, the direct fuel combustion associated with those activities declines and eventually disappears from its Scope 1 emissions accounts.

The timing of the effect reinforces this interpretation. The absence of a clear reduction in 2022, followed by a stronger decline in 2023, 2024 and 2025, is consistent with the practical process of corporate withdrawal from a foreign market. Firms may announce exits, suspend investments or freeze activities shortly after a geopolitical shock but the operational consequences usually take longer to materialise. Supply contracts must expire or be renegotiated, assets must be wound down, facilities may need to be closed gradually, and local legal entities often require months or years to be dissolved. Therefore, the lag between the invasion and the reduction in Scope 1 emissions should not be interpreted as a delayed corporate response, but rather as the time needed for managerial decisions to translate into actual operational change.

BP's withdrawal from Russia following the invasion of Ukraine represents a perfect case study aligned with the above disengagement interpretation. On 27 February 2022, BP announced that it would exit its 19.75% shareholding in Rosneft and that its nominated directors would resign from Rosneft's board with immediate effect (BP, 2022). BP stated that the invasion represented a fundamental change in its relationship with Russia, and the company subsequently stopped equity-accounting for Rosneft, recording large charges linked to the loss of significant influence and

its decision to exit Russian operations. Public reporting indicates that BP's exposure to Rosneft was substantial, with Rosneft previously accounting for a significant share of BP's reserves and production.

For what concerns Scope 2, the positive estimated effect, which would imply that exposed firms increased their indirect emissions from purchased electricity after the war, cannot be taken at face value because the parallel-trends assumption is rejected for this outcome. Treated firms had already been reducing their Scope 2 emissions relative to the control group before the invasion, and the post-war increase may therefore partly reflect a mean-reversion effect rather than a genuine causal consequence of the shock.

However, the Scope 2 result can also be interpreted through a second, economically plausible mechanism that is coherent with the reduction observed in Scope 1 emissions. If exposed firms scaled down or exited carbon-intensive operations in Russia and Ukraine, their direct fuel combustion would decline, producing a reduction in Scope 1 emissions. At the same time, the war caused sharp increases in oil, gas and electricity prices. IEA (2022) notes that the crisis encouraged fuel switching away from gas toward more price-competitive sources, including coal in some regions. As a result, companies may not necessarily have consumed more electricity in physical terms; instead, the electricity they purchased may have become more carbon-intensive because it was generated using more polluting energy sources. This mechanism would be reflected in firms' Scope 2 emissions through a "waterfall" effect: changes in the carbon intensity of the electricity grid are transmitted to the indirect emissions reported by firms that rely on purchased electricity.

This interpretation remains only suggestive, because the failure of parallel trends prevents a causal reading of the Scope 2 coefficient. Nevertheless, it helps reconcile the positive Scope 2 estimate with the negative Scope 1 result: exposed firms may have reduced direct emissions by leaving or downsizing operations linked to Russia and Ukraine, while simultaneously facing higher indirect emissions because residual activity relied more heavily on purchased electricity and because that electricity may have been produced with a more carbon-intensive energy mix after the shock.

## 6.2. *Interpreting the pattern of results: efficiency and substitution mechanisms*

An additional interpretation of the Scope 1 reduction is that the invasion may have operated as an efficiency shock, pushing exposed firms to reduce the energy intensity of their operations. The robustness test controlling for firm revenues is particularly relevant for this interpretation because it shows that the negative Scope 1 effect is not only explained by the fact that exposed firms become smaller after the invasion. Instead, they increased revenues, as previously explained. If the reduction in direct emissions were merely the consequence of a decline in firm scale, the inclusion of revenues should have substantially weakened the  $Treat \times Post$  coefficient. Instead, the coefficient remains negative, statistically significant and economically similar across all fixed-effects specifications. This suggests that exposed firms reduced direct emissions even if revenues increased.

One plausible explanation is that the war-related shock to energy costs and operational uncertainty created strong incentives for exposed firms to invest to compress their energy intensity. Firms facing higher input costs, disrupted supply relationships or the need to reorganise production may have accelerated efficiency-oriented adjustments, such as improving production processes, reducing energy waste, optimising fuel use, strengthening maintenance practices or bringing forward investments in newer, more energy-efficient machinery. Under this interpretation, the Scope 1 reduction reflects much more than just the disappearance of emissions from discontinued activities, but also a change in how remaining operations were managed. Firms may have produced the same or similar revenue-generating output with lower direct fuel combustion, leading to a fall in Scope 1 emissions that cannot be fully attributed to lower firm size. A further possible, although not verifiable, channel is that some exposed firms may have reorganised part of their production toward jurisdictions with higher environmental standards and stricter emissions controls. If this occurred, it could have reinforced the reduction in Scope 1 emissions by forcing firms to operate under more demanding efficiency and compliance requirements.

For Scope 2, this second interpretation suggests a possible substitution effect between direct and indirect emissions. The combination of a significant reduction in Scope 1 emissions and a positive estimated effect for Scope 2 may indicate that exposed firms did not necessarily reduce their overall level of activity but rather changed the way their energy needs were satisfied. Firms may have reduced on-site fuel combustion, which is recorded as Scope 1 emissions, while relying more heavily on purchased electricity, which is recorded as Scope 2 emissions. Under this mechanism, the increase in Scope 2 would not imply higher production or greater energy use in absolute terms, but rather a shift from direct energy generation or direct fuel use toward externally supplied electricity.

This interpretation is coherent with the idea that the war acted as a shock to firms' energy choices and production organisation. Exposed firms facing higher energy costs, disrupted supply chains, or the need to reorganise operations may have optimised their production processes or altered their energy supply structure. In some cases, firms may have externalised more energy-intensive activities or consolidated production in facilities powered by external electricity grids rather than by on-site fuel combustion. This would reduce direct emissions while increasing indirect emissions, generating the observed pattern of lower Scope 1 and higher Scope 2.

Overall, the two interpretations are complementary rather than mutually exclusive. The Scope 1 reduction may partly reflect the direct environmental footprint of corporate disengagement from Russia and Ukraine, and partly an efficiency-driven adjustment in the operations of exposed firms.

### *6.3. Limitations*

Revenue exposure is just one of the possible proxies for the channels through which the war affected firms. Commercial ties to Russia and Ukraine extended beyond the direct sale of goods and services: firms may have held physical assets in the region, sourced critical inputs from local suppliers or relied on Russian natural gas as a production input without reporting meaningful revenues from those markets. Under this study's treatment definition, such firms may therefore be classified in the control group despite being materially exposed to the shock. Revenue was used because it is the most consistently available and reliable firm-level measure of exposure. By contrast, other potentially relevant dimensions of exposure, such as asset holdings, supplier dependence or energy reliance, are often difficult to observe systematically, not publicly disclosed or not comparable across firms. The exposure measure thus captures one important dimension of the firm-conflict relationship but inevitably leaves others unobserved.

The post-invasion period is also characterised by a confluence of concurrent shocks that the fixed-effects structure may not fully absorb. The years 2022 to 2025 saw the continuation of post-pandemic supply chain disruptions, a global energy price shock extending beyond Russian gas, a significant tightening of monetary policy and changes in the EU's sustainability reporting agenda. Some of these developments may have affected exposed and unexposed firms in ways not fully captured by country-by-year or industry-by-year fixed effects.

Finally, the sample consists exclusively of publicly listed firms covered by the Trucost Environment dataset, which biases the analysis toward larger, more internationally active and more sustainability-transparent companies. This restriction partly reflects the practical difficulty of obtaining reliable and harmonised data for private firms. Unlike listed companies, private firms often do not disclose consistent information on emissions, revenues or geographic exposure required for the analysis, making systematic comparison much more difficult. Restricting the sample to listed firms therefore improves data quality and comparability but necessarily limits the generalisability of the results. Smaller and private firms, for which reputational and regulatory pressures may have been weaker and operational disruption potentially more severe, are absent from the sample. Taken together, these limitations suggest that the findings are best interpreted as informative evidence on the environmental consequences of geopolitical exposure among large, publicly listed firms, rather than as a definitive causal estimate applicable to the full universe of firms affected by the conflict.

### *6.4. Conclusion*

This paper set out to examine whether the Russian invasion of Ukraine of 2022 led to a differential change in the greenhouse gas emissions of firms with pre-war commercial exposure to the affected region. Using a two-way fixed-effects difference-in-differences design applied to a global panel of nearly 18,000 publicly listed firms observed annually between 2018 and 2025, and measuring exposure through the firm's pre-war share of revenues originating from Russia and Ukraine, the analysis produces a clear and internally consistent answer for Scope 1 emissions and a methodologically constrained one for Scope 2.

With respect to the guiding research question, whether exposed firms exhibited a different change in emissions following the onset of the war, the evidence points firmly in the affirmative, at least for direct emissions.

The first hypothesis, that, after the onset of the war, exposure to Russia and Ukraine led to a significant change in Scope 1 emissions for exposed firms, is verified. In fact, it is proved by the fact that these exposed firms reduced their direct emissions by approximately 4.9% relative to unexposed peers in the post-invasion period, a finding that survives the inclusion of demanding country-by-year and industry-by-year fixed effects and is further proved by a clean parallel-trends test. The event-study profile, with no detectable effect in 2022 and a steadily deepening reduction

through 2023 to 2025, is consistent with the two interpretations provided: the gradual operational disengagement of exposed firms from the Russian and Ukrainian markets and the increasing implementation of energy-efficiency adjustments, optimisation strategies and substitution mechanism.

The second hypothesis, that exposure led to a significant change in Scope 2 emissions, cannot be confirmed in causal terms: while the estimated coefficients are positive and statistically significant across all specifications, the decisive rejection of the parallel-trends assumption for this outcome precludes any reliable causal reading and the post-invasion differential most plausibly reflects the mean reversion of a pre-existing divergence between treated and control firms.

The findings also have forward-looking managerial implications. For exposed firms, the key challenge is whether shock-induced emissions reductions can be transformed into structurally more sustainable operating models through cleaner energy inputs, reconfigured supply chains and more efficient production processes. While part of the observed decline may be driven by the scaling down or termination of carbon-intensive activities, the evidence of the revenues control also suggests that firms may have reduced their energy intensity through efficiency-enhancing adjustments that go beyond changes in firm scale. As sustainability reporting, regulatory pressure and investor expectations around the green transition continue to intensify, managers will need to ensure that any short-run reduction in emissions evolves into a credible long-term decarbonisation strategy rather than remaining a temporary consequence of geopolitical disruption.

Our results both partially confirm and extend the existing evidence. Feng et al. (2024) document an inhibitory effect of geopolitical risk on per-capita CO<sub>2</sub> emissions across 31 countries, while Banerjee et al. (2025) find that US firms reduce their combined Scope 1 and Scope 2 emissions by approximately 5.4% in response to heightened general political risk, with environmental innovation as the primary mediating channel. Our estimated Scope 1 reduction of 4.9% is similar in magnitude to the latter, despite the different empirical settings: a global sample rather than US-only, a specific geopolitical shock rather than a continuous risk index, and a quasi-experimental DiD design rather than an OLS-based approach.

These findings provide new firm-level causal evidence that a major geopolitical shock can produce measurable reductions in corporate direct emissions, complementing macro-level studies that document geopolitical risk as a driver of national carbon intensity and extending work on the war, which has focused predominantly on financial and operational outcomes, to the environmental domain. They also speak to a broader conceptual point: geopolitical shocks can function as involuntary decarbonisation mechanisms, but through multiple and not necessarily aligned channels. On the one hand, emissions may decline as firms disengage from affected markets and scale down carbon-intensive activities. On the other hand, the shock may induce efficiency-enhancing adjustments in remaining operations, reducing the energy intensity of production beyond what would be explained by changes in firm scale. Whether these reductions are durable, that is, whether they reflect structural changes in firms' energy sourcing and production footprint or merely temporary contractions in output, is a question that future research, with a longer post-war panel, will be better placed to address.

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