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Renewable demand or sanctions? A descriptive decomposition of Russia–China mineral trade dynamics

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Abstract

After comprehensive Western economic sanctions were imposed in 2022, Russia's critical mineral exports to China surged from a pre-sanctions (2000–2021) annual average of $277 million per mineral to $1.02 billion per mineral in 2022–2024, both in current U.S. dollars — a 268% increase. This raises a fundamental attribution question: does the export surge stem from sanctions-induced trade diversion or from concurrent global renewable energy transition demand? Because the two processes occurred simultaneously, documenting the distinct contribution of each poses a significant empirical challenge. This study uses panel data on eight critical minerals exported from Russia to China over 2000–2024, employing three model specifications with progressively introduced controls based on fixed-effects regression: baseline sanctions estimation, renewable demand incorporation, and interaction testing. The sanctions effect coefficient falls from 3.682 to 0.946 and loses statistical significance once renewable energy demand variables are controlled for, whereas the renewable energy transition coefficient remains significant, at the 10% level or better, across the main robustness specifications. Analysis of differences across mineral categories suggests that sanctions effects appear primarily in highly standardized base materials, while technology-intensive minerals show stronger alignment with renewable demand patterns. Cross-mineral heterogeneity reveals a systematic gradient in renewable demand sensitivity — 1.135 for battery-critical materials against 0.237 for base materials — that mirrors the functional roles of minerals in the energy value chain and cannot be attributed to common time trends. The paper's contribution lies in documenting three descriptive patterns: pre-existing import trends, cross-mineral heterogeneity, and coefficient trajectories under progressive controls, which together provide observational insights into Russia–China mineral trade dynamics.

Keywords: sanctions effect, renewable energy transition, descriptive pattern documentation, trade dynamics, trade diversion, Sino-Russian economic cooperation.
JEL classification: F14, F51, Q31.

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1. Introduction

Following the Russia–Ukraine conflict in 2022, Western nations imposed unprecedented economic sanctions on Russia — the most comprehensive in modern history — spanning critical sectors including finance, technology, and energy. Although the 2022 sanctions did not directly target critical minerals, they exert substantial indirect effects through financial and logistical channels. Fig. 1 shows the evolution of China's critical mineral imports from Russia (left panel) and from global sources (right panel) over 2013–2024. After the sanctions, Russia's critical mineral exports to China grew sharply: aluminum and lithium exports rose by 380% and 286%, respectively (2022–2024 average against the 2019–2021 average), while other minerals such as cobalt also increased noticeably.

Yet the right panel reveals a more complex picture. China's aggregate imports from global sources show sustained upward trajectories that predate 2022, particularly for minerals linked to renewable energy applications. This raises a fundamental attribution question: does the surge in Russian mineral exports stem from sanctions-induced trade diversion or from concurrent global renewable energy transition demand? The complexity arises because 2022 was

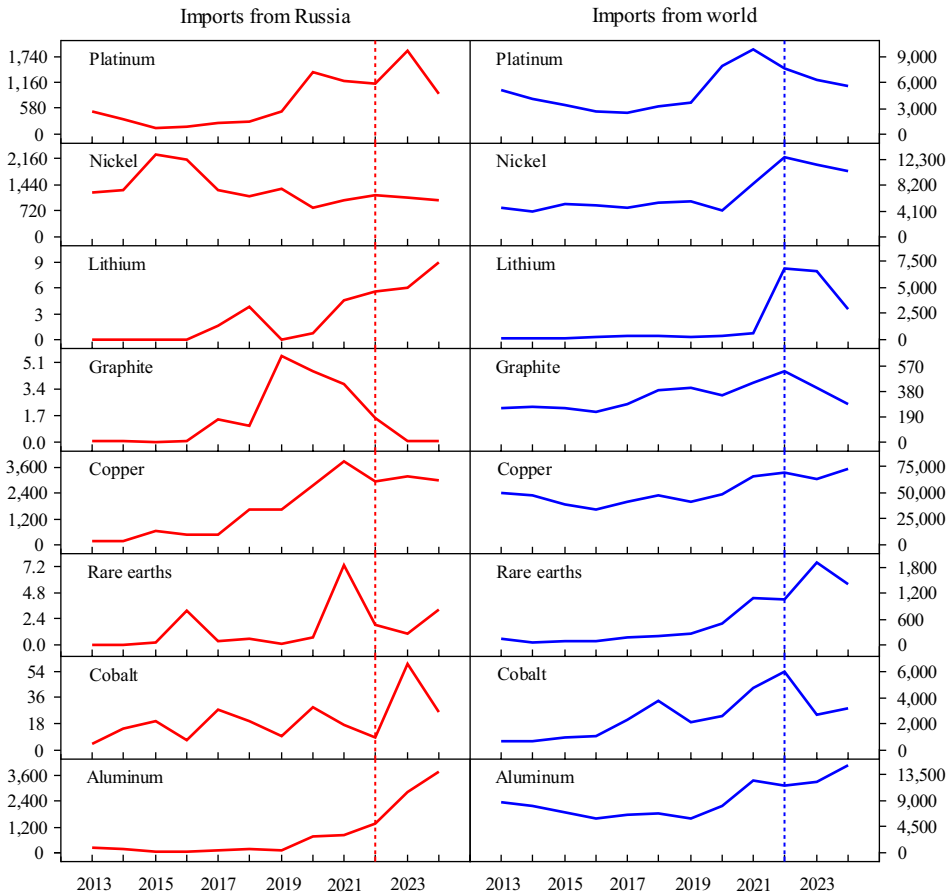

Fig. 1. China's critical mineral import trends, 2013–2024 (million U.S. dollars, current prices).

Source: UN Comtrade.

simultaneously a year of geopolitical upheaval and a critical inflection point in the global renewable energy transition, marked by Chinese new energy vehicle sales passing 6.887 million units and by a substantial escalation in clean energy investment worldwide. The temporal coincidence between the implementation of sanctions and the acceleration of the renewable transition makes precise mechanism decomposition exceptionally challenging.

While the existing literature has examined sanctions effect assessment and energy transition impact analysis extensively (Early, 2015; Felbermayr et al., 2025), a critical gap remains in the decomposition of driver mechanisms. Although sanctions research has examined trade diversion mechanisms (Mahlstein et al., 2022; M. Wang and Hannan, 2023; Isachenko and Medvedkova, 2024; Shishov et al., 2025) and the renewable energy literature has explored critical mineral demand growth (Dyomina and Mazitova, 2024; Mariev and Islam, 2025), few studies systematically address the descriptive decomposition challenges that arise when several events occur simultaneously. Specifically, when major policy interventions coincide with structural economic transformations, simple before-after comparisons risk misattributing temporal coincidence to causality, and the literature lacks replicable frameworks for documenting how observed trade patterns align with each competing explanation.

To address these gaps, this study examines two competing mechanisms — sanctions-induced trade diversion and renewable energy transition demand — through a descriptive decomposition approach that documents how coefficient patterns and cross-mineral heterogeneity align with each explanation, providing suggestive evidence on which mechanism is more consistent with the observed trade patterns.

This study uses panel trade data on eight critical minerals exported from Russia to China over 2000–2024, employing three model specifications with progressively introduced controls based on fixed-effects panel regression. All models incorporate mineral-specific fixed effects to control for unobserved heterogeneity and to mitigate omitted variable bias. Through this progressive control strategy, we examine systematically how the sanctions coefficient changes as structural demand controls are introduced, documenting the observed co-variation between the two mechanisms.

Coefficient patterns show stronger alignment with renewable energy transition demand: the sanctions coefficient attenuates substantially once renewable demand is controlled for.

The theoretical contribution of this study lies in providing a systematic descriptive decomposition framework for settings with several concurrent events. Rather than claiming causal identification, the paper documents how coefficient patterns and cross-mineral heterogeneity jointly offer suggestive observational insights into the patterns underlying Russia–China mineral trade dynamics, providing a replicable approach for analogous observational settings. Methodologically, it demonstrates the usefulness of introducing control variables progressively in concurrent multiple-event scenarios, providing operational analytical tools for analogous policy evaluation research. Practically, it offers descriptive evidence on how sanctions and structural demand interact with observed trade patterns, giving policymakers a more nuanced basis for assessing the effectiveness of geopolitical instruments.

2. Theoretical background and descriptive expectations

2.1. Economic sanctions and trade diversion effects

Economic sanctions, a pivotal policy instrument in international relations, have generated sustained academic debate about their actual effectiveness. The rapid escalation in sanctions deployment — with the number of active sanctions worldwide rising by 31.2%, 25%, and 23% from 2021 to 2023, respectively — has renewed scholarly interest in sanctions mechanisms and effectiveness (Felbermayr et al., 2025). Traditional sanctions theory posits a relatively linear relationship between economic pressure and political concessions; this simplification has been challenged both by substantial empirical research and, on conceptual grounds, by Baldwin's (2020) *Economic statecraft*, which insists that sanctions be judged against the alternative instruments available rather than by economic pressure alone. Russian scholarship on the 2022 sanctions corroborates this complexity. Kaigorodtsev (2023) shows that Western sanctions in 2022–2023, while unprecedented in scope, proved ineffective in altering Russian foreign policy — their primary objective — and failed to destroy the Russian economy, though they inflicted substantial damage on specific economic actors and on the broader macroeconomy. Potemkin (2024) finds that sanctions raised transaction costs and fragmented the financial system while accelerating Russia's shift toward local currency settlement and structural economic adjustment. Özdamar and Shahin (2021) note that research on the consequences of sanctions is considerably fragmented, with divergent methodologies yielding disparate conclusions. Felbermayr et al. (2020) document that merely 34% of sanctions achieve their intended objectives; while comprehensive trade sanctions reduce bilateral trade flows by approximately 80%, third-party nations frequently benefit. Duration analysis by Caetano et al. (2023) finds that the effectiveness of sanctions varies significantly with target country characteristics: higher levels of democracy and globalization paradoxically increase the probability of sender capitulation.

Khurshid et al. (2023) show that geopolitical shocks such as the Russia — Ukraine conflict are important drivers of fluctuations in the prices of key minerals. Price effects, however, do not equate to trade-flow effects. Russian exports to China rose rather than fell under sanctions. This surge raises the core question of this study: was it driven by sanctions-induced trade diversion, or by structural demand strong enough to override price effects? As Mahlstein et al. (2022) demonstrate using CGE modeling, when a sanctioned country holds critical resources, the trade creation with third parties induced by sanctions may outweigh the trade destruction with sanctioning states, so that the sanctioned country's total trade volume need not fall; the same analysis simulates the gains accruing to third-party nations under an allied trade embargo. Shingal (2024) provides evidence of domestic trade diversion within sanctioning countries, showing that sanctions reduce cross-border imports where domestic suppliers are more competitive. Early (2015) shows that third-party nations substantially attenuate the effectiveness of sanctions, particularly when they are geographically close to, or strategically complementary with, target states. M. Wang and Hannan (2023) use Mexican sectoral data to show that trade diversion effects frequently exceed the estimates reported in the literature, with sanctions generating both direct trade impacts and

indirect consequences through supply chain linkages. Bove et al. (2023) find that neighboring countries reacted to sanctions in different ways: some increased trade flows by circumventing sanctions, while others may have suffered economic losses from trade disruption. Aponte-Garcia (2024) documents that trade diversion successfully mitigated the impact of the 2022 sanctions on Russian hydrocarbon commerce. Isachenko and Medvedkova (2024) demonstrate empirically a substantial post-sanctions reorientation of Russian trade, with the magnitude and trajectory of redirection varying considerably across commodity categories. Shishov et al. (2025) further document that Western sanctions have catalyzed structural shifts in Russian exports to China across multiple product categories, with changes extending beyond energy resources to agricultural products and high-tech goods. EU and U.S. sanctions precipitated a contraction in Russia–West trade, and the center of gravity of Russian commerce has shifted progressively toward China, India, and Turkey — aggregate trade with these nations now surpassing EU volumes (Shengfu and Davidson, 2024). Gutmann et al. (2024) use difference-in-differences and event study estimation to examine whether China and Russia undermine Western sanctions; they find no evidence of systematic sanctions busting by Russia and no robust increase in China's overall trade with targeted countries, but they do find that China's trade with those countries in raw materials and critical goods increases notably.

Russia's "Pivot to the East" strategy has progressively raised China's centrality in Russian economic relations (Spartak, 2024). Wang (2024) shows that the transformation of Russian trade has sustained the internationalization of the renminbi in trade settlement, with bilateral financial cooperation deepening from trade settlement to capital flows and monetary architecture. Felbermayr et al. (2025) identify pronounced third-country effects of the 2022 Russia sanctions, with trade growth between Russia and non-sanctioning nations (China, India, Turkey) exceeding conventional trade diversion predictions. Although the 2022 Western sanctions did not directly target critical minerals, they exert substantial indirect effects through financial and logistical channels. Besedeš et al. (2024) document "collateral damage" to non-embargoed goods through payment system disruption. Ghironi et al. (2024) show that systemic increases in transaction costs persist even with third-country rerouting. Gavoille (2025) identifies a "scarecrow effect" whereby firms disengage because of legal risk. Our *Sanction_2022* variable captures this comprehensive sanctions environment — disrupted payments, elevated costs, and compliance uncertainty — rather than the direct targeting of commodities.

While the existing literature documents substantial trade reorientation after sanctions, a critical gap remains: trade diversion effects vary considerably across commodity categories (Mahlstein et al., 2022; Isachenko and Medvedkova, 2024). Standardized base metals are highly fungible, whereas battery-grade materials face institutional barriers including quality certification and technical compatibility. These distinctions suggest heterogeneous sanctions effects across mineral types.

2.2. Renewable energy transition and critical mineral demand

The global renewable energy transition is fundamentally reconfiguring resource demand patterns. IEA (2021) project that electric vehicles and energy storage

batteries will account for approximately 50% of the growth in clean energy mineral demand over the next two decades under both the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS). By 2040, mineral requirements in these sectors will expand tenfold under STEPS and more than thirtyfold under SDS. Woodley et al. (2024) show that limited production of battery-grade graphite and cobalt may constrain the deployment of electric vehicles particularly severely, and that supply chain bottlenecks could undermine emissions reduction targets. Cheng et al. (2024) find that 80% of nickel-manganese-cobalt (NMC) cathode materials and 92% of lithium-iron-phosphate (LFP) cathode materials contain minerals that pass through China, and that the combined vulnerability of multiple supply chain links far exceeds the vulnerability of any single link. Mariev and Islam (2025) document a positive correlation between mineral import volumes and clean energy development in European markets: under conditions of economic growth, political stability, and reasonable pricing, cross-border mineral trade has a pronounced facilitative effect on the energy transition. Cherepovitsyn and Illeritskiy (2024) underscore the role of Russian critical minerals as pivotal enablers of the global clean energy transition. China, the world's largest new energy vehicle market and battery manufacturing hub, treats nations capable of ensuring stable mineral supply as strategic partners. Dyomina and Mazitova (2024) show that China's energy transition drives demand growth for base metals, minerals, and rare earth elements. While Russia's potential to expand in China's fossil fuel markets is largely exhausted (natural gas excepted), Russia retains competitive advantages in critical minerals for the energy transition through geographic proximity and resource endowment.

China's intensification of renewable energy represents a sustained policy commitment spanning several Five-Year Plans. The 13th Five-Year Plan (2016–2020) established ambitious solar and wind capacity targets, while the 14th Five-Year Plan (2021–2025) further accelerated the adoption of new energy vehicles and the deployment of battery storage. The Third Plenum decisions of July 2024 reaffirmed these green development priorities. This long-term policy trajectory shows that the surge in Chinese critical mineral demand reflects a structural transformation that predates the 2022 sanctions period.

These studies establish that China's renewable expansion generates substantial structural demand for critical minerals. An empirical challenge emerges, however. The 2022 sanctions coincided with China's renewable acceleration, creating observational equivalence, and simple time-series analysis cannot distinguish whether export growth stems from sanctions-induced diversion or from renewable demand pull. Comparing these mechanisms descriptively requires examining cross-mineral heterogeneity and coefficient stability under progressive controls.

2.3. Descriptive expectations

Building on this theoretical analysis, this study examines two competing explanations for the growth of Russian mineral exports.

Descriptive expectation 1 (sanctions-consistent pattern):

Sanctions-induced disruption of access to European and U.S. markets generates export reorientation, directing Russian critical mineral exports toward non-sanctioning nations, particularly China.

Descriptive expectation 2 (demand-consistent pattern):

Structural demand from China's renewable energy expansion constitutes an independent driver of Russian mineral export growth, operating alongside sanctions-induced reorientation as a potential contributor to observed trade patterns.

Under Descriptive Expectation 1, sanctions-induced market reorientation would show up most directly in post-2022 bilateral trade volumes. If this pattern is clearly visible in the data, we would expect that (a) the post-2022 sanctions indicator retains a positive and statistically significant association even after controlling for China's renewable energy expansion; (b) the association is relatively uniform across mineral categories; and (c) trade expansion is concentrated in the post-2022 period.

Under Descriptive Expectation 2, structural renewable demand generates sustained pull for mineral categories linked to the energy value chain. If this pattern is clearly visible in the data, we would expect that (a) the sanctions coefficient attenuates substantially or loses significance once renewable demand is introduced; (b) export growth is concentrated in minerals with central roles in the energy value chain; and (c) the renewable energy capacity variable maintains consistent positive associations across specifications that do not include a time-based control.

These two sets of descriptive expectations are not mutually exclusive; both mechanisms may contribute to observed patterns. The empirical exercise that follows documents which set of patterns is more clearly visible in the data.

3. Data and methodology

3.1. Data sources and variable construction

This study constructs a panel database covering 2000–2024 for eight critical minerals exported from Russia to China. The minerals are classified by their function in the renewable energy value chain: battery-critical materials (lithium, cobalt, nickel, graphite), renewable energy base materials (copper, aluminum), and advanced manufacturing materials (platinum, rare earths). The data are drawn primarily from the UN Comtrade database, which ensures the authority of the trade flow data and their comparability over time.

Table 1 reports descriptive statistics for the variables used. The dependent variable — Russian mineral exports to China — is measured in current U.S. dollars as reported by UN Comtrade and it enters the fixed-effects specifications ln(1 + value) to accommodate zero trade flows (23 of 200 observations); China's renewable capacity likewise enters as ln(1 + GW). Core explanatory

Table 1
Descriptive statistics of the principal variables

Variable	Obs	Mean	Std. dev.	Min	Max
Russia–China mineral exports (million U.S. dollars, current prices)	200	367.00	728.00	0.00	3,910.00
China renewable capacity, solar and wind (GW)	200	250.68	363.67	0.37	1,408.37
Mineral price (natural logarithm; U.S. dollars per tonne, platinum per troy ounce)	188	8.25	1.28	6.00	10.86
USD/RUB exchange rate (rubles per U.S. dollar, annual average)	200	46.10	21.23	24.85	92.79

Source: Author's calculations.

variables are the *Sanction_2022* binary indicator and *China_Renewable* (China's installed solar and wind capacity). The *Sanction_2022* dummy equals one from 2022 onward and is designed to capture the comprehensive post-2022 sanctions environment — disrupted payment systems, elevated transaction costs, legal uncertainty, and systemic trade frictions — rather than the direct policy targeting of these specific minerals. Although Western sanctions did not explicitly embargo these minerals, they exert substantial indirect effects through financial restrictions, logistical reconfiguration, and compliance costs that affected all Russia-related trade. *China_Renewable* aggregates installed solar and wind capacity and proxies the cumulative development of China's renewable energy infrastructure and the intensity of its transition. We also collect two further determinants of trade — international mineral price indices and the USD/RUB exchange rate — which enter the robustness specification reported in Table 5 rather than the baseline models. Price and renewable capacity data come from Our World in Data; exchange rate data come from the International Monetary Fund.

The descriptive statistics reveal substantial variability both across minerals and over time. The standard deviation of Russia–China mineral exports is approximately twice the mean, which reflects the wide dispersion of trade values across the eight minerals as well as their growth over the period. China's renewable capacity is markedly dynamic, with its maximum value approaching 4,000 times the minimum, which captures the rapid expansion of renewable capacity over the period.

3.2. Methodology and pattern documentation strategy

This study employs three model specifications with progressively introduced controls to document systematically the coefficient patterns associated with the competing mechanisms underlying the observed trade patterns. Informed by recent advances in gravity model estimation (Larch et al., 2025), we employ a fixed-effects model. The specification incorporates mineral fixed effects to account for unobserved, time-invariant heterogeneity across minerals. Model (1) estimates the baseline sanctions effect, capturing "surface" pre-post sanctions variation, with the coefficient β_1 reflecting the direct sanctions association. Model (2) adds renewable transition variable, documenting how the sanctions coefficient β_2 changes once renewable demand is introduced. Model (3) adds an interaction term, with coefficient δ capturing potential synergistic or countervailing relationships between sanctions effects and renewable demand.

Model (1): baseline sanctions effect

$$\ln(Export_{it}) = \alpha_i + \beta_1 Sanction_t + \varepsilon_{it}. \quad (1)$$

Model (2): controlling for renewable energy demand

$$\ln(Export_{it}) = \alpha_i + \beta_2 Sanction_t + \gamma\, ChinaRenewable_t + \varepsilon_{it}. \quad (2)$$

Model (3): interaction effect testing

$$\ln(Export_{it}) = \alpha_i + \beta_3 Sanction_t + \gamma \ln ChinaRenewable_t + \\ + \delta(Sanction \times \ln ChinaRenewable)_t + \varepsilon_{it}. \quad (3)$$

The gravity model literature (Yotov et al., 2016; Larch et al., 2025) typically recommends year fixed effects. Our key explanatory variables — the post-2022 sanctions dummy and China's renewable capacity — are, however, pure time-series variables that do not vary across minerals. Year fixed effects would absorb the temporal variation we seek to decompose, precluding identification of our research question, namely the relative contributions of sanctions and structural demand. We instead model these time-varying factors explicitly and employ progressive controls and robustness checks. Consistent with the framing in Yotov et al. (2016) and Heid et al. (2021), we treat this collinearity as a fundamental design constraint of the single-dyad panel rather than as a methodological choice. The constraint implies that the coefficient estimates should be understood as descriptive associations reflecting shared temporal variation (Heid et al., 2021) rather than as causal parameters. We therefore position this study explicitly as a descriptive decomposition exercise.

The key advantage of this approach is that it documents how coefficient patterns evolve as controls are added progressively. By tracking how the sanctions coefficient changes as controls for structural factors are added, we can assess whether the initial correlation reflects a sanctions effect or is confounded by concurrent trends. While this cannot prove causation, it provides systematic evidence on how the sanctions coefficient responds when structural demand factors are introduced as competing controls.

The post-2022 period saw several contemporaneous shocks, including commodity price volatility, the reconfiguration of shipping routes, and regional supply disruption. The robustness specification in Table 5 addresses these in part by adding controls for international mineral prices and exchange rates: the price index absorbs commodity market dynamics, and the exchange rate captures financial market shocks. While the absence of year fixed effects means that we cannot isolate all contemporaneous factors, our robustness checks (PPML estimation, varying time windows) suggest that the core findings are not artifacts of the estimation method or of unmodeled shocks, though they do not speak to the separate question of a common time trend, which Section 4.3 takes up. More fundamentally, both key regressors are pure time-series variables that carry no cross-mineral variation, so a time-based control absorbs almost all of their variation in this sample. This structural feature of the data implies that the empirical leverage of the paper lies in cross-sectional heterogeneity, which exploits variation across mineral functional categories rather than over time. The coefficient trajectory analysis documents how the sanctions association evolves as structural demand controls are introduced, providing descriptive context for the heterogeneity analysis that follows.

Renewable energy capacity may not be strictly exogenous to mineral markets, but several factors mitigate this concern. First, China's renewable expansion is driven primarily by policy mandates (Five-Year Plans, carbon neutrality targets) rather than by mineral supply constraints. Second, China sources minerals from many countries, which makes Russian supply a relatively small factor in deployment decisions. Third, we use installed capacity, which represents realized outcomes and is less subject to short-term supply fluctuations. While complete exogeneity cannot be claimed, renewable capacity is a reasonable proxy for policy-driven structural demand in our pattern documentation framework. Given these design constraints, the coefficient trajectories and heterogeneity patterns

reported below should be read as observational descriptions of the data patterns, providing descriptive context rather than causal identification.

4. Empirical results and analysis

4.1. Core coefficient pattern findings

Before the core regressions, we examined the fundamental properties of the data. Variance inflation factor (VIF) diagnostics yield an average VIF of 2.54 across the principal variables — substantially below the conventional threshold of 10 — which indicates the absence of severe multicollinearity.

The empirical analysis documents a clear coefficient trajectory across the three model specifications. The baseline regression yields a sanctions effect coefficient of 3.682, statistically significant ($t = 3.14$, $p = 0.016$). This result requires cautious interpretation, however: the sanctions dummy mechanically captures the post-2022 period of elevated imports, which makes statistical significance expected rather than evidence of causation. Because the dummy variable overlaps temporally with high-import years, Model (1) alone cannot distinguish whether sanctions caused the surge or merely coincided with it.

Incorporating China's renewable transition variables, however, changes the picture substantially. The sanctions coefficient falls to 0.946 — a reduction of 74.3% — and statistical significance disappears entirely (Table 2). The renewable transition coefficient, by contrast, is 0.754 in that specification and is significant at the 5% level. The sanctions coefficient remains insignificant when international mineral price and exchange rate controls are added in the robustness specification of Table 5, where the renewable coefficient is 0.526 ($p = 0.087$). This pattern is consistent with the interpretation that the initial sanctions coefficient partly reflects an omitted variable problem, while the renewable coefficient stays positive and significant at the 10% level or better in every robustness specification of

Table 2
Coefficient trajectories across progressive control specifications.

Variable	(1)	(2)	(3)
	Baseline sanctions	Controlling for renewable demand	Interaction testing
sanction_2022	3.682**	0.946	7.031
	(1.172)	(0.745)	(6.678)
ln_china_renewable		0.754**	0.755**
		(0.260)	(0.262)
sanction_2022_X_renewable			−0.877
			(1.022)
Observations	200	200	200
Adjusted R^2	0.7052	0.7641	0.7630
AIC	1,066.98	1,023.35	1,025.23
F-statistic	9.87	5.19	6.11

Note: The dependent variable is ln(1 + Russia's exports of mineral *i* to China in year *t*), in current U.S. dollars. *sanction_2022* is a dummy equal to one from 2022 onward; *ln_china_renewable* is ln(1 + China's installed solar and wind capacity, GW); *sanction_2022_X_renewable* is their product. Standard errors clustered by mineral (8 clusters) in parentheses. All models control for mineral fixed effects. . *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Table 5, although its magnitude varies. While we cannot attribute causality given the single-dyad structure and the absence of year fixed effects, the coefficient trajectory provides suggestive descriptive evidence consistent with the renewable demand pattern documented in the heterogeneity analysis.

Interaction effect testing leaves the renewable transition coefficient essentially unchanged between Models (2) and (3), at 0.754 and 0.755. The coefficient on the sanctions × renewable demand interaction is −0.877 and statistically insignificant ($p = 0.420$).

The trajectory of the sanctions coefficient across the three models illustrates how systematic pattern documentation tracks the evolution of the sanctions association as competing factors are controlled progressively.

4.2. Heterogeneity analysis

Mineral categories differ substantially in their responsiveness to sanctions, which offers insight into trade adjustment mechanisms (Table 3). Renewable energy base materials (copper, aluminum) are the most responsive, with a coefficient of 1.630 that is highly significant ($p < 0.001$). This finding follows from product characteristics: base metals are highly standardized and vary little in quality, which facilitates supplier switching and the reconfiguration of trade routes.

Battery-critical materials (lithium, cobalt, nickel, graphite) show a contrasting pattern: the sanctions coefficient is 0.587 and statistically insignificant ($p = 0.672$). This weak response reflects the inherent complexity of battery material supply chains. Transforming raw ore into battery-grade material requires sophisticated chemical purification and processing, specialized technical processes, and rigorous quality control, so simple trade route diversion is inadequate for establishing effective alternative supply relationships quickly.

Advanced manufacturing materials (platinum group metals, rare earths) show intermediate responsiveness, with a coefficient of 0.978 that is statistically insignificant ($p = 0.157$). These materials are distinguished by high technological barriers and protracted certification cycles: even where latent demand exists, establishing a new supply relationship requires extensive technical verification and commercial certification, which places their sanctions response between that of base materials and that of battery materials.

Table 3
Heterogeneity analysis by mineral category.

Variable	(1)	(2)	(3)
	Battery-critical	Base materials	Advanced manufacturing
sanction_2022	0.587	1.630***	0.978
	(1.383)	(0.355)	(0.680)
ln_china_renewable	1.135***	0.237***	0.507**
	(0.181)	(0.074)	(0.201)
Observations	100	50	50
Adjusted R^2	0.7368	0.5307	0.6714

Note: Heteroscedasticity-robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Beyond the heterogeneity of sanctions effects, China's renewable energy demand variable also differs systematically across mineral categories, which further illuminates potential mechanisms of trade growth. Battery-critical materials are the most sensitive to renewable energy demand, with a coefficient of 1.135 ($p < 0.001$), above that of advanced manufacturing materials at 0.507 ($p < 0.05$) and that of base materials at 0.237 ($p < 0.01$).

This gradient reflects the differing functional importance of minerals in the energy transition. The pronounced sensitivity of battery materials stems from their dual demand channels — electric vehicle production and energy storage systems — both of which are growing rapidly in China. Kannan et al. (2025) note that current electric vehicle battery designs require substantial quantities of critical minerals, and that the rapid rise in global EV production has produced exponential demand growth, particularly for lithium, cobalt, and nickel.

Although base materials such as copper and aluminum are used directly in renewable energy infrastructure, their regression coefficient is relatively modest, which may reflect China's diversified procurement. For such bulk commodities Russia is merely one of many supply sources, whereas in battery materials and rare earths its position is more pivotal because supply chains are more concentrated. In addition, the wide application of base materials across industrial sectors dilutes the specific pull of installed renewable energy capacity on their trade.

Crucially, the renewable energy coefficient remains significant across all categories, while the sanctions effect is significant only for base materials. This asymmetry is consistent with structural demand being more prominent for technology-intensive critical minerals, while the sanctions association is weak except where products are highly standardized and suppliers can be switched quickly.

Sanctions effects also merit attention in the temporal dimension. Stratifying the sample by policy junctures into three event windows reveals patterns of temporal evolution that echo the product heterogeneity above (Table 4). The variable *sanction_2014* is a dummy equal to one from 2014 onward, capturing the sanctions imposed following the 2014 Crimea events.

Over the 2000–2013 baseline period the renewable transition coefficient is 0.456 and insignificant, consistent with the slow pace of global renewable development at the time. In the second window (2010–2018) it rises to 1.762 and is significant

Table 4
Temporal heterogeneity analysis.

Variable	(1)	(2)	(3)
	2000–2013	2010–2018	2018–2024
sanction_2014		−1.014	
		(1.059)	
sanction_2022			−0.392
			(0.280)
ln_china_renewable	0.456	1.762*	1.080
	(0.273)	(0.875)	(0.578)
Observations	112	72	56
Adjusted R^2	0.8403	0.7305	0.8598

Note: Windows overlap in 2010–2013 (columns 1 and 2) and in 2018 (columns 2 and 3). Cluster-robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

at the 10% level; in the third (2018–2024) it is 1.080 and no longer significant at conventional levels. The sanctions coefficients estimated in the two windows that include a sanctions dummy (−1.014 and −0.392) are not statistically distinguishable from zero ($t = -0.96$ and −1.40), and the confidence interval in the second window spans both a large negative and a large positive effect, so neither their sign nor their magnitude is interpretable. Table 4 is accordingly reported as a description of sub-period estimates rather than as evidence bearing on the attribution question, which rests on the cross-mineral heterogeneity of Table 3.

The systematic cross-mineral heterogeneity documented in Table 3 aligns with recent gravity literature emphasizing that sector-level estimation reveals differential responses that aggregate specifications obscure (Breinlich et al., 2024), which lends additional methodological support to our disaggregated approach.

4.3. Robustness checks

To check the reliability of our conclusions, we implement robustness checks along several dimensions. Sensitivity analysis of the temporal window shows that restricting the sample to the years from 2010 onward yields a negative sanctions coefficient (−0.258) that is insignificant ($p = 0.680$). The negative point estimate is not distinguishable from zero and is not read here as evidence of a suppressive effect.

Given the zero values and heteroscedasticity prevalent in trade data, we re-estimate using Poisson pseudo-maximum likelihood (PPML). The sanctions coefficient is 0.334 and remains insignificant ($p = 0.402$). PPML handles the distributional characteristics of trade flow data and zero values better than least squares, and the consistency of its result provides additional support for our findings.

We also conduct a placebo test on the pre-2022 sample (2000–2021), assuming artificially that sanctions occurred in 2015. The "pseudo-sanctions" coefficient is 0.969 ($p = 0.309$), and adding international mineral prices and the USD/RUB exchange rate as controls to the baseline specification yields a sanctions coefficient of −0.853 ($p = 0.455$).

These checks address concerns about contemporaneous shocks, and PPML estimation accounts for heteroscedasticity in trade data. The sanctions coefficient is statistically indistinguishable from zero in the baseline (0.946, $p = 0.245$) and in every robustness specification in Table 5, and the 2015 placebo has no identified baseline effect against which to be judged. This is the same structural constraint documented in Table 6: because both key regressors are pure time-series variables, no exercise that varies the timing of the cutoff can identify a sanctions effect in this sample. The placebo is accordingly reported for transparency rather than as corroboration. The renewable demand coefficient, by contrast, is positive and significant in every specification in Table 5 (0.754 in the baseline, $p = 0.023$; 1.482 for the window from 2010 onward, $p = 0.031$; 0.336 under PPML, $p = 0.001$; 0.596 in the placebo specification, $p = 0.0997$; 0.526 with price and exchange-rate controls, $p = 0.087$), although its magnitude varies considerably; in the period splits of Table 4 it is significant only for the 2010–2018 window (1.762). What these checks establish is that the failure to detect a sanctions effect is not an artifact of the estimation method, of the sample window, or of the omission of price and exchange-rate controls.

As a further transparency check, we estimated specifications with time-based controls. When either a global linear time trend or mineral-specific linear time

Table 5
Baseline model and the main robustness checks.

Specification	Sanctions coefficient	*p*-value	Renewable coefficient	*p*-value
Baseline model	0.946	0.245	0.754	0.023**
Time window (2010 onward)	−0.258	0.680	1.482	0.031**
PPML estimation	0.334	0.402	0.336	0.001***
Placebo test (2015)	0.969	0.309	0.596	0.0997*
Price and exchange rate controls	−0.853	0.455	0.526	0.087*

Note: *p*-values are based on cluster-robust standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Table 6
Coefficient estimates under time-based controls.

Specification	Sanctions coefficient	*p*-value	Renewable coefficient	*p*-value
Baseline (no trend)	0.946	0.245	0.754	0.023**
Global linear trend	0.260	0.608	−0.113	0.883
Mineral-specific trends	0.260	0.614	−0.113	0.885

Note: *p*-values are based on cluster-robust standard errors. All models control for mineral fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

trends are added to the baseline specification, the renewable energy coefficient loses statistical significance, and the two trend specifications give virtually identical results (see Table 6; under mineral-specific trends, sanctions: $\beta = 0.260$, $p = 0.614$, renewable: $\beta = -0.113$, $p = 0.885$; the global trend gives the same two coefficients with $p = 0.608$ and $p = 0.883$). This outcome is a near-mechanical consequence of the data structure: both key regressors are pure time-series variables that carry no cross-mineral variation, so a time-based control absorbs almost all of their variation in this sample. The coefficient trajectory in Table 2 should therefore be understood as documenting shared temporal co-variation rather than as evidence distinguishing the relative contribution of each mechanism. This structural constraint does not, however, affect the heterogeneity analysis in Table 3, which exploits cross-sectional variation across mineral functional categories rather than temporal variation and is therefore the most defensible empirical contribution of the paper.

5. Discussion and limitations

The descriptive pattern documentation in this study offers insight into Russia–China mineral trade dynamics during a period of overlapping structural and policy shocks. On the supply side, the expansion of Russian mineral exports is consistent not with an ad hoc response to sanctions but with the combination of long-term strategic positioning and emergent market opportunity. Zulyar and Zulyar (2025) trace the evolution of this strategy systematically, from tactical considerations to a long-term strategic framework. In 2012 Russia announced at the APEC summit its intention to strengthen cooperation with Eastern nations, and after the 2014 Crimea events the strategy accelerated markedly. The forward-looking deployment of the "Pivot to the East" strategy laid the foundations for

the post-2022 restructuring of trade, and this long-term planning may substantially influence how sanctions effects materialize.

On the demand side, the global renewable transition has offered Russia unprecedented opportunities. Chinese new energy vehicle production rose from 1.366 million units in 2020 to 12.888 million units in 2024. Each electric vehicle requires roughly 66.3 kg of graphite, 53.2 kg of copper, 39.9 kg of nickel, 13.3 kg of cobalt, and 8.9 kg of lithium. This structural demand pull is consistent with the observed coefficient patterns, which align more closely with renewable demand than with the post-2022 sanctions indicator across the robustness specifications of Table 5.

Three mechanisms could account for the increase in China's mineral imports from Russia. First, Chinese importers may substitute Russian supplies for those from sanctioning countries. Second, buyers may build strategic stockpiles given potential price advantages. Third, the imports may serve China's surging renewable energy manufacturing demand directly. Our coefficient patterns align most closely with the third mechanism. Even if Russian price discounts facilitated some transactions, the renewable coefficient keeps its sign and remains significant at the 10% level or better, though not at a constant magnitude, across the robustness specifications in Table 5.

The heterogeneity analysis provides further evidence against price-driven explanations. If trade growth were driven primarily by sanctions-induced price discounts, we would observe uniform growth across all mineral categories and the temporary surge patterns characteristic of arbitrage. Instead, the sensitivity of trade growth to renewable demand is concentrated in battery-critical and renewable-intensive minerals, while base materials respond far less on that margin despite similar price exposure. This selective pattern is more consistent with structural demand than with price incentives as an explanation of the observed trade dynamics.

Our findings complement recent empirical work on the 2022 Russia sanctions while revealing important nuances. Isachenko and Medvedkova (2024) and Felbermayr et al. (2025) document substantial trade reorientation after the sanctions, with Russia–China trade growth exceeding what conventional trade diversion models would predict. Yet these studies tend to attribute such growth primarily to sanctions-induced diversion without fully considering what else was happening at the same time. Our analysis suggests that this interpretation may be incomplete. Once China's renewable energy expansion is controlled for systematically, the coefficient patterns of Model (2) align more closely with structural demand than with sanctions — a pattern consistent with the heterogeneity evidence in Table 3 — which suggests that the attribution question deserves more careful decomposition in future multi-dyad designs. The temporal coincidence of sanctions and the renewable transition may partly account for the strong sanctions coefficients found in simpler before-after comparisons. This matters for policy assessment: when major interventions coincide with structural economic shifts, simple before-after comparisons risk misattributing effects.

A deeper theoretical implication follows: where several events occur simultaneously, descriptive patterns alone may be insufficient to distinguish the relative contributions of competing factors, which underscores the value of systematic decomposition. Forces of structural economic transformation appear to be reshaping global trade architectures, and their influence warrants careful separation from geopolitical shocks in future research.

Several methodological limitations warrant acknowledgment. First, we omit year fixed effects in order to identify time-varying explanatory variables, which means that we cannot perfectly isolate the sanctions effect from all contemporaneous changes in 2022, when multiple global shocks occurred simultaneously. The price and exchange rate controls added in the robustness specification of Table 5 partially mitigate this by capturing commodity market dynamics and financial market shocks. More fundamentally, China's renewable capacity and Russia–China mineral trade both exhibit strong upward trends, which raises concerns about spurious correlation in the absence of year fixed effects. We argue, however, that the systematic cross-mineral heterogeneity documented in Table 3 substantially mitigates this concern: battery-critical materials are 4.8 times more sensitive to renewable demand than base materials, which common time trends cannot explain. This cross-sectional variation provides descriptive leverage that goes beyond a common time trend explanation. Our robustness checks, including PPML estimation and varying time windows, further suggest that the core findings are not artifacts of the estimation method or of unmodeled shocks. They do not speak to the trend question: as Section 4.3 reports, a linear trend control absorbs almost all of the variation in both key regressors, and it is the cross-mineral heterogeneity of Table 3, not these checks, that bears on spurious correlation.

Second, potential endogeneity of renewable capacity cannot be ruled out entirely, since mineral availability could in theory influence the pace of deployment. A formal instrumental variable approach, as demonstrated in gravity settings by Egger et al. (2011), would address this concern more rigorously and remains a direction for future research. Third, we cannot claim causal identification without a natural experiment or instrumental variables. Our contribution is methodological: it demonstrates how coefficient trajectory analysis combined with cross-sectional heterogeneity can document differential patterns consistent with competing explanations in observational settings. Despite these limitations, the coefficient patterns in the robustness specifications of Table 5 consistently show a positive renewable coefficient, significant at the 10% level or better, alongside an insignificant sanctions coefficient, which provides descriptive support for the patterns documented above.

These constraints notwithstanding, the study makes three descriptive contributions that retain substantive value. First, Figure 1 documents that China's critical mineral imports from Russia were already trending upward before 2022, which provides important context for interpreting the post-sanctions surge. Second, and most importantly, the heterogeneity analysis in Table 3 reveals a systematic gradient in renewable demand sensitivity across mineral categories that mirrors their functional roles in the energy value chain — a pattern difficult to attribute to common time trends alone. Third, the coefficient trajectory in Table 2 documents a pattern in which the sanctions coefficient loses significance once renewable demand is controlled for, while the renewable coefficient keeps its positive sign and remains significant, at the 10% level or better, across the robustness checks reported in Table 5. Together, these three patterns constitute the empirical core of the paper. Extending the design to a multi-dyad panel would make year fixed effects feasible, alongside mineral-specific time trends of the kind estimated in Table 6, and would allow stronger causal claims; it is a natural direction for future research.

6. Conclusion and policy implications

Through systematic pattern documentation, this study provides descriptive decomposition evidence on the competing explanations for the surge in Russian critical mineral exports to China. Using panel data on eight critical minerals over 2000–2024 and three progressively controlled model specifications, we find that the coefficient patterns align more closely with global renewable transition demand than with a direct sanctions response. The sanctions effect coefficient falls from 3.682 to 0.946 and loses statistical significance once renewable demand is controlled for, whereas the renewable transition coefficient remains significant, at the 10% level or better, across the robustness specifications reported in Table 5. The heterogeneity analysis suggests that sanctions effects appear primarily in highly standardized base materials (copper, aluminum), while technology-intensive minerals show patterns more consistent with structural demand. These patterns suggest that the apparent sanctions effect may partly reflect the temporal coincidence of the implementation of sanctions and the acceleration of the renewable transition rather than a robust structural relationship.

The patterns documented in this study illustrate a methodological challenge: when major structural transformations coincide with policy interventions, simple before-after comparisons in a single-dyad setting may not attribute observed trade changes cleanly to either factor. In the present case, the temporal overlap between the 2022 sanctions and China's ongoing renewable energy expansion means that separating the two sources of variation would require cross-country variation in both sanction exposure and structural demand. For analysts assessing the effectiveness of sanctions in such settings, the cross-commodity heterogeneity approach illustrated here offers one way to document differential responses across product categories, providing descriptive leverage on which explanation is more consistent with observed patterns even without formal causal identification.

Battery-critical materials show stronger alignment with structural renewable demand, while base materials show more pronounced sanctions-associated responses, which suggests that Russia–China mineral trade dynamics differ systematically across commodity categories. For battery-critical minerals, supply chain assessments may need to give more weight to shifts in energy transition trajectories than to policy disruption; for base materials such as copper and aluminum, developments in the policy environment may be more directly relevant, particularly given China's central role in the production, consumption, and trade of critical minerals (Ren et al., 2025).

The differential response patterns documented here are broadly consistent with the general observation that standardized base materials offer more scope for rapid trade reorientation than technology-intensive minerals, which involve longer adjustment periods linked to quality standards and supply chain integration. Kannan et al. (2025) note that ongoing innovation in battery material processing is expanding the supply options for key minerals; as these supply conditions evolve, the demand-driven and policy-associated patterns documented here may shift in ways that merit continued attention in this bilateral trade relationship.

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Additional information

Data availability

The data and replication code underpinning the analysis reported in this paper are deposited in Zenodo at https://doi.org/10.5281/zenodo.20473017