GMR
The Original

CRITICAL METAL SECURITY PREMIUMS IN THE GLOBAL ENERGY TRANSITION: MEASUREMENT AND FINANCIAL GOVERNANCE MITIGATION EFFECTS

Gan Yu[1], Chujiang Wen[2*]

[1]School of Finance, Guangxi University of Finance and Economics, Guangxi, 530000, China, 2016210003@gxufe.edu.cn
[2*]School of Finance, Guangxi University of Finance and Economics, Guangxi, 530000, China, wenchujiang95@126.com
Corresponding author:Chujiang Wen，wenchujiang95@126.com

Abstract
Background. The global energy transition has increased strategic dependence on critical metals that are essential for electrification, battery production, renewable-energy systems, and clean-energy industrial supply chains. As demand rises, mineral access has become a question of financing capacity, ownership, and governance rather than geological abundance alone.
Objective. This study measures critical metal security premiums by examining how strategic mineral value is reflected in Chinese official financing for transition-mineral projects, and it tests whether financial governance mechanisms mitigate those premiums.
Data and methods. The empirical basis is AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0, which records Chinese official-sector grant and loan commitments from 2000 to 2023. The recommended aggregate loan-event sample contains 311 records, with a total identified financing amount of approximately US$98.11 billion in constant 2023 US dollars. Because the dataset does not contain commodity spot or futures prices, security premiums are captured through financing behavior, using the size of Chinese official financing, the interest rate at commitment, and the margin on reference rate, alongside collateralization, commodity-backed finance, ownership, and product-control arrangements. Security-sensitive critical metals are defined as loan events involving copper, cobalt, nickel, lithium, or rare earth elements, and other transition minerals form the comparison group. Analysis combines descriptive comparison with ordinary least squares regression that includes region, financing period, and project-activity controls, robust standard errors, and a critical-metal by governance-mitigation interaction term.
Results. Chinese official financing is strongly concentrated in security-sensitive critical metals, which account for approximately US$87.55 billion of the total portfolio, against US$10.57 billion for other transition minerals. These minerals receive larger average commitments, at approximately US$350.19 million per event versus US$251.58 million, and show higher raw loan-pricing indicators. Regression evidence indicates that the strongest premium appears in financing size, while loan-pricing effects depend more on project and governance characteristics. Governance mechanisms, including non-public debt exposure, host-government participation, local procurement, local employment, workforce development, and rehabilitation or post-closure planning, show evidence of mitigating some components of the premium, particularly loan-margin pressure.
Conclusions. Critical metal security premiums are not only market-price phenomena. They are also embedded in project-level financing structures, and financial governance can partially reduce their cost. The study contributes to debates on critical mineral security, energy-transition finance, Chinese overseas finance, and global financial governance.

KEYWORDS: critical minerals; energy-transition finance; security premium; Chinese official finance; transition minerals; financial governance; project finance; loan pricing.

1. INTRODUCTION

The global energy transition is rapidly converting critical minerals from conventional industrial inputs into strategic financial and security assets. Technologies central to decarbonization, including electric vehicles, grid-scale battery storage, solar photovoltaics, wind turbines, transmission networks, and advanced power electronics, depend heavily on minerals such as copper, lithium, nickel, cobalt, graphite, and rare earth elements. The International Energy Agency projects substantial long-term increases in demand for these materials under climate-driven scenarios, with lithium, graphite, nickel, cobalt, copper, and rare earth elements occupying especially important positions in clean-energy supply chains [1], [2]. The World Bank likewise emphasizes that the clean-energy transition is mineral intensive,

estimating that more than three billion tons of minerals and metals will be needed to deploy low-carbon technologies at the scale required for climate targets [3]. Mineral availability is therefore no longer only a matter of geological abundance. It has become a matter of financing capacity, ownership control, geopolitical access, contract design, and supply-chain resilience. This shift creates a need to examine not only how much supply can be produced, but also how the financial structures behind extraction and processing projects shape the cost of strategic access.

This study develops the concept of a critical metal security premium to capture the additional financial and strategic value attached to minerals that are essential for the transition but exposed to supply concentration, political risk, processing bottlenecks, and ownership competition. In traditional commodity-market analysis, a premium is usually read from price spreads, futures curves, or spot volatility. In the context of transition minerals, however, security premiums may also appear before the commodity reaches the market. They can be embedded in financing terms, loan size, collateral arrangements, commodity-backed repayment structures, product-control rights, and ownership positions that determine who gains access to future supply. This broader interpretation is important because mining and processing projects are capital intensive, geographically uneven, and slow to reach production [4]. When strategic minerals are linked to electric mobility, renewable power, and national industrial policy, financiers may accept larger exposures, tighter control mechanisms, or higher pricing to secure long-term access. A financing-based measurement of security premiums thus provides a valuable complement to market-price approaches by identifying how strategic value is built into project finance itself.

The need for such an approach is reinforced by the growing concentration of critical mineral supply chains. The IEA reports that refining and processing capacity for many key minerals has become more concentrated rather than less concentrated in recent years. In 2024, the average market share of the top three refining nations for key energy minerals rose to 86 percent, while supply growth remained heavily concentrated among a few leading producers, including China, Indonesia, and the Democratic Republic of the Congo [2]. Long-horizon demand scenarios point to the same set of materials, which confirms the strategic weight of copper for electrification and of lithium, nickel, and cobalt for batteries [5], [6]. Material-bottleneck assessments warn that rapid deployment of green technologies could strain the supply of several of these metals [7]. IRENA further notes that criticality designations can influence capital allocation, encourage higher environmental and social standards, and support international collaboration [8]. Mineral criticality is therefore increasingly financialized. Capital flows, credit conditions, and governance arrangements now help determine whether countries and firms can secure reliable access to transition minerals.

China's overseas transition-mineral finance offers a highly relevant empirical setting for measuring this financing-based premium. AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0 tracks approximately US$98 billion in Chinese official-sector financial commitments for transition-mineral extraction and processing operations across 47 countries from 2000 to 2023 [9]. The dataset is valuable because it connects financing commitments with mineral type, project activity, host country, financier identity, ownership structure, loan terms, collateralization, commodity backing, and governance-related safeguards. These features allow the present study to move beyond general statements about strategic mineral competition and to test empirically whether commitments are systematically larger or more costly for security-sensitive minerals such as copper, cobalt, nickel, lithium, and rare earth elements. The dataset also makes it possible to examine whether financial governance mechanisms, such as co-financing, multilateral participation, public-liability limits, host-government ownership, local procurement and employment requirements, workforce development, and rehabilitation or post-closure planning, reduce the premium embedded in strategic mineral finance.

Accordingly, this paper investigates two related questions. First, how can critical metal security premiums be measured using project-level financing data rather than only market-price data? Second, do financial governance mechanisms mitigate these premiums by reducing loan margins, diversifying financing risk, or strengthening institutional safeguards around extraction and processing projects? In answering these questions, the study makes three contributions. It proposes a financing-based measurement framework for critical metal security premiums, using loan size, interest rates, reference-rate margins, collateralization, commodity backing, ownership, and product-control arrangements as observable indicators of strategic value. It provides empirical evidence from Chinese official financing for transition minerals, a major but previously opaque segment of global mineral finance. It evaluates the mitigation role of financial governance, showing how institutional safeguards and diversified financing arrangements may reduce the financial cost of securing critical metal access. The energy transition will not be determined by mineral demand alone. It will also depend on whether the financial architecture of mineral supply can balance strategic security, investment efficiency, and responsible governance.

2. LITERATURE REVIEW

2.1 Critical Minerals and the Security Logic of the Global Energy Transition

Research on the global energy transition increasingly identifies critical minerals as a central foundation of low-carbon energy security. Unlike fossil-fuel systems, which depend on continuous fuel supply, clean-energy systems require large upfront inputs of minerals and metals for batteries, electric vehicles, solar photovoltaics, wind turbines, grid

infrastructure, and power electronics. Minerals such as copper, lithium, nickel, cobalt, graphite, and rare earth elements have therefore become strategic resources that enable electrification and renewable-energy deployment. The World Bank estimated that more than three billion tons of minerals and metals would be required to deploy wind, solar, geothermal, and storage technologies under a below-two-degree pathway [3]. The IEA reaches a similar conclusion, tying demand for these materials directly to clean-energy technology deployment and national energy-security strategies [1], [2]. This body of work establishes that the transition is not only a technological change but also a mineral-intensive restructuring of global production and finance.

A major theme is that mineral security depends on far more than geological availability. Månberger and Johansson argued that the renewable-energy transition generates new geopolitical concerns because several metals and metalloids used in low-carbon technologies are geographically concentrated [10]. Overland similarly showed that the geopolitics of renewable energy differs from that of fossil fuels, yet it does not remove resource-security concerns; instead, it creates new dependencies around extraction, processing, and clean-technology manufacturing [11]. Scenario-based analysis of nickel, cobalt, lithium, graphite, and copper reinforces the point that supply may struggle to keep pace with transition demand [12]. Owen and colleagues add that transition-mineral development often intersects with land-connected peoples, so security cannot be separated from local rights and legitimacy [13]. These studies provide the basis for treating critical metals as security-sensitive assets rather than ordinary commodities.

The sustainability literature adds a further dimension by arguing that mineral security cannot be divorced from social and environmental governance. Sovacool and colleagues warned that the low-carbon transition may reproduce extractive harms if mineral expansion is not managed through stronger labor, environmental, and community safeguards [14]. Complementary work documents the social and environmental complexity of extracting energy-transition metals and the biodiversity pressures created by renewable-energy expansion [15], [16]. The concept of a social licence to operate shows that community acceptance shapes whether projects proceed [17], while earlier reviews established mining's contested environmental footprint [18]. Responsible-sourcing scholarship on conflict minerals and cobalt shows how supply-chain initiatives attempt to manage these risks [19], [20], and Global South perspectives caution that criticality framings can overlook producer-country interests [21]. Critical mineral security is therefore multidimensional. It involves supply availability, processing concentration, financial access, ownership control, environmental legitimacy, and social responsibility, which supports the present study's focus on financing structures and governance mechanisms.

2.2 Measuring Critical Metal Security Premiums: From Market Prices to Financial Contracts

Existing studies commonly measure critical mineral risk through commodity prices, price volatility, trade dependence, import concentration, reserve scarcity, or geopolitical supply exposure. A large criticality-assessment literature formalizes these measures. Foundational frameworks quantify supply risk and vulnerability across many metals and establish standard indicators for criticality [22], [23]. By-product metals receive particular attention because their supply is tied to host-metal production and is therefore difficult to expand [24]. Reviews of raw-material supply risk and vulnerability synthesize these methods and highlight their data requirements [25], [26]. Battery-material supply risks and comprehensive methodological reviews extend the toolkit to the specific minerals that dominate clean-energy demand [27], [28]. These approaches are useful because commodity markets respond quickly to disruptions, shortages, and export restrictions. They do not, however, fully capture the strategic value embedded in the financing stage of mineral supply, before production begins.

This study therefore builds on the idea that security premiums can be observed in financing behavior, not only in spot prices. In project finance, a premium can appear as larger loan commitments, higher interest rates, wider reference-rate margins, stronger collateral requirements, commodity-backed repayment, ownership-linked lending, and product-control rights. The project-finance literature provides the analytical grounding for reading strategic value from loan structures. Studies of large projects show why project finance is used for capital-intensive, long-horizon assets [29], and comparative work distinguishes project-finance loans from ordinary syndicated credits [30]. The term structure of credit spreads in project finance links pricing to risk and maturity [31], while research on political risk shows how development-bank participation shapes syndication and pricing in risky jurisdictions [32]. Alongside these mechanisms, geopolitical risk is increasingly quantified and connected to resource markets. The geopolitical-risk index has become a standard measure [33], and recent work links geopolitical risk and mineral prices to the energy transition [34], [35], including analyses of Chinese influence in rare earth and lithium markets [36]. Reading premiums from financial contracts complements this price-based work by revealing how future access is secured before minerals enter trade.

2.3 Chinese Official Finance and Transition-Mineral Supply Chains

China's role in global transition-mineral supply chains is a major focus of academic and policy debate. China is important not only as a consumer of critical minerals but also as a leading processor, refiner, manufacturer, financier, and overseas investor. Its industrial strategy connects mineral access with downstream sectors such as electric vehicles, batteries, solar technologies, and wind power. Chinese overseas mineral finance therefore cannot be read only as ordinary development finance or commercial lending. It may also function as a mechanism for securing long-term

supply, strengthening processing chains, supporting Chinese firms abroad, and reducing exposure to external disruption. A growing empirical literature on Chinese development finance clarifies these dynamics. Studies show that the determinants of Chinese state financing differ from those of traditional donors [37] and that Chinese development finance has measurable effects on recipient growth [38]. Analyses of China's overseas lending document its scale, collateralization, and often non-public terms [39], while critical assessments caution against simplistic debt-trap narratives [40].

The AidData Chinese Financing for Transition Minerals Dataset provides a particularly useful empirical basis for this issue. The dataset records Chinese official-sector financial commitments for transition-mineral extraction and processing across 47 countries from 2000 to 2023, with approximately US$98 billion in commitments in Version 2.0 [9]. Unlike aggregate trade or investment statistics, it links financing events to mineral type, host country, activity, financier, loan pricing, collateralization, commodity backing, product-control arrangements, ownership structures, and governance safeguards. This makes it possible to examine whether Chinese official finance is concentrated in particular minerals and activities, and whether financial terms differ for minerals that are central to the transition. Official finance can perform strategic functions that private capital may not perform to the same degree. It can support long-payback projects, absorb political or commercial risk, connect lending to ownership or product access, and use collateral or commodity-backed structures to secure repayment and supply. Chinese official transition-mineral finance is therefore an appropriate setting for measuring whether critical minerals carry a security premium.

2.4 Financial Governance as a Mitigation Mechanism

The financial governance literature emphasizes that resource security should be managed through transparency, accountability, risk sharing, environmental safeguards, local-development requirements, and responsible investment. In critical minerals, governance is especially important because the pressure to expand supply quickly can create environmental damage, labor risks, sovereign-debt exposure, community conflict, or weak local value creation. Sovacool and colleagues argued that low-carbon mineral supply chains must be made more sustainable and just [14]. Recent responsible-finance work emphasizes that financing structures should support sustainable mineral production rather than simply accelerate extraction [41], [42]. Governance is thus part of the institutional architecture through which secure and legitimate supply is created, not a background condition external to it.

Financial governance can reduce critical metal security premiums through several channels. Co-financing with non-Chinese or international financiers can diversify project risk and reduce dependence on a single state-linked lender. Multilateral participation can introduce stronger monitoring, disclosure, and environmental standards. Non-public or non-guaranteed debt structures can limit host-country sovereign liability. Host-government ownership can align projects with domestic development goals, although the effect may depend on governance quality. Local procurement, local employment, workforce development, and rehabilitation or post-closure planning can improve social legitimacy and reduce long-term environmental and political risk. These mechanisms are particularly relevant in transition-mineral projects, where social opposition, environmental risk, and weak local development outcomes can delay production and raise financing costs. The present study treats these mechanisms as financial governance mitigation effects. The argument is not that governance removes the strategic value of critical metals. Governance can, however, reduce the financial cost, risk concentration, and institutional vulnerability associated with securing access.

2.5 Literature Review Comparison and Research Gap

Table 1 compares the most relevant literature streams and situates the present study within them. Previous research has contributed strongly to understanding mineral demand, geopolitical supply risk, sustainability concerns, and responsible finance. Most existing studies, however, do not directly measure critical metal security premiums through project-level financing behavior. They also provide limited empirical evidence on whether governance mechanisms reduce the financial cost of securing transition-mineral access. The present study addresses this gap by using Chinese official financing data to measure security premiums through loan size, interest rates, reference-rate margins, collateralization, commodity backing, ownership control, and governance safeguards.

Table 1. Literature Review Comparison and Positioning of the Present Study

Author(s) / Source	Main Focus	Data / Method	Key Contribution	Limitation or Gap	Relevance to Present Study
Overland (2019)	Geopolitics of renewable energy	Conceptual and policy analysis	Shows that renewable energy changes, rather than removes, geopolitical energy-security concerns	Does not empirically measure mineral-finance mechanisms or security premiums	Supports the argument that the energy transition creates new forms of strategic resource dependence

Author(s) / Source	Main Focus	Data / Method	Key Contribution	Limitation or Gap	Relevance to Present Study
Månberger and Johansson (2019)	Geopolitics of metals and metalloids used in renewable-energy technologies	Metal-level assessment of geographic concentration, market size, and strategic relevance	Demonstrates that several renewable-energy metals have geopolitical importance because of supply concentration	Focuses on resource concentration rather than financing terms or governance mitigation	Provides theoretical support for treating transition metals as security-sensitive assets
Hund et al. (2020) / World Bank	Mineral intensity of clean-energy technologies	Scenario-based mineral-demand assessment	Shows that the clean-energy transition will require very large quantities of minerals and metals	Does not analyze project-level finance or Chinese official lending	Establishes the demand-side importance of critical minerals for the global energy transition
Sovacool et al. (2020)	Sustainable mineral and metal supply for a low-carbon future	Interdisciplinary review	Highlights environmental, social, labor, and justice challenges in mineral extraction	Does not quantify how financial governance affects loan pricing or security premiums	Supports the inclusion of governance, local employment, rehabilitation, and responsible-finance variables
IEA (2024, 2025)	Global critical mineral demand, supply, and refining concentration	Global energy and mineral-market assessment	Identifies copper, lithium, nickel, cobalt, graphite, and rare earth elements as central to clean-energy supply chains	Primarily focuses on demand, supply, and market concentration rather than project-level financial contracts	Justifies the classification of selected transition minerals as security-sensitive
IRENA and NUPI (2024)	Ranking critical materials for the energy transition	Multi-indicator criticality ranking	Provides a structured approach to identifying globally critical materials for renewable-energy applications	Does not examine loan-event data, financing premiums, or Chinese official finance	Supports the paper's mineral criticality framing and security-premium rationale
AidData (2026)	Chinese official financing for transition minerals	Project-level dataset covering Chinese official financial commitments from 2000 to 2023	Provides granular loan-event, financier, mineral, ownership, collateral, and governance information	Dataset is descriptive and requires analytical modeling to measure premiums and mitigation effects	Serves as the main empirical source for measuring financing-based security premiums
Ekins (2026)	Financing responsible supply of energy-transition minerals	Policy and responsible-finance analysis	Argues that sustainable mineral supply depends on responsible financing and governance	Does not empirically test mitigation effects using loan-level data	Supports the paper's financial governance mitigation framework
UNEP (2025)	Responsible financing and investment in energy-	Policy report	Emphasizes sustainable finance, human rights, environmental	Does not provide a quantitative security-premium model	Reinforces the importance of governance safeguards in

Author(s) / Source	Main Focus	Data / Method	Key Contribution	Limitation or Gap	Relevance to Present Study
	transition minerals		protection, and responsible investment in mineral supply chains		transition-mineral finance
Present study	Critical metal security premiums and financial governance mitigation effects	AidData Chinese transition-mineral finance dataset; loan-event-level analysis	Measures security premiums through financing size, interest rates, margins, collateralization, commodity backing, ownership, and product control; tests governance mitigation effects	Focuses on financing-based premiums rather than spot-market commodity-price premiums	Contributes a new empirical framework linking critical mineral security, Chinese official finance, and financial governance

The comparison shows that this paper sits at the intersection of three research areas: critical mineral security, transition-mineral finance, and financial governance. Existing studies establish that critical minerals are essential for the transition and that supply chains are exposed to concentration and governance risks. They have not sufficiently examined how security premiums are embedded in financing contracts before minerals reach the commodity market. The paper therefore shifts the measurement of critical metal security premiums from market prices alone to project-level financial structures, and it tests whether governance mechanisms mitigate those premiums. In doing so, it links resource-security analysis with financial-governance theory.

3. RESEARCH GAP

Although previous studies have examined critical minerals through supply concentration, demand growth, geopolitical risk, refining dominance, and commodity-market volatility, limited research has measured how the strategic value of transition minerals is embedded in project-level financing structures. Existing literature also discusses China's role in global critical mineral supply chains, but it rarely tests whether Chinese official finance provides larger or costlier commitments for security-sensitive metals such as copper, cobalt, nickel, lithium, and rare earth elements. In addition, the role of financial governance in reducing such premiums remains underexplored, particularly through mechanisms such as co-financing, multilateral involvement, non-public debt exposure, host-government ownership, local procurement, local employment, workforce development, and rehabilitation planning. This study addresses that gap by developing a financing-based framework for measuring critical metal security premiums and by examining whether financial governance mechanisms mitigate these premiums in Chinese official financing for transition-mineral projects during the global energy transition.

4. DATA AND METHODS

4.1 Dataset

This study uses AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0, which records China's official-sector grant and loan commitments for transition-mineral extraction, processing, and commodity-trading activities from 2000 to 2023 [9]. The dataset aligns directly with the purpose of this paper because it provides project-level and loan-event-level evidence on how Chinese official finance is allocated across transition minerals, host countries, financing structures, ownership arrangements, collateralization, commodity backing, and governance-related safeguards. According to the dataset documentation, the full dataset covers Chinese official financial commitments related to 32 transition minerals across 47 countries, while the recommended aggregate loan-event sample used in this study contains 311 loan-event records, including 293 loans, 16 debt-rescheduling records, one grant record, and one vague or TBD flow-type record. The total identified Chinese official financing amount in the recommended aggregate sample is approximately US$98.11 billion in constant 2023 US dollars. The dataset is therefore suitable for measuring critical metal security premiums through financing behavior rather than through commodity spot-market prices.

The dataset contains four main analytical views: Financial Contribution, Loan Event, Organization Role, and Mineral Operation Ownership. The Loan Event view is the primary dataset for this paper because each row represents a complete financing event linked to a specific loan agreement, mineral activity, host country, financier structure, and

financing amount. This view is used to measure the main dependent variables, including the size of Chinese official financing, the interest rate at commitment, and the margin on reference rate. The Financial Contribution view records creditor-level contributions and is useful for identifying the role of individual Chinese official financiers. The Organization Role view records all organizations involved in each mineral-finance event, including financiers, co-financiers, recipients, implementers, guarantors, collateral providers, and project owners. The Mineral Operation Ownership view identifies equity ownership in mining or processing operations and is used to understand Chinese ownership, host-government ownership, and broader control structures. Together, these views connect financing, mineral security, ownership, and governance in one empirical framework.

The key identity variables in the dataset are essential for avoiding double counting and for ensuring consistent analysis. Loan_Event_ID identifies each financing event and is the main unit of analysis. AidData_Record_ID identifies individual financial contributions by specific Chinese official creditors or donors and is used mainly in the Financial Contribution view. Investors_Ownership_ID links financing events to ownership structures in mineral operations, while Mining_Site_ID identifies the relevant mining or processing site where such information is available. Country_of_Activity and Region_of_Activity identify the host-country and regional location of the financed activity. Transition_Minerals and Primary_Minerals identify the minerals involved in each project, while Primary_Mining_Activity identifies whether the activity relates to mine development, mine acquisition, processing, working capital, commodity trade, or other purposes. These identity variables make it possible to classify the dataset by country, region, mineral type, project activity, financing structure, and ownership or control relationship. Table 2 summarizes the four dataset views, their main identifying variables, their size in number of rows, and the analytical role each view plays in this study.

Table 2. Dataset Views and Analytical Use in This Study

Dataset view	Main identity variable	Number of rows	Main purpose in this study
Financial Contribution	AidData_Record_ID	492	Identifies individual Chinese official financial contributions and creditor-level financing participation
Loan Event	Loan_Event_ID	331 total; 311 recommended for aggregate analysis	Main analytical sample for measuring financing amount, loan pricing, security premiums, and governance mitigation
Organization Role	Loan_Event_ID; Organization_Name; Organization_Role	3,867	Identifies financiers, co-financiers, recipients, implementers, guarantors, collateral providers, and other participating organizations
Mineral Operation Ownership	Investors_Ownership_ID; Mining_Site_ID	306	Identifies equity ownership, operator ownership, Chinese ownership, host-government ownership, and control structures

For this paper, the most important analytical classification is the distinction between security-sensitive critical metals and other transition minerals. Guided by the title and the energy-transition focus of the study, copper, cobalt, nickel, lithium, and rare earth elements form the core security-sensitive group. These minerals are highly relevant to electrification, battery production, renewable-energy technologies, and clean-energy industrial supply chains. The remaining transition minerals form the comparison group. This classification allows the study to test whether strategically important minerals receive larger financing commitments, higher interest rates, wider loan margins, stronger collateral requirements, greater commodity-backed financing, or stronger Chinese ownership and product-control arrangements. In this way, the dataset operationalizes the concept of critical metal security premiums using financing variables rather than market-price variables.

The main dependent variables are drawn from the Loan Event view. The first is Chinese_Official_Funding_Amount_Constant_USD_2023, which measures the size of Chinese official financing in constant 2023 US dollars and captures the financing-intensity component of the premium. The second is Interest_at_T0, which measures the interest rate at the time of commitment and captures the loan-pricing component. The third is Margin_on_Reference_Rate, which captures the spread above the reference rate and is especially useful for identifying risk-pricing differences across mineral groups and governance conditions. Together, these variables allow the study to measure whether security-sensitive critical metals carry larger or costlier financing commitments.

The independent variables capture mineral security, financial control, and governance mitigation. The main mineral-security variable is a binary indicator identifying whether a loan event involves copper, cobalt, nickel, lithium, or rare

earth elements. Additional security and control variables include Collateralized, Commodity_backed, Chinese_Control_of_Mineral_Products, and Level_of_Chinese_Ownership. These variables show whether the financing arrangement is linked to collateral, commodity-backed repayment, Chinese product-control rights, or Chinese ownership. They are central to the paper because they reveal how strategic access can be embedded in financial contracts and ownership structures. The governance-mitigation variables are drawn from the Loan Event and Ownership views. They include Involving_Non_Chinese_Financier, Non_Chinese_Financing_Percent, Involving_Multilateral, PPG_Debt_Status, Level_of_Public_Liability, Level_of_Host_Government_Ownership, Requirement_for_Local_Procurement, Requirement_for_Local_Employment, Workforce_Development, and Rehabilitation_and_Post_Closure_Plan. These variables are used to examine whether financial governance mechanisms reduce the premium associated with security-sensitive metals. Table 3 lists these variables in three groups, dependent, security and control, and governance, together with the underlying dataset field and the meaning assigned to each variable in this study.

Table 3. Main Variables Used for Measuring Security Premiums and Governance Mitigation

Variable identity	Dataset variable	Meaning in this study
Financing premium	Chinese_Official_Funding_Amount_Constant_USD_2023	Measures the size of Chinese official financing committed to transition-mineral projects
Loan-pricing premium	Interest_at_T0	Measures the interest rate at the time of commitment
Spread premium	Margin_on_Reference_Rate	Measures the margin above the loan reference rate
Critical metal identity	Transition_Minerals; Primary_Minerals	Identifies whether the project involves copper, cobalt, nickel, lithium, rare earth elements, or other transition minerals
Project activity identity	Primary_Mining_Activity; Mining_Activity_Detail	Identifies whether finance supports mine development, acquisition, processing, working capital, or mineral trade
Geographic identity	Country_of_Activity; Region_of_Activity	Identifies the host country and region of each financed activity
Chinese control identity	Level_of_Chinese_Ownership; Chinese_Control_of_Mineral_Products	Measures Chinese ownership and product-control arrangements
Collateral identity	Collateralized; Collateral; Collateral_Provider	Identifies whether the loan is secured through collateral and who provides it
Commodity-backed identity	Commodity_backed; Commodity	Identifies whether repayment or security is linked to commodity flows
Co-financing governance	Involving_Non_Chinese_Financier; Non_Chinese_Financing_Percent	Measures financial diversification through non-Chinese co-financiers
Multilateral governance	Involving_Multilateral	Identifies whether multilateral actors are involved in the financing structure
Debt-risk governance	PPG_Debt_Status; Level_of_Public_Liability	Measures whether the loan creates public or publicly guaranteed debt exposure
Host-country governance	Level_of_Host_Government_Ownership	Captures host-government ownership or participation in mineral operations
Local-development governance	Requirement_for_Local_Procurement; Requirement_for_Local_Employment; Workforce_Development	Measures whether the project includes local procurement, local employment, or workforce-development requirements
Environmental governance	Rehabilitation_and_Post_Closure_Plan	Measures whether the project includes rehabilitation or post-closure planning

The final analytical sample is constructed using Recommended_for_Aggregates, which identifies records suitable for aggregate analysis and helps avoid double counting across related financial contributions and loan events. This filtering matters because syndicated loans or multi-creditor arrangements may appear in different views. Using the recommended aggregate loan-event sample ensures that each financing event is counted once in the main analysis. The study therefore uses the Loan Event view as its main empirical base and draws on the other views to explain creditor identity, organization roles, ownership structures, and governance mechanisms. The dataset does not contain global spot prices, futures prices, or market-trading data for metals. This study therefore measures security premiums not as commodity-market price premiums, but as financing-based security premiums, reflected in loan-event size, interest rates, reference-rate margins, collateralization, commodity-backed finance, Chinese ownership, and product-control structures.

4.2 Data Preprocessing

The dataset was preprocessed so that the empirical analysis matched the objective of measuring critical metal security premiums and examining financial governance mitigation effects. First, the AidData dataset was reviewed across its main views, including loan-event information, financial contributions, organization roles, and mineral-operation ownership. The Loan Event view was selected for the main analysis because it provides the most suitable unit of observation: each row represents a financing event linked to a specific transition-mineral activity, host country, financing amount, loan-pricing condition, ownership structure, collateral arrangement, commodity-backed feature, and governance safeguard. To avoid double counting, only records recommended for aggregate loan-event analysis were retained, while duplicate creditor-level entries and overlapping financial-contribution records were excluded from the main estimation sample.

Second, all financial variables were cleaned and standardized. The variable measuring Chinese official financing amount was converted into a consistent numeric format and expressed in constant 2023 US dollars, allowing comparison across years and countries. Because financing amounts are highly skewed in large-scale mineral and infrastructure lending, the natural logarithm of the financing amount was used as the main financing-premium indicator. Loan-pricing variables, including the interest rate at commitment and the margin on reference rate, were also converted into numeric form and checked for missing or non-standard values. Observations with missing values in a specific dependent variable were excluded only from the relevant model, while they were retained for descriptive or control analyses where the necessary information was available.

Third, mineral identities were standardized to classify each financing event according to its transition-mineral exposure. A core security-sensitive critical metal indicator was created for loan events involving copper, cobalt, nickel, lithium, and rare earth elements, because these minerals are directly linked to electrification, batteries, renewable-energy technologies, and clean-energy industrial supply chains. Other transition minerals were retained as the comparison group. For events involving multiple minerals, mineral names were harmonized and used to identify whether at least one core security-sensitive mineral was present. In descriptive mineral-allocation analysis, multi-mineral records were treated carefully to avoid overstating mineral exposure, while the regression analysis used the binary critical-metal classification.

Fourth, the study constructed financing-based measures of the critical metal security premium. The first measure was the logged value of the financing amount, capturing whether strategic minerals attract larger commitments. The second was the interest rate at commitment, capturing the direct loan-pricing component. The third was the margin on reference rate, capturing the spread or risk-pricing component. These measures are appropriate because the dataset does not contain global commodity spot or futures prices, so the premium is measured through project-level financial behavior rather than market-price movements. Fifth, financial governance mitigation variables were cleaned and converted into usable indicators, including non-Chinese co-financier involvement, share of non-Chinese financing, multilateral participation, public or publicly guaranteed debt status, public-liability exposure, host-government ownership, local procurement and employment requirements, workforce development, and rehabilitation or post-closure planning. A composite financial governance mitigation index was then constructed from these variables, with higher values indicating stronger governance characteristics. Finally, additional control variables were prepared to reduce omitted-variable bias, classifying financing events by host region, host country, financing period, mineral activity type, and project purpose.

4.3 Operational Label Derivation

To align the analysis with the title of the study, the first operational label derived from the dataset is the critical metal security premium. This label identifies whether a loan event involved minerals that are strategically important for the transition, particularly copper, cobalt, nickel, lithium, and rare earth elements. Financing events involving at least one of these minerals were assigned the critical-metal label, while other transition-mineral events formed the comparison group. The premium itself was operationalized through financing-based indicators, namely the financing amount, the interest rate at commitment, and the margin on reference rate.

The second operational label is the strategic control and security-structure label, which captures whether financing arrangements contained mechanisms that strengthen access, repayment security, or mineral control. It was derived

from variables related to collateralization, commodity-backed finance, Chinese ownership, and Chinese control of mineral products. A financing event was treated as having a stronger security-control structure when it involved collateral, commodity-backed repayment, significant Chinese ownership, or product-control arrangements. These indicators show how strategic access can be embedded in financial contracts and ownership structures rather than only reflected in commodity-market prices. The third operational label is the financial governance mitigation label, which identifies whether a financing event contained governance mechanisms that may reduce risk, improve transparency, diversify financing exposure, or support host-country development. It was derived from variables such as non-Chinese co-financier involvement, multilateral participation, non-public or non-guaranteed debt status, host-government ownership, local procurement and employment requirements, workforce development, and rehabilitation or post-closure planning. Events with stronger governance features were classified as having higher mitigation potential.

4.4 Exploratory Data Analysis

Exploratory analysis was conducted to examine whether the dataset provides initial evidence of critical metal security premiums and financial governance mitigation effects. The recommended aggregate loan-event sample contains 311 financing records, of which 292 report usable financing amounts. The total identified financing volume is approximately US$98.11 billion in constant 2023 US dollars. Chinese official transition-mineral finance expanded substantially after 2008. As shown in Figure 1, financing increased from approximately US$4.61 billion during 2000 to 2007 to US$53.13 billion during 2008 to 2015, and remained high at US$40.38 billion during 2016 to 2023. Chinese official finance therefore became increasingly connected to transition-mineral access during the period in which clean-energy technologies, battery supply chains, and mineral-security concerns intensified.

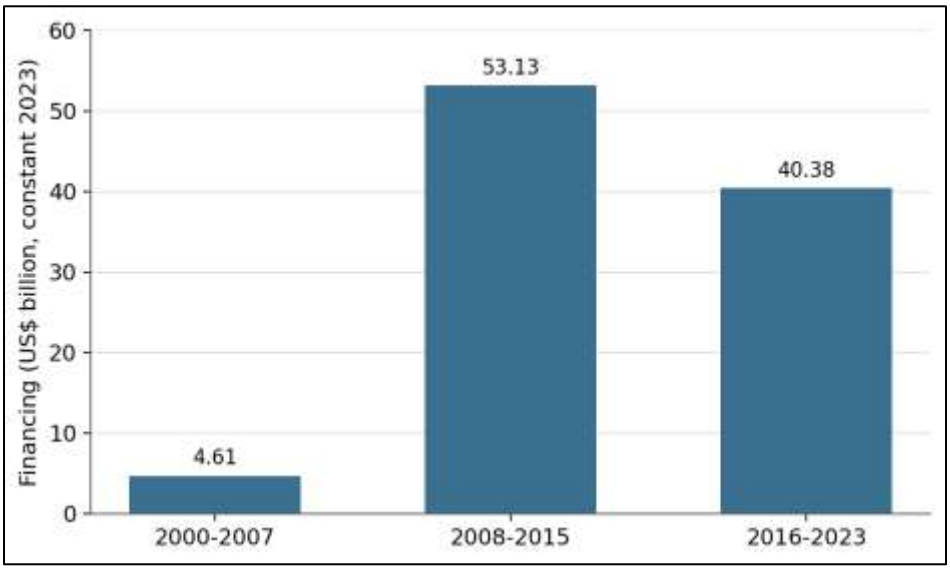

Figure 1. Chinese official transition-mineral financing by period (US$ billion, constant 2023).

The regional distribution shows a strong concentration in resource-rich regions. America received the largest amount of Chinese official transition-mineral financing, with approximately US$34.91 billion, followed by Africa with US$21.99 billion and Asia with US$20.40 billion. Europe and Oceania each received slightly above US$10 billion, while the Middle East accounted for a very small share. This pattern matters because critical metal security is shaped not only by mineral type but also by the geography of resource access. The concentration of financing in America, Africa, and Asia suggests that Chinese official finance is closely linked to regions that host strategically important transition-mineral deposits and mining operations.

Mineral-level exploration supports the paper's central argument that financing is concentrated in security-sensitive critical metals. Using fractional allocation across multi-mineral projects, copper receives the largest exposure, with approximately US$34.31 billion, followed by silver, cobalt, nickel, molybdenum, zinc, and lithium. As summarized in Figure 2, the core security-sensitive group of copper, cobalt, nickel, lithium, and rare earth elements accounts for approximately US$87.55 billion, compared with US$10.57 billion for other transition minerals. The average financing amount is also higher for security-sensitive metals, at approximately US$350.19 million per event, compared with US$251.58 million for other transition minerals. This provides initial descriptive evidence that strategically important minerals receive larger commitments, consistent with a financing-based critical metal security premium.

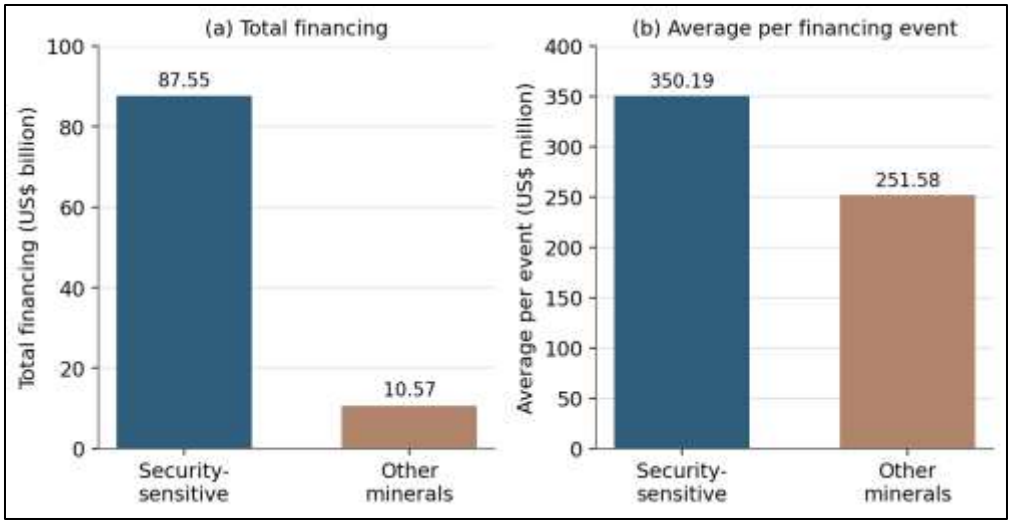

Figure 2. Financing for security-sensitive critical metals versus other transition minerals: (a) total financing and (b) average financing per event.

The loan-pricing indicators also show preliminary evidence of a premium. As shown in Figure 3, the average interest rate at commitment is approximately 4.05 percent for security-sensitive critical metals, compared with 3.12 percent for other transition minerals. The average margin on reference rate is approximately 2.86 percent for security-sensitive metals, compared with 2.40 percent for other transition minerals. These descriptive differences suggest that the premium may appear not only through larger volumes but also through higher pricing. They should be read as exploratory, because loan pricing may also be influenced by host-country risk, project activity, repayment structure, maturity, collateralization, and financing period.

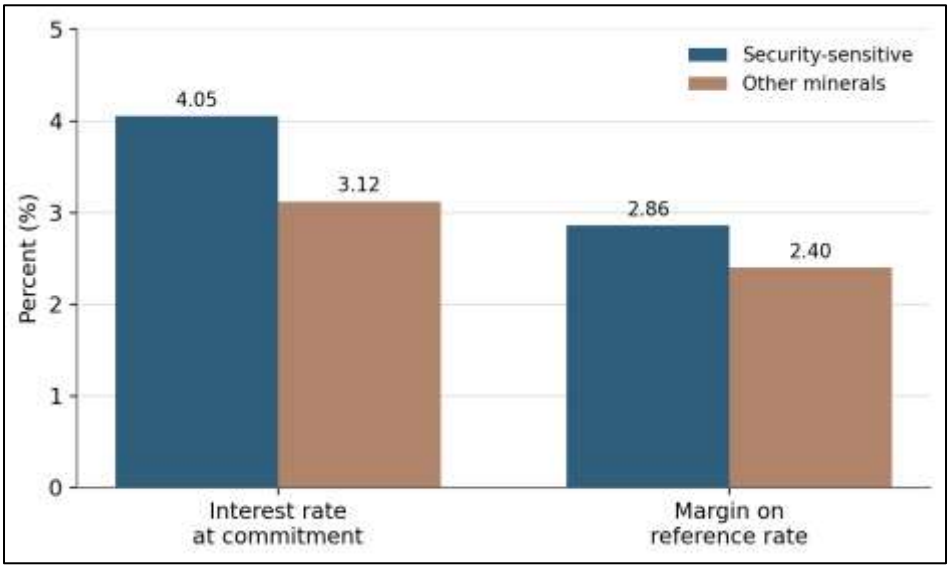

Figure 3. Average loan-pricing indicators by mineral group: interest rate at commitment and margin on reference rate.

Financial governance mechanisms are unevenly distributed across the portfolio. As shown in Figure 4, non-public or non-publicly guaranteed debt status covers approximately 88.9 percent of the total financing amount, suggesting that much of the financing does not directly create public or publicly guaranteed debt exposure. Workforce development is associated with approximately 58.8 percent of financing, local employment requirements with 50.7 percent, rehabilitation or post-closure planning with 45.6 percent, and local procurement requirements with 34.9 percent. Host-government significant or majority ownership is present in approximately 21.7 percent of financing, while non-Chinese co-financier involvement and multilateral involvement remain limited at 12.7 percent and 1.3 percent,

respectively. Some project-level safeguards are therefore common, but international financial diversification and multilateral oversight are relatively weak.

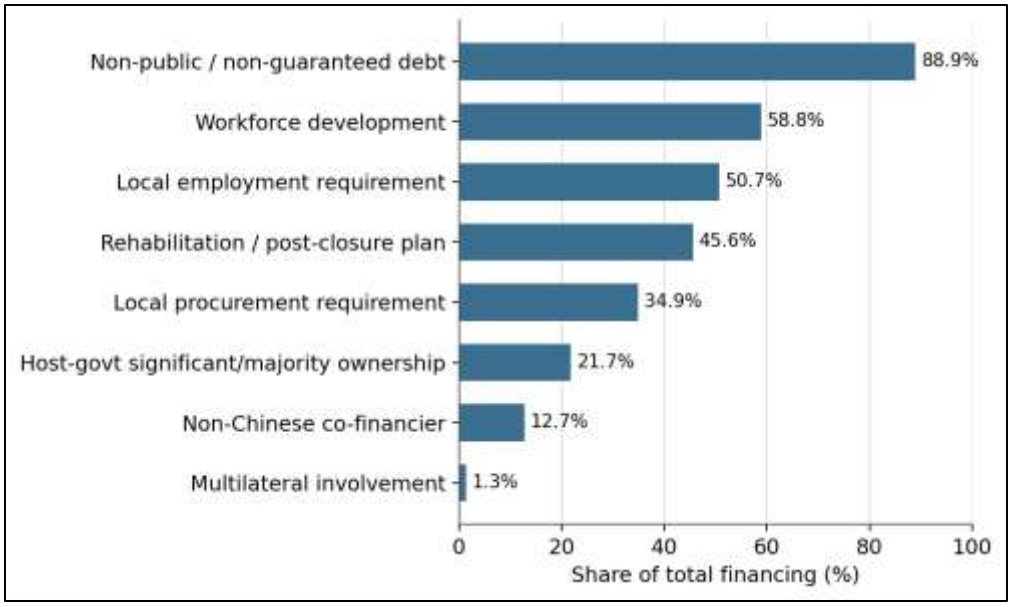

Figure 4. Prevalence of financial governance mechanisms as a share of total financing.

Overall, the exploratory analysis confirms that the dataset is suitable for the paper's research problem. Chinese official financing is concentrated after 2008, directed toward major resource-hosting regions, and heavily associated with security-sensitive minerals such as copper, cobalt, nickel, lithium, and rare earth elements. These minerals receive larger average commitments and higher raw loan-pricing indicators than other transition minerals, supporting the initial presence of a financing-based critical metal security premium. Governance-related variables such as workforce development, local employment, local procurement, rehabilitation planning, and debt-risk limitation provide a basis for testing whether governance mechanisms mitigate such premiums. These findings justify the formal empirical models that follow.

4.5 Methodology

4.5.1 Research Design

This study uses a quantitative loan-event-level research design to measure critical metal security premiums and to examine financial governance mitigation effects in Chinese official financing for transition-mineral projects. The analysis is based on AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0, where each recommended aggregate loan event is treated as the main unit of observation.

4.5.2 Measurement of Security Premiums

Critical metal security premiums are measured through three financing-based indicators: the logarithm of Chinese official financing amount in constant 2023 US dollars, the interest rate at commitment, and the margin on reference rate. A binary critical-metal indicator is created for financing events involving copper, cobalt, nickel, lithium, or rare earth elements, while other transition minerals form the comparison group.

4.5.3 Governance Mitigation Measures

Financial governance mitigation is measured using variables related to non-Chinese co-financing, multilateral involvement, non-public debt exposure, host-government ownership, local procurement, local employment, workforce development, and rehabilitation or post-closure planning. These indicators capture whether governance safeguards reduce the financial cost, risk exposure, or control intensity associated with strategic mineral access.

4.5.4 Empirical Strategy

The empirical strategy first compares descriptive differences between security-sensitive critical metals and other transition minerals. It then estimates regression models to test whether critical-metal identity is associated with larger or costlier financing commitments, and whether governance mechanisms mitigate these premiums. Control variables for region, financing period, and project activity are included, and robust standard errors are applied to address heteroskedasticity. Because the dataset is observational, the results are interpreted as financing-based associations rather than strict causal effects.

4.6 Model Development

The model development stage measures whether security-sensitive critical metals receive a financing premium and whether financial governance mechanisms mitigate that premium. Because the dataset does not contain commodity spot or futures prices, the study develops a financing-based security premium model using loan-event-level indicators. The main analytical unit is the recommended aggregate loan event. Three dependent variables capture different dimensions of the premium: the logarithm of Chinese official financing amount, the interest rate at commitment, and the margin on reference rate. The key explanatory variable is the critical metal indicator, which equals one when a loan event involves copper, cobalt, nickel, lithium, or rare earth elements, and zero otherwise. These minerals are treated as security-sensitive because they are central to electrification, battery production, renewable-energy technologies, and clean-energy manufacturing.

The first model estimates the financing-size premium, testing whether security-sensitive critical metals receive larger commitments than other transition minerals. The dependent variable is the natural logarithm of the financing amount in constant 2023 US dollars, a transformation used because mineral-finance amounts are highly skewed, with some very large loan events. The second model estimates the loan-pricing premium, using the interest rate at commitment, and tests whether security-sensitive metals are associated with higher borrowing costs at commitment. The third model estimates the spread premium, using the margin on reference rate, and captures the risk-pricing component of loan finance, which is especially important for identifying whether governance mechanisms reduce financing costs.

To examine financial governance mitigation, a governance mitigation index was developed using project-level and financing-level indicators. The index includes non-Chinese co-financier involvement, multilateral participation, non-public or non-publicly guaranteed debt status, host-government ownership, local procurement and employment requirements, workforce development, and rehabilitation or post-closure planning. These variables represent mechanisms that may reduce project risk, diversify financing exposure, improve local development benefits, and strengthen institutional safeguards. The interaction between the critical metal indicator and the governance mitigation index is included to test whether governance mechanisms weaken the financing or pricing premium associated with security-sensitive metals. The general model is specified as follows.

Security Premium Indicator = β_0 + β_1 Critical Metal + β_2 Governance Mitigation + β_3 (Critical Metal × Governance Mitigation) + β_4 Controls + ε

Each term in the equation has a specific meaning. The dependent term, the security premium indicator, refers separately to three outcomes estimated in three models: the natural logarithm of the Chinese official financing amount in constant 2023 US dollars in Model 1, the interest rate at commitment in Model 2, and the margin on reference rate in Model 3. The term Critical Metal is the binary indicator that equals one when a loan event involves copper, cobalt, nickel, lithium, or rare earth elements, and zero otherwise. The term Governance Mitigation is the composite governance mitigation index constructed from the non-Chinese co-financing, multilateral, non-public debt, host-government ownership, local procurement, local employment, workforce-development, and rehabilitation variables described above. The term (Critical Metal × Governance Mitigation) is the interaction between the critical-metal indicator and the governance index. The term Controls is the vector of control variables for region, financing period, and project activity type, which account for geographic, temporal, and operational differences across loan events. The coefficient β_0 is the constant, or intercept, which captures the baseline level of the security premium indicator when all explanatory variables equal zero. The coefficient β_1 measures the direct premium associated with security-sensitive critical metals. The coefficient β_2 measures the independent effect of governance mitigation. The interaction coefficient β_3 is the main mitigation parameter, and a negative value indicates that governance mechanisms reduce the premium associated with critical metal financing. The coefficient β_4 is the vector of coefficients on the control variables. The final term ε is the error term, which captures unobserved factors that affect the outcome but are not included in the model. Robust standard errors are applied because financing amounts and loan-pricing variables vary substantially across minerals, countries, and project types.

Table 4 sets out the three-model framework in full. For each model it identifies the dependent variable, the main explanatory variable, the governance variable and its interaction term, the control variables, and the specific hypothesis the model is designed to test.

Table 4. Model Development Framework

Model	Dependent variable	Main explanatory variable	Governance variable	Control variables	Purpose
Model 1: Financing-size premium	Log of Chinese official financing amount in constant 2023 US dollars	Critical metal indicator for copper, cobalt, nickel, lithium, and rare earth elements	Governance mitigation index and its interaction with	Region, financing period, and project activity type	Tests whether security-sensitive critical metals receive

Model	Dependent variable	Main explanatory variable	Governance variable	Control variables	Purpose
			the critical metal indicator		larger financing commitments
Model 2: Loan-pricing premium	Interest rate at commitment	Critical metal indicator for copper, cobalt, nickel, lithium, and rare earth elements	Governance mitigation index and its interaction with the critical metal indicator	Region, financing period, and project activity type	Tests whether security-sensitive critical metals are associated with higher loan-pricing costs
Model 3: Spread premium	Margin on reference rate	Critical metal indicator for copper, cobalt, nickel, lithium, and rare earth elements	Governance mitigation index and its interaction with the critical metal indicator	Region, financing period, and project activity type	Tests whether governance mechanisms reduce the risk-pricing component of critical metal finance

The framework aligns directly with the title of the study. It first measures critical metal security premiums through financing amount, interest rate, and loan-margin indicators, and then evaluates whether financial governance mechanisms mitigate these premiums. This design moves beyond descriptive mineral-security discussion and formally examines how strategic access to transition minerals is priced and governed through Chinese official finance

5. RESULTS AND DISCUSSION

5.1 Descriptive Evidence of Critical Metal Security Premiums

The results show clear descriptive evidence that Chinese official transition-mineral finance is concentrated in security-sensitive critical metals. In the recommended aggregate loan-event sample, the total identified financing amount is approximately US$98.11 billion in constant 2023 US dollars. Financing events involving copper, cobalt, nickel, lithium, and rare earth elements account for approximately US$87.55 billion, while other transition minerals account for only US$10.57 billion. The majority of Chinese official financing is therefore directed toward minerals that are central to electrification, battery manufacturing, renewable-energy technologies, and clean-energy industrial supply chains. The average financing amount is also higher for security-sensitive metals, at approximately US$350.19 million per event, compared with US$251.58 million for other transition minerals. These findings, illustrated earlier in Figure 2, support the core argument that critical metal security premiums can be observed through financing behavior, not only through commodity-market prices.

The loan-pricing indicators provide additional evidence of a financing-based premium. The average interest rate at commitment is approximately 4.05 percent for security-sensitive critical metals, compared with 3.12 percent for other transition minerals. The average margin on reference rate is approximately 2.86 percent for security-sensitive metals, compared with 2.40 percent for other transition minerals. These descriptive differences, shown in Figure 3, suggest that critical metals may carry both a financing-size premium and a loan-pricing premium. Security-sensitive minerals tend to receive larger commitments and higher raw pricing indicators. The pattern is consistent with the theoretical argument that strategic access to transition minerals may be priced into financial contracts, ownership structures, and loan terms before the minerals enter global commodity markets.

5.2 Regression Results

The regression results clarify the relationship between critical-metal identity, financing premiums, and governance mitigation. Table 5 presents the key coefficients from the three empirical models. Model 1 uses the logarithm of Chinese official financing amount as the dependent variable, Model 2 uses the interest rate at commitment, and Model 3 uses the margin on reference rate. All models include controls for region, financing period, and project activity type, and robust standard errors are applied.

Table 5. Regression Results for Critical Metal Security Premiums and Governance Mitigation

Variable	Model 1: Log financing amount	Model 2: Interest rate at commitment	Model 3: Margin on reference rate
Critical metal indicator	1.359 ($p < 0.01$)	0.820 (n.s.)	-0.160 (n.s.)

Variable	Model 1: Log financing amount	Model 2: Interest rate at commitment	Model 3: Margin on reference rate
Governance mitigation index	2.210 ($p < 0.05$)	-3.751 ($p < 0.10$)	-2.804 ($p < 0.01$)
Critical metal × governance mitigation	-2.215 ($p < 0.05$)	1.634 (n.s.)	1.638 ($p < 0.10$)
Region controls	Yes	Yes	Yes
Period controls	Yes	Yes	Yes
Project activity controls	Yes	Yes	Yes
Observations	292	104	75
R-squared	0.198	0.476	0.396

Note: Robust standard errors are used. Statistical significance is reported in parentheses; n.s. denotes a coefficient that is not statistically significant at the 0.10 level.

Model 1 shows that the critical metal indicator has a positive and statistically significant coefficient of 1.359. After controlling for region, financing period, and project activity type, financing events involving copper, cobalt, nickel, lithium, or rare earth elements are associated with larger Chinese official commitments than other transition-mineral events. This provides the strongest formal evidence of a financing-size security premium. The interaction term between critical metal identity and the governance mitigation index is negative and significant at -2.215, indicating that governance mechanisms weaken the additional financing premium associated with security-sensitive metals. Stronger governance structures may reduce the need for unusually large strategic exposure, or they may distribute financing risk more effectively across institutional safeguards.

Model 2 examines whether security-sensitive metals carry a higher loan-pricing premium through the interest rate at commitment. The coefficient for the critical metal indicator is positive at 0.820 but not statistically significant after controls are added. Although the raw descriptive results show higher average interest rates for security-sensitive metals, the controlled model suggests that this difference may partly reflect other project characteristics, such as region, financing period, project type, maturity, or financing structure. The governance mitigation index has a negative coefficient of -3.751, which is weakly significant and consistent with lower interest rates under stronger governance. The evidence for an interest-rate premium is therefore weaker than the evidence for a financing-size premium.

Model 3 tests the margin on reference rate, which captures the spread or risk-pricing component of loan finance. The governance mitigation index has a negative and statistically significant coefficient of -2.804. Stronger governance-mitigation mechanisms are therefore associated with lower loan margins. In practical terms, financing events with stronger governance features, such as co-financing, non-public debt exposure, local-development requirements, workforce development, and rehabilitation planning, appear to carry lower risk-pricing burdens. The critical metal indicator itself is not statistically significant in this model, at -0.160, meaning that the spread premium is not driven only by mineral identity. Governance quality plays a more important role in explaining the margin component of financing costs.

5.3 Discussion of Findings

The findings support the central argument that critical metal security premiums can be measured through project-level financing behavior. The strongest evidence appears in the financing-size model, where security-sensitive metals receive significantly larger commitments than other transition minerals. This is consistent with the view that strategic minerals such as copper, cobalt, nickel, lithium, and rare earth elements are not treated as ordinary mineral assets. Because these minerals are essential for batteries, electrification, renewable-energy technologies, and clean-energy manufacturing, Chinese official finance appears to allocate larger commitments toward projects involving them. Security value is embedded in financing structures before it appears in commodity-market prices.

The findings also show that the security premium is multidimensional. Descriptive results indicate higher average financing amounts, higher average interest rates, and higher average margins for security-sensitive metals. The regression results, however, show that the most robust premium appears in financing size, while pricing effects depend more on governance and project characteristics. Chinese official finance may therefore express strategic mineral security primarily through the scale of commitments rather than only through higher interest rates. Larger volumes may reflect the strategic importance of securing long-term access, supporting Chinese-linked ownership, enabling mine acquisition or development, and strengthening supply-chain control.

The governance results speak directly to the second part of the study's title. The negative and significant interaction in the financing-size model suggests that governance mechanisms reduce the additional premium associated with critical metals. The negative and significant governance coefficient in the margin model indicates that stronger safeguards are associated with lower reference-rate margins. Financial governance can therefore mitigate the cost and

risk burden of critical metal finance. Mechanisms such as co-financing, non-public debt exposure, host-government ownership, local procurement, local employment, workforce development, and rehabilitation planning may reduce financial uncertainty, strengthen institutional legitimacy, and improve risk allocation.

At the same time, governance mitigation is uneven. Descriptive analysis indicates that some mechanisms, such as non-public debt status, workforce development, local employment requirements, and rehabilitation planning, are relatively common. International financial diversification remains limited, however, because non-Chinese co-financier involvement and multilateral participation account for a small share of total financing. Project-level safeguards may reduce some risks, but the overall financing structure remains strongly shaped by Chinese official finance. Governance mitigation exists, yet it does not fully transform the financing architecture into a broadly multilateral or highly diversified system. Overall, the evidence shows that financing is concentrated in security-sensitive metals, that these minerals receive larger commitments, and that governance mechanisms can reduce some components of the premium. Critical metal security premiums are therefore not only market-price phenomena. They can be observed in the size, pricing, and governance structure of project-level financing, which matters for the transition because mineral supply security depends not only on where minerals are located but also on how they are financed, controlled, and governed.

5.4 Novelty and Contribution

The novelty of this study lies in shifting the measurement of critical metal security premiums from commodity-market prices to project-level financing structures. Most prior criticality research reads risk from reserves, production shares, import dependence, trade concentration, substitutability, recycling potential, or spot prices. This study instead treats loan-event size, interest rates, reference-rate margins, collateralization, commodity backing, ownership, and product control as observable indicators of strategic value. The approach integrates productivity of financing, its pricing, its control structures, and its governance safeguards within a single empirical framework applied to a major but previously opaque segment of global mineral finance. To the authors' knowledge, this is among the first studies to quantify a financing-based critical metal security premium using Chinese official transition-mineral finance and to test, within the same models, whether financial governance mechanisms mitigate that premium. The resulting evidence maps how strategic mineral access is financed, priced, controlled, and partially mitigated through governance, and it offers a template that can be extended to other financiers and datasets.

5.5 Strengths and Limitations

The study has several strengths. It uses a granular, project-level dataset that links financing to mineral identity, ownership, collateral, commodity backing, and governance safeguards, which allows a financing-based premium to be measured directly. It combines descriptive comparison with regression models that control for region, financing period, and project activity, and it applies robust standard errors. It also treats governance as a measurable financial variable rather than a background condition. The study has limitations that should be acknowledged honestly. It relies on a single dataset of Chinese official-sector finance, so the results describe Chinese official financing behavior and may not generalize to private capital or to other financiers. The dataset does not contain commodity spot or futures prices, so the analysis cannot compare financing-based premiums with market-price premiums directly. Some models rest on smaller subsamples, because loan-pricing variables are reported for fewer events than financing amounts, which reduces statistical power for the interest-rate and margin models. Because the data are observational, the estimates are financing-based associations rather than strict causal effects, and unobserved project or country characteristics may influence both mineral selection and financing terms. These limitations point directly to the future work outlined below.

6. CONCLUSION

This study examined critical metal security premiums in the global energy transition by using Chinese official financing for transition-mineral projects as a financing-based measure of strategic mineral value. Chinese official finance is strongly concentrated in security-sensitive critical metals, particularly copper, cobalt, nickel, lithium, and rare earth elements, which are central to electrification, battery production, renewable-energy technologies, and clean-energy industrial supply chains. These minerals received substantially larger commitments than other transition minerals, at approximately US$87.55 billion against US$10.57 billion, and they showed higher raw loan-pricing indicators. The results support the central argument that critical metal security premiums are not limited to commodity-market prices. They can also be observed in project-level financing behavior, loan size, financial terms, collateral arrangements, commodity-backed structures, ownership control, and product-control mechanisms. This financing-based perspective provides a useful empirical framework for understanding how strategic mineral access is priced and secured before minerals enter global markets.

The study also confirms that financial governance mechanisms can mitigate some components of the premium, although the mitigation effect is uneven. Governance features such as non-public debt exposure, host-government participation, workforce development, local employment and procurement requirements, and rehabilitation or post-closure planning are associated with stronger institutional safeguards and, in some models, lower financing-cost pressure. The limited presence of non-Chinese co-financing and multilateral participation, however, suggests that

Chinese official transition-mineral finance remains relatively concentrated within China-linked structures. The findings contribute to the literature on critical mineral security, energy-transition finance, and global financial governance by showing that mineral security depends not only on geological supply and market prices, but also on how mineral projects are financed, governed, controlled, and embedded in long-term strategic supply chains. For practice, the results are relevant to critical mineral security policy, to sustainable and development finance, and to responsible-investment standards that seek to balance strategic access with transparency, risk sharing, and host-country benefit.

7. Future Work

Future research can extend this study by combining project-level financing data with global commodity spot prices, futures prices, price volatility, and geopolitical-risk indicators to develop a broader measurement of critical metal security premiums [33]. Because the present study measures premiums through financing amount, loan-pricing terms, collateralization, commodity-backed finance, ownership control, and governance safeguards, future studies can compare financing-based premiums with market-based price premiums to test whether financial contracts anticipate supply-security risks before they appear in commodity markets. Further work can incorporate host-country institutional quality, ESG performance, mining regulations, political stability, and environmental-risk indicators to examine how domestic governance conditions influence the cost and structure of transition-mineral finance.

Future work may also move beyond Chinese official finance by comparing it with financing from multilateral development banks, Western development finance institutions, private banks, and host-country public agencies. Such comparison would help determine whether critical metal security premiums are specific to Chinese official finance or represent a broader feature of global transition-mineral finance. In addition, future studies can analyze individual minerals separately, especially copper, cobalt, nickel, lithium, and rare earth elements, to identify whether each mineral carries a distinct type of security premium. This would provide deeper evidence on how the energy transition is reshaping mineral finance, supply-chain security, and financial governance across regions and strategic resource categories.

Data Availability Statement

The data used in this study are publicly available from AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0, published by AidData at William & Mary [9]. The dataset provides project-level and loan-event-level information on Chinese official-sector financing commitments for transition-mineral extraction, processing, and related activities from 2000 to 2023. The study used the Loan Event view as its main analytical source, particularly the recommended aggregate loan-event records, to measure financing-based critical metal security premiums and financial governance mitigation effects. No new primary data were collected. All variables were derived from the publicly available AidData dataset, including financing amount, interest rate, margin on reference rate, mineral identity, collateralization, commodity-backed finance, ownership structure, co-financing, multilateral involvement, public-liability exposure, local procurement, local employment, workforce development, and rehabilitation or post-closure planning. The dataset is accessible through AidData's official data repository, and the processed variables are available from the corresponding author on reasonable request.

Artificial Intelligence Disclosure Statement

During the preparation of this manuscript, artificial intelligence-assisted tools were used only for language refinement, structural organization, and improving the clarity of academic expression. The conceptual framework, dataset selection, variable interpretation, empirical analysis, results, discussion, and final conclusions were reviewed and verified by the authors. No artificial intelligence tool was used to generate, fabricate, or alter the dataset. All empirical findings are based on AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0, and the authors take full responsibility for the accuracy, integrity, and interpretation of the research. The use of artificial intelligence did not influence the scientific validity, analytical judgment, or conclusions regarding critical metal security premiums and financial governance mitigation effects in the global energy transition.

Funding

This work was supported by the Annual Research Projects in Philosophy and Social Sciences in Guangxi (2025), Project "Cross-Border Coordination Mechanisms for Realising the Value of Guangxi-ASEAN Ecological Products under the RCEP Framework" (Grant No. 25JYF173).

REFERENCES

[1] International Energy Agency, Global Critical Minerals Outlook 2024. Paris, France: IEA, 2024. [Online]. Available: https://www.iea.org/reports/global-critical-minerals-outlook-2024

[2] International Energy Agency, Global Critical Minerals Outlook 2025. Paris, France: IEA, 2025. [Online]. Available: https://www.iea.org/reports/global-critical-minerals-outlook-2025
[3] K. Hund, D. La Porta, T. P. Fabregas, T. Laing, and J. Drexhage, Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. Washington, DC: World Bank, 2020. [Online]. Available: https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action
[4] M. D. Bazilian, "The mineral foundation of the energy transition," The Extractive Industries and Society, vol. 5, no. 1, pp. 93-97, 2018, doi: 10.1016/j.exis.2017.12.002.
[5] S. Deetman, S. Pauliuk, D. P. van Vuuren, E. van der Voet, and A. Tukker, "Scenarios for demand growth of metals in electricity generation technologies, cars, and electronic appliances," Environmental Science & Technology, vol. 52, no. 8, pp. 4950-4959, 2018, doi: 10.1021/acs.est.7b05549.
[6] L. Grandell, A. Lehtilä, M. Kivinen, T. Koljonen, S. Kihlman, and L. S. Lauri, "Role of critical metals in the future markets of clean energy technologies," Renewable Energy, vol. 95, pp. 53-62, 2016, doi: 10.1016/j.renene.2016.03.102.
[7] A. Valero, A. Valero, G. Calvo, and A. Ortego, "Material bottlenecks in the future development of green technologies," Renewable and Sustainable Energy Reviews, vol. 93, pp. 178-200, 2018, doi: 10.1016/j.rser.2018.05.041.
[8] International Renewable Energy Agency, Geopolitics of the Energy Transition: Critical Materials. Abu Dhabi, UAE: IRENA, 2023. [Online]. Available: https://www.irena.org/publications/2023/Jul/Geopolitics-of-the-energy-transition-Critical-materials
[9] B. Escobar, A. A. Malik, S. Zhang, K. Walsh, A. Joosse, B. C. Parks, J. Zimmerman, and R. Fedorochko, AidData's Chinese Financing for Transition Minerals Dataset, Version 2.0. Williamsburg, VA: AidData at William & Mary, 2026. [Online]. Available: https://www.aiddata.org/datasets
[10] A. Månberger and B. Johansson, "The geopolitics of metals and metalloids used for the renewable energy transition," Energy Strategy Reviews, vol. 26, art. 100394, 2019, doi: 10.1016/j.esr.2019.100394.
[11] I. Overland, "The geopolitics of renewable energy: Debunking four emerging myths," Energy Research & Social Science, vol. 49, pp. 36-40, 2019, doi: 10.1016/j.erss.2018.10.018.
[12] S. Shannak, L. Cochrane, and D. Bobarykina, "Strategic analysis of metal dependency in the transition to low-carbon energy: A critical examination of nickel, cobalt, lithium, graphite, and copper scarcity using IEA future scenarios," Energy Research & Social Science, vol. 118, art. 103773, 2024, doi: 10.1016/j.erss.2024.103773.
[13] J. R. Owen, D. Kemp, A. M. Lechner, J. Harris, R. Zhang, and É. Lèbre, "Energy transition minerals and their intersection with land-connected peoples," Nature Sustainability, vol. 6, pp. 203-211, 2023, doi: 10.1038/s41893-022-00994-6.
[14] B. K. Sovacool, S. H. Ali, M. Bazilian, B. Radley, B. Nemery, J. Okatz, and D. Mulvaney, "Sustainable minerals and metals for a low-carbon future," Science, vol. 367, no. 6473, pp. 30-33, 2020, doi: 10.1126/science.aaz6003.
[15] É. Lèbre, M. Stringer, K. Svobodova, J. R. Owen, D. Kemp, C. Côte, A. Arratia-Solar, and R. K. Valenta, "The social and environmental complexities of extracting energy transition metals," Nature Communications, vol. 11, art. 4823, 2020, doi: 10.1038/s41467-020-18661-9.
[16] L. J. Sonter, M. C. Dade, J. E. M. Watson, and R. K. Valenta, "Renewable energy production will exacerbate mining threats to biodiversity," Nature Communications, vol. 11, art. 4174, 2020, doi: 10.1038/s41467-020-17928-5.
[17] J. R. Owen and D. Kemp, "Social licence and mining: A critical perspective," Resources Policy, vol. 38, no. 1, pp. 29-35, 2013, doi: 10.1016/j.resourpol.2012.06.016.
[18] G. Bridge, "Contested terrain: Mining and the environment," Annual Review of Environment and Resources, vol. 29, pp. 205-259, 2004, doi: 10.1146/annurev.energy.28.011503.163434.
[19] R. Deberdt and P. Le Billon, "Conflict minerals and battery materials supply chains: A mapping review of responsible sourcing initiatives," The Extractive Industries and Society, vol. 8, no. 4, art. 100935, 2021, doi: 10.1016/j.exis.2021.100935.
[20] R. Deberdt and P. Le Billon, "The green transition in context: Cobalt responsible sourcing for battery manufacturing," Society & Natural Resources, vol. 35, no. 7, pp. 784-803, 2022, doi: 10.1080/08941920.2022.2049410.
[21] S. Nakanwagi, "Critical minerals and the global energy transition: Recognising Global South perspectives," Global Energy Law and Sustainability, vol. 4, no. 1-2, pp. 115-137, 2023, doi: 10.3366/gels.2023.0096.
[22] T. E. Graedel et al., "Methodology of metal criticality determination," Environmental Science & Technology, vol. 46, no. 2, pp. 1063-1070, 2012, doi: 10.1021/es203534z.
[23] N. T. Nassar et al., "Criticality of the geological copper family," Environmental Science & Technology, vol. 46, no. 2, pp. 1071-1078, 2012, doi: 10.1021/es203535w.
[24] N. T. Nassar, T. E. Graedel, and E. M. Harper, "By-product metals are technologically essential but have problematic supply," Science Advances, vol. 1, no. 3, art. e1400180, 2015, doi: 10.1126/sciadv.1400180.

[25] B. Achzet and C. Helbig, “How to evaluate raw material supply risks: An overview,” Resources Policy, vol. 38, no. 4, pp. 435-447, 2013, doi: 10.1016/j.resourpol.2013.06.003.
[26] C. Helbig, L. Wietschel, A. Thorenz, and A. Tuma, “How to evaluate raw material vulnerability: An overview,” Resources Policy, vol. 48, pp. 13-24, 2016, doi: 10.1016/j.resourpol.2016.02.003.
[27] C. Helbig, A. M. Bradshaw, L. Wietschel, A. Thorenz, and A. Tuma, “Supply risks associated with lithium-ion battery materials,” Journal of Cleaner Production, vol. 172, pp. 274-286, 2018, doi: 10.1016/j.jclepro.2017.10.122.
[28] D. Schrijvers et al., “A review of methods and data to determine raw material criticality,” Resources, Conservation and Recycling, vol. 155, art. 104617, 2020, doi: 10.1016/j.resconrec.2019.104617.
[29] B. C. Esty, “Why study large projects? An introduction to research on project finance,” European Financial Management, vol. 10, no. 2, pp. 213-224, 2004, doi: 10.1111/j.1354-7798.2004.00247.x.
[30] S. Kleimeier and W. L. Megginson, “Are project finance loans different from other syndicated credits?” Journal of Applied Corporate Finance, vol. 13, no. 1, pp. 75-87, 2000, doi: 10.1111/j.1745-6622.2000.tb00043.x.
[31] M. Sorge and B. Gadanecz, “The term structure of credit spreads in project finance,” International Journal of Finance & Economics, vol. 13, no. 1, pp. 68-81, 2008, doi: 10.1002/ijfe.350.
[32] C. Hainz and S. Kleimeier, “Political risk, project finance, and the participation of development banks in syndicated lending,” Journal of Financial Intermediation, vol. 21, no. 2, pp. 287-314, 2012, doi: 10.1016/j.jfi.2011.10.002.
[33] D. Caldara and M. Iacoviello, “Measuring geopolitical risk,” American Economic Review, vol. 112, no. 4, pp. 1194-1225, 2022, doi: 10.1257/aer.20191823.
[34] O. Ozkan and S. S. Akadiri, “How does geopolitical risk affect energy transition minerals?” Energy Research Letters, vol. 7, 2026, doi: 10.46557/001c.142284.
[35] L. A. Attílio, “Impact of critical mineral prices on energy transition,” Applied Energy, vol. 377, art. 124688, 2025, doi: 10.1016/j.apenergy.2024.124688.
[36] L. A. Attílio, J. R. Faria, and E. Silva, “Critical minerals, clean tech, geopolitical risk and the global energy transition: An exploration of the Chinese influence on rare earth and lithium markets through the GVAR model,” Cambridge Prisms: Energy Transitions, vol. 1, art. e7, pp. 1-19, 2025, doi: 10.1017/etr.2025.10005.
[37] A. Dreher, A. Fuchs, B. C. Parks, A. M. Strange, and M. J. Tierney, “Apples and dragon fruits: The determinants of aid and other forms of state financing from China to Africa,” International Studies Quarterly, vol. 62, no. 1, pp. 182-194, 2018, doi: 10.1093/isq/sqx052.
[38] A. Dreher, A. Fuchs, B. Parks, A. Strange, and M. J. Tierney, “Aid, China, and growth: Evidence from a new global development finance dataset,” American Economic Journal: Economic Policy, vol. 13, no. 2, pp. 135-174, 2021, doi: 10.1257/pol.20180631.
[39] S. Horn, C. M. Reinhart, and C. Trebesch, “China’s overseas lending,” Journal of International Economics, vol. 133, art. 103539, 2021, doi: 10.1016/j.jinteco.2021.103539.
[40] D. Brautigam, “A critical look at Chinese ‘debt-trap diplomacy’: The rise of a meme,” Area Development and Policy, vol. 5, no. 1, pp. 1-14, 2020, doi: 10.1080/23792949.2019.1689828.
[41] P. Ekins, P. Christmann, M. M. Ciftci, F. Larosa, and B. Verrier, “Financing the responsible supply of energy transition minerals,” Mineral Economics, pp. 1-19, 2026, doi: 10.1007/s13563-026-00637-8.
[42] United Nations Environment Programme, International Resource Panel, Financing the Responsible Supply of Energy Transition Minerals for Sustainable Development. Nairobi, Kenya: UNEP, 2025. [Online]. Available: https://www.unep.org/resources/report/financing-responsible-supply-energy-transition-minerals-sustainable-development