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Critical Mining Asset Control and Geoeconomic Fragmentation: What Is Left for Developing Countries?

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Critical mining asset control and geoeconomic fragmentation: What's left for developing countries?

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Résumé
L'économie verte offre un important potentiel de développement grâce aux biens axés sur le climat, mais l'accès aux minerais critiques est essentiel. Les pays en développement sont souvent cantonnés au rôle de fournisseurs de matières premières et doivent faire face à la domination étrangère exercée par les grandes puissances, ce qui limite leur développement. Les risques indirects liés à la concentration de la propriété financière des minerais critiques, ainsi que leur interaction avec l'actuelle fragmentation géoéconomique, restent insuffisamment compris.

Cet article examine trois dimensions du contrôle : la concentration selon (i) la géographie, (ii) la compagnie minière et (iii) le pays d'origine des investisseurs, et confronte ces concentrations à des indicateurs de fragmentation géoéconomique. En utilisant des données de production et de réserves issues de Standard & Poor's pour 2023, portant sur 1 858 actifs miniers en activité et couvrant la majorité de l'offre mondiale de 20 minerais, nous constatons que la concentration selon l'entreprise minière (propriété directe) et la propriété des investisseurs est généralement plus faible que la concentration géographique, avec d'importantes exceptions comme le cuivre, le lithium et le nickel, où la concentration des investisseurs est la plus élevée.

Et contrairement à la dimension géographique, seuls quelques pays dominent les dimensions de concentration liées à la propriété directe et aux investisseurs pour l'ensemble des minerais. La fragmentation géoéconomique entre pays qui contrôlent les minerais est également plus prononcée lorsqu'on analyse la propriété directe et pour investisseurs, plutôt que la distribution géographique, ce qui suggère que négliger ces dimensions de contrôle non géographiques conduit à sous-estimer les risques d'approvisionnement en minerais critiques. Des consultations multilatérales visant à établir des corridors sécurisés pour garantir des flux transfrontaliers minimaux pourraient contribuer à assurer la disponibilité des approvisionnements pour toutes les régions en période de fragmentation.

Mots-clés
Minerais critiques, Fragmentation géoéconomique, Risque de concentration.

Classification JEL
F23, G32, L72, O13, Q34

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Abstract

The green economy offers major development potential through climate-focused goods, but access to critical minerals is essential. Developing countries are often limited to supplying raw materials and face the challenges of foreign control by major economies, restricting their development. The indirect risks from concentrated financial ownership of critical minerals and their interaction with the ongoing geoeconomic fragmentation are insufficiently understood. This paper investigates three dimensions of control: concentration by (i) geography, (ii) mining company and (iii) equity investor country of origin, and confronts these concentrations with indicators of geoeconomic fragmentation. Using a cross section of production and reserves data from Standard and Poor's for 2023 from 1,858 active mining assets covering the majority of global supply for 20 minerals we find that concentration in the mining company (direct ownership) and equity ownership dimensions are typically lower than in geography, with important exceptions such as copper, lithium and nickel where the equity ownership concentration is the highest. And unlike geography, only a few countries dominate in direct and equity ownership dimensions of concentration across all minerals. Geoeconomic fragmentation among controlling countries is similarly more pronounced when analyzing direct and equity ownership rather than geographical distribution, suggesting that ignoring these non-geographical control dimensions underestimates the supply risks of critical minerals. Multilateral consultations to establish safe corridors for minimum cross-border flows could help ensure the availability of supplies for all regions in a time of fragmentation.

Keywords:

Critical minerals, Geoeconomic fragmentation, Concentration risk.

JEL code:

F23, G32, L72, O13, Q34

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1. Introduction

The green economy, that is producing all the capital and durable goods key to climate change mitigation, promises large market growth opportunities, and participating in it requires access to critical minerals. According to the International Energy Agency, the production of critical minerals—those essential for green technologies—would need to grow on average sixfold by 2040 to meet net-zero targets in 2050 (IEA, 2021). For countries rich in critical mineral reserves, this shift presents the prospect of substantial revenues, and for developing countries, important opportunities for industrialization. On average, mining already represents 15.4 per cent of GDP in developing economies, a share that rises further when accounting for value added through backward and forward linkages (UNDESA, 2025). Leveraging these resources can advance progress toward the Sustainable Development Goals, as critical minerals have the potential to attract both foreign and domestic investment, generate employment, and increase fiscal revenues, exports, and economic growth.

Recent geopolitical debates have focused on access by industrialized countries, notably in the face of an increasing share of mining and refining carried out in China. Chinese companies hold a large position in mining and they are the leading refiner of metals crucial for the energy transition like Cobalt, Lithium, Manganese and Rare Earths among others (see table 3 below). While in the past, domestic production wasn't associated with access to minerals (Andrieu, Cervantes Barron, et al., 2025), concerns in industrialized countries are growing about the reliability of the supply of these minerals in the mid-transition period and a potential slowdown of the transition (Miller et al., 2023; Espagne et al., 2023). As a response, more and more policies are designed to secure the supply chains for green technologies, especially the access to critical minerals (Müller, 2023; Riofrancos, 2023). The Inflation Reduction Act (IRA) in the US and the Critical Raw Materials Act (CRMA) in the European Union include provisions that aim to reduce dependency on geopolitical competitors (Müller, 2023). These policies establish national ownership criteria for suppliers of green technologies to prioritize domestic production and encourage national companies to invest abroad. This fusion of climate and security goals reflects a strategic shift as sustainability is increasingly framed as a matter of national interest. In this so-called, "Sustainability-Security Nexus", green industrial policy now serves dual purposes—accelerating the energy transition while reinforcing geopolitical autonomy (Riofrancos, 2023).

Absent from these debates about national access are developing countries. In the current international production structure of critical minerals, developing countries are largely positioned as raw material suppliers, where the share of some countries for certain minerals is high (Andrieu et al. 2025a). But these countries often face foreign control of these resources (Leruth et al., 2022). If geopolitical tensions mount and industrialized countries secure supply chains for domestic manufacturing, this could constrain the access to critical minerals by developing countries.[1] But these countries require secure access to critical

[1] Such supply constrains would add to longstanding concerns about "ecological inequality," as producer countries bear the ecological and social costs of extraction while consumers capture most of the downstream value (Bonnet,

minerals to move into more complex forms of manufacturing, including green technologies, which remain a proven path to economic development. It is therefore important to understand just how much control developing countries currently exert on critical minerals production, and how exposed they are to geopolitical fragmentation.

Existing concentration of control measures highlights the dominance of developing countries in mineral production but fails to capture the extent of foreign ownership and influence. Standard criticality assessments tend to focus narrowly on mine locations (Bucciarelli et al., 2024). In reality, the sector's complex ownership structures — encompassing multinational mining firms and their financial backers, including private institutions, governments, and technology companies — make it difficult to identify who ultimately controls supply. These higher levels of ownership are themselves often highly concentrated, creating risks of distorted competition, higher prices, and missed opportunities for resource-rich countries to fully benefit from their mineral wealth (Leruth et al., 2022).

This paper examines the degree of supply concentration across a wide range of potentially critical minerals, not only geographically but also in terms of mining company control and shareholder ownership. We focus on what this means for equitable access, particularly for developing countries seeking to participate in the green economy. Specifically, we revisit market concentration in critical mineral production in the context of growing geoeconomic fragmentation, with attention to both direct control (through mining companies) and indirect control (through their equity owners). To achieve this, we rely on the mining asset data provided by Standard and Poor's, which gives us access to the ownership structure of critical mining assets for 20 minerals.[2] First, we analyze the market concentration of critical mineral producers according to three definitions of national control: by geography (the mine's physical location), direct ownership (the headquarter location of the mining company), and equity ownership (the financial shareholders' country of origin). These three dimensions allow us to obtain a comprehensive picture of the different potential risks associated with concentrated national control. Second, we propose to link these new measures of concentration to geoeconomic fragmentation—the division of the global economy into distinct blocs driven by geopolitical tensions—by comparing them with measures of geopolitical distance, which capture the degree of alignment between countries' foreign policies based on differences in their UN General Assembly voting patterns. Although refining constitutes a crucial stage in the industrialization process, we restrict our scope to the 2142 critical mineral mining assets from the S&P Metals and Mining database, rather than refining infrastructure. Our objective is to assess what this means for equitable access to critical minerals, while weighing the ecological and social costs of mining against the financial and developmental gains from ownership.

2024; D. Brown et al., 2024). Mining continues to be among the most ecologically destructive and economically low-value segments of global supply chains, frequently associated with human rights abuses and violence, which in turn often spark local opposition (Luckeneder et al., 2021; Riofrancos, 2023).

[2] We do not attempt to identify which of these are 'critical' (on the pitfalls of doing so, see Andrieu, Heydari, et al., 2025), rather we cover a broad range of minerals many of whom have been argued to exhibit criticality under certain low-carbon transition scenarios.

In the context of geoeconomic fragmentation, we complement the concentration analysis with measures of geopolitical risk, assessing whether supply is clustered within or spread across countries with divergent geopolitical positioning. The recent rise in fragmentation has heightened security concerns over the stable supply of critical minerals essential for the transition. Until recently, the global economy was marked by unprecedented interconnectedness through complex trade networks, cross-border financial flows, and internationalized supply chains (Aiyar et al., 2023). However, the Covid-19 crisis beginning in 2020, Russia's invasion of Ukraine in 2022, the Palestine conflict and more recently, the re-election of Donald Trump—along with his administration's tariff policies—have all contributed to destabilizing this model, leading the IMF to warn about a possible reversal of global economic integration – which they call geoeconomic fragmentation – that could inter alia affect commodity trade and the supply of critical minerals (Aiyar et al., 2023). Commodity markets are especially vulnerable to fragmentation, which drives sharp price fluctuations and volatility, with long-term effects falling unevenly across countries—hitting developing and low-income economies with the steepest projected losses in real income (Aiyar et al., 2023). These tensions create an environment that favors a small group of producers taking a dominant position on the market (De La Torre De Palacios & Espí Rodríguez, 2024). In recent years, there has notably been little advancement in the diversification of supply sources of critical minerals, the geographic concentration has even increased for some minerals (notably nickel and cobalt), as highlighted by the latest edition of the IEA Critical Mineral Outlook (IEA, 2025).

The study highlights how industrialized countries significantly shape concentration and geoeconomic risks through their control over the ownership structures of critical mineral mining assets. While the production of raw critical minerals is typically concentrated in different groups of countries depending on the mineral, ownership — whether direct or through financial investors — remains concentrated in a few countries irrespective of the mineral. Major international mining companies, headquartered in a handful of countries, control most of the production through investments in significant mineral deposits. These companies are predominantly owned by equity investors from major economies. Most notably, control in the equity ownership dimension tends to increase the average geopolitical distance between the countries overseeing mineral production from the rest of the world.

These results also point to the many risks that the current fragmentation of the world economy poses for the sustainable supply of critical minerals and underscore the need for new multilateral mechanisms. The growing use of unilateral or protectionist measures by countries that directly or indirectly control a large share of critical mineral production for geopolitical purposes could seriously endanger the energy transition (Figures 1 & 2). Such actions risk creating disfavorable trade conditions, particularly for many developing countries where geopolitical blocs are redefined and generally less stable. At the same time, legitimate concerns in resource-rich developing countries about losing control over their own resources may lead to forced nationalization of mining assets, as has recently occurred in parts of Africa. A recent example is Guinea, where the government seized the country's main bauxite mine from an Emirati-based mining company[3]. To address these challenges, we argue for the creation of "safe corridors" for critical minerals, as uncoordinated national policies only exacerbate supply chain vulnerabilities by deepening geoeconomic fragmentation. Such mechanisms could build on and integrate with emerging international initiatives aimed at fostering fairer production and trade of critical minerals, including the African Green Minerals Strategy (AGMS) and the United Nations Panel on Critical Energy Transition Minerals principles (United Nations, 2024).

This paper is structured as follows. Section 2 presents a review of the recent literature on the market concentration of critical minerals. Section 3 introduces data - including the S&P database – and the main methodology to assess the ownership control. Section 4 presents the main results for market concentration by critical minerals. Finally, we discuss in the last section the potential implications of those results for the low-carbon transition.

[3] https://www.lemonde.fr/afrique/article/2025/08/06/en-guinee-la-junte-retire-une-mine-de-bauxite-a-un-groupe-emirati_6627112_3212.html

2. Literature review

The criticality of minerals can be broadly defined as a measure of their importance to an economy, industry, or for a specific application, as well as the measure of the associated supply and demand risks (Schrijvers et al., 2020). The study of mineral criticality is not new; it dates to at least the Cold War era, when the strategic importance of minerals for national economies — especially in the defense sector — prompted governments to closely monitor their supply. This concept has seen a notable resurgence with the double transition, energy and digital, driven by life-cycle analysis efforts that aim to pinpoint vulnerabilities in the value chains of products, such as renewable energy technologies, which are increasingly reliant on a diverse range of minerals (Hayes & McCullough, 2018; IEA, 2021).

Although there is a growing number of studies on critical minerals, no consensus has emerged on how to calculate this criticality. The methods surrounding the evaluation of the criticality of minerals for the low-carbon transition do not rely on any purely scientific assessment but rather aim at guiding public action (Prina Cerai, 2024).[4] The methods and objectives of criticality assessment studies often vary depending on the institutions conducting them (Schrijvers et al., 2020). However, in recent years, these assessments have increasingly emphasized the geopolitical dimension associated with mineral supply. This focus has gained significance in the context of green industrialization and the increasing dependence of many countries on imported minerals, particularly when these resources are sourced from geopolitically distant countries. Thus, the concentration of producers is problematic when considering the geoeconomic dimension of international relations. Indeed, the less diversity there is between producers, the higher the risk of market disruption if one of them unilaterally decides to adopt measures restricting exports (quotas, taxes, etc.).

Control over production has thus become a central focus in current analyses of the criticality of minerals vital to the ongoing "double transition" — the shift toward both energy and digital economies. The ability of private entities or governmental bodies to control mining production is a complex issue, shaped by the intricacies of global mining operations (Hodge et al., 2022). This topic has only recently gained attention, largely due to the resurgence of new critical mineral policies in OECD countries (Figure 1) and increased trade barriers targeting critical minerals (Figure 2). By examining different perspectives on control over mining production, researchers have identified three distinct approaches that assess the criticality of mining operations through measures of market concentration.

The first approach in the literature considers the production site, *i.e.* the geographical location of the mine, as the main criterion for determining control of this production. The country hosting the mine is therefore considered to have ultimate control over the production and export of minerals. This method is particularly useful for capturing supply risks dependent on national factors, whether political (e.g. export restrictions) or natural (mining accidents, natural disasters). This approach prevails in most current classifications of critical minerals, notably those produced by the International Energy Agency (IEA, 2021),

[4] Methods are also liable to methodological flaws and inconsistencies (Andrieu 2025b).

the World Bank (Hund et al., 2020), the Joint Research Center of the European Commission[5] or the U.S. Department of Energy[6] (DOE). However, this approach fails to integrate the complexity of the mineral resources sector, characterized by many intra- and inter-company exchanges (Hodge et al., 2022). It does not consider the influence of mining companies, whether national, international or state-owned. Thus, the risks associated with the various off-take contracts and other agreements between mining companies and the host state are not considered in this first stream of criticality analysis. This is particularly important in the case of small states, which can be crucial for the supply of certain minerals, and where multinational mining companies operating in them can be influential.

A second approach in the literature on critical minerals considers mine production control at the level of the mining companies that own or hold extraction rights for the mines. This approach highlights the extraterritorial transfer of rights when mining companies are foreign-based, and the impact of technological and investment capacities. Ericsson et al., (2020) analyzed Chinese influence in African mining sector, finding it weaker than expected and noting the continued dominance of Anglo-Saxon transnational companies. Recently, Leruth et al., (2022) suggested however that China's control over global value chains involving critical minerals and rare earths is more significant than expected. Finally, Sun et al., (2024) compared market concentration from both a geographical perspective and the origin of the mining company. Their analysis confirmed that transnational investments play a significant role in the value chains of lithium, platinum, cobalt and nickel. For the latter two, ownership analysis reveals that China holds the highest level of overseas production control. They suggested that by controlling the production of critical minerals abroad, countries with high demand manage to compensate for their insufficient domestic production of these minerals.

A third approach attributes the control of mining production to the shareholders of mining companies exploiting critical minerals. This equity ownership of critical mining production looks into financial linkages rather than direct mining production. Although this area is still underexplored, it has started to appear in deep supply chain analyses, revealing close connections between mining companies, investors, and end clients. As Prina Cerai (2024) noted, complex relationships exist among these entities. End clients, such as automotive companies and battery manufacturers, are now directly investing in mining companies or in projects involving existing operations and the development of new mining facilities. For instance, the battery manufacturer CATL is heavily integrated into the lithium mining ecosystem. Investment funds, banks, and insurance companies are also increasingly investing in mining companies and projects. This growing blurring of boundaries between financiers, clients, and mining companies has been little studied, raising many questions about the financial ties between states and this booming sector. As noted by the pioneer work of Leruth et al., (2022)[7], China's control over critical minerals and rare earths is found to

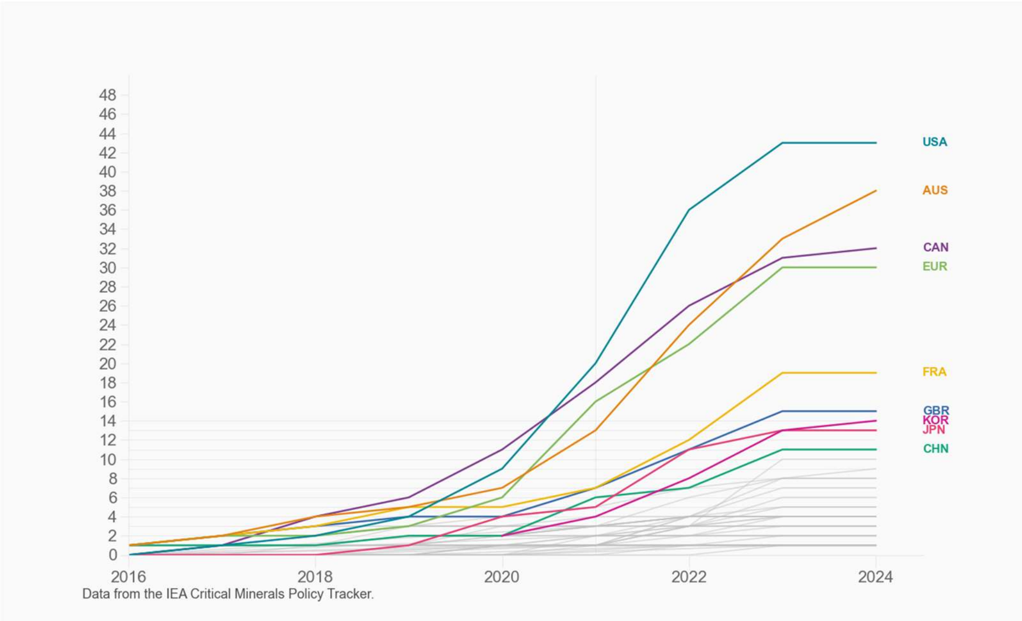
[5] https://rmis.jrc.ec.europa.eu/eu-critical-raw-materials

[6] https://www.federalregister.gov/documents/2023/08/04/2023-16611/notice-of-final-determination-on-2023-doe-critical-materials-list

[7] They used a proprietary software called "Zeno-indices" to better estimate control based on investor share sizes.

be more significant than previously thought due to the presence of Chinese non-mining investors.

Figure 1: Evolution of the number of critical mineral policies



Caption: The Critical Minerals Policy Tracker developed by the IEA records the key policies implemented in each country related to critical minerals needed for the energy transition. It includes over 35 countries and 450 polices, with the expansion, focusing on the third policy area on reducing environmental, social and governance impacts. Though not exhaustive, it aims to offer a valuable overview of evolving mineral supply chain governance.

Figure 2.a : Evolution of the number of trade barriers targeting critical minerals

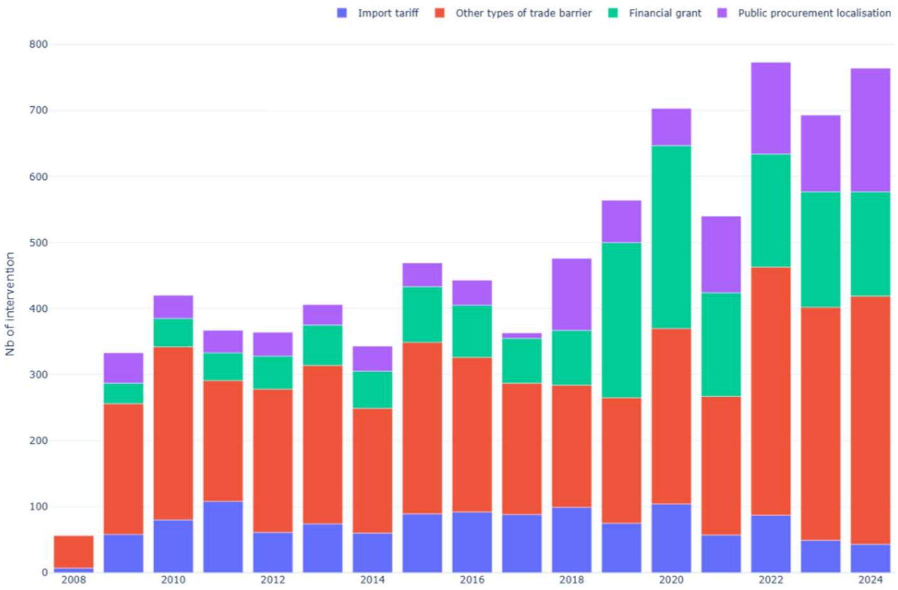
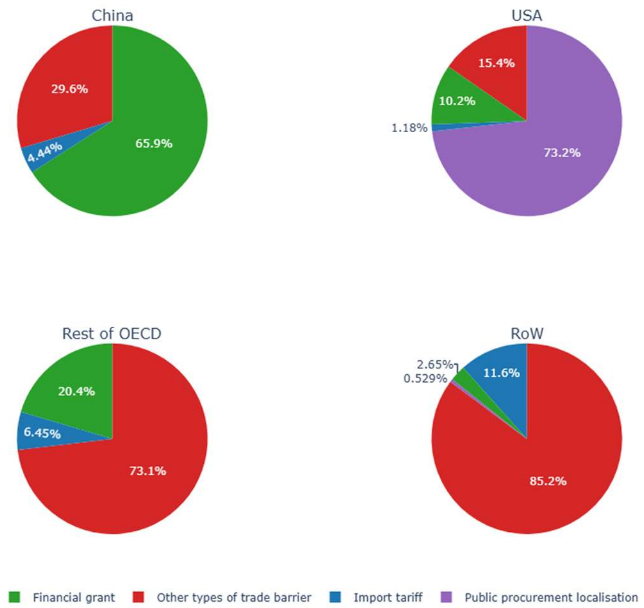


Figure 2.b : Distribution of Intervention Types in 2024 by Country Group



Caption: The graph on top shows the upward trend since 2008 in the number of public interventions considered to be barriers to international trade in critical minerals by the Global Trade Alert Database[8]. The graph below presents the distribution of intervention types in 2024 for four country groups: China, USA, Rest of OECD and Rest of the World (RoW).

[8] https://www.globaltradealert.org/

Despite increasingly detailed analyses of the sources of control, which reveal economic and financial ties between critical mineral-producing and importing countries, the understanding of the impact of geoeconomic fragmentation in criticality assessments has seen little evolution. Traditionally, the market concentration indicator has been deemed sufficient for analyzing this risk, assuming all producing countries can trade freely with importing countries. To overcome this limitation, analysts have started to weight this indicator by considering the risk associated with mineral-producing countries, using the World Bank's World Governance Index (WGI) (Prina Cerai, 2024). The WGI offers a score for institutional quality and good governance, which are seen as proxies for a country's capacity to sustainably manage its mineral resources.[9] However, this indicator fail to reflect real geoeconomic risk, especially since it was conceived before the emergence of discussions on geoeconomic fragmentation, which arose following the successive crises of COVID-19 and the Russia-Ukraine conflict.

Geoeconomic Fragmentation (GEF) is a new emerging concept that describes the division of the global economy into distinct blocs due to geopolitical tensions, leading to reduced international cooperation, trade barriers, and divergent economic systems. As a new concept in the economic literature, there is no consensus yet on how to measure it. Current efforts to quantify geoeconomic fragmentation rely on a few key metrics. One such metric is the Geopolitical Risk Index, developed by Dario Caldara and Matteo Iacoviello (2022), which measures the risk of negative geopolitical events by analyzing newspaper content on geopolitical tensions from 1900 to 2024. Another important metric is Geopolitical Distance, which assesses the geopolitical distance between countries based on their foreign policy behavior, particularly their voting patterns in the United Nations General Assembly (UNGA). This metric calculates the mean discordance in UNGA voting by squaring the differences between two countries' votes and then standardizing the result, with a value of 0 indicating complete opposition and 10 indicating full agreement.

However, the connection between geoeconomic fragmentation (GEF) and mineral resource production remains underexplored. Recent studies (Adajar et al., 2019; Aiyar et al., 2023; Wang et al., 2023) have begun to touch on this topic, particularly within the friendshoring debate. Notably, the IMF has made a significant contribution by being the first to analyze GEF in relation to the location of critical mineral production using the geopolitical distance indicator (Aiyar et al., 2023). Their research reveals dependencies between critical mineral exporters and importers which are often far apart on the geopolitical spectrum. However, the IMF's analysis is limited to the geographical origins of these minerals and does not address which country controls their production. In doing so, it omits the geopolitical constraints that may be added to the high market concentration caused by international mining companies or the financial or government institutions that control them.

[9] For example, the Democratic Republic of Congo's (DRC) dominant role in cobalt production, coupled with its particularly low WGI score, has led criticality analyses to often deem this source of production unreliable.

3. Method

3.1. Definition(s) of critical minerals and their key usage for low carbon or digital technologies

The concept of critical minerals, also known as energy transition minerals (ETMs), was introduced by several major institutions to identify minerals essential for producing renewable energy technologies and infrastructures. The World Bank Group first listed these minerals in 2017, followed by the International Energy Agency (IEA, 2021) with a more detailed list in 2021, reflecting advanced projections for a decarbonized energy mix. These lists result from energy modeling projections of future energy mixes and the mineral content needed for renewable technologies, such as platinum for hydrogen fuel cells or lithium and cobalt for the batteries of electric vehicles.

The 32 critical minerals listed by the IEA have varying patterns of production. While some have been produced for a long time and in many countries (such as iron), others are only produced in a handful of countries. For instance, China accounts for about 85% of the world's production of rare earth minerals (Lanthanides hereafter). The production of several minerals produced in few countries relies heavily on low-income economies. This is notoriously the case for cobalt, for which the Democratic Republic of Congo produces around 65% of the world's output in 2023.

To better assess their role in the energy transition, we classify critical minerals into three categories. Base metals comprise minerals with broad applications across the economy, extending well beyond the energy transition. Battery minerals refer to those essential for manufacturing electric vehicle batteries, particularly those with nickel–manganese–cobalt (NMC) cathodes. Specialty minerals encompass minerals with more limited economic uses, as well as precious minerals.

3.2. Mine level production and ownership

We obtain detailed information on 2142 critical mineral mining assets from the S&P Metals and Mining database (last access in July 2023). For each asset, we collect a range of information, including geographical location and development status: active or inactive. Active assets are mines capable of producing minerals. Inactive assets, on the other hand, are mines still at the project stage or that have been put on hold, characterized by their non-productive status (as of July 2023). Active assets are associated with values of the flow of production and the stock of mineral reserves for the year 2022, expressed in metric tons (Table 1).

In addition to the production and reserves data, we extract information on the ownership structure of mining assets, active as well as non-active. For each mining asset, we identify the direct owners, *i.e.*, the institutional entities with an explicit share in the mine's capital, which are predominantly mining companies. There can be more than one mining company involved (joint ventures) and mining companies can include public companies, private companies, state-owned companies, state or local government entities, or private individuals. The vast majority of these entities are composed of private and public mining companies.

Each mining company that holds a share of any mining asset has its own ownership structure. The S&P database reports up to 10 shareholders for each mining company. Listed mining companies are the easiest to track as they are legally forced to declare their ownership structure. However, not all mining companies have a tracked ownership structure, especially if they are owned by private entities. Junior mining companies for instance generally have no institutional shareholder structure, as they are often formed by a few individuals to minimize the risk of failure due to their highly speculative nature. However, junior mining companies typically account for a small share of overall mineral production, as they primarily focus on the early stages of project development.

Despite being one of the most comprehensive mining asset databases available, the S&P Metals and Mining database cannot be directly compared to common mineral production statistics from the USGS or BGS due to differences in data collection methods[10]. This comparison is complicated by the high level of mine-level disaggregation in the S&P database, which makes reconciliation with aggregated national-level statistics from USGS and BGS particularly challenging. Also the S&P database is the only one linking mining production data with ownership data. The USGS collects data through government channels, surveys, and estimates, covering a wide range of operations, including smaller and private entities. In contrast, S&P focuses primarily on publicly available data from larger, publicly traded companies (S&P, 2023). While the USGS aims to provide a comprehensive national and global overview, encompassing both large- and small-scale operations, public and private, S&P's emphasis is more on major mining projects and large, publicly listed companies (S&P, 2023). Depending on the mineral and year, the S&P database contains 50-90% of the global mining production identified by major geological institutions. This issue can be attributed to several factors. First, the method of collection of the data is heavily dependent on the mining companies' production and reserves declaration through the publication of reports. As a result, smaller firms and those operating in jurisdictions with limited business reporting infrastructure are often underrepresented. Second, while geological institutions such as the USGS and BGS compile nationwide assessments that include both public and private entities, S&P focuses exclusively on individual mining assets, primarily those linked to publicly listed companies.

Given these constraints, the S&P dataset should be viewed as a reflection of production by major mining companies, rather than a comprehensive account of global output. In particular, mineral production from Artisanal and Small-Scale Mining (ASSM) and non-listed mining corporations is likely not accounted for in our analysis. Consequently, the concentration measures we derive from this dataset should be interpreted as good

10 https://www.usgs.gov/centers/national-minerals-information-center/historical-statistics-mineral-and-material-commodities

indicators of market structure, but not as exhaustive assessments of global supply dynamics.

Table 1 - Number of active mines and ongoing mining projects in development for the major critical minerals

	Mineral	Active mines	Projects
Base minerals	**Bauxite**	84	421
	Tungsten	31	47
	Chromite	58	173
	Iron Ore	685	0
	Copper	383	1799
	Lead	63	1284
	Tin	22	78
	Zinc	213	211
	Total	1539	4013
Specialty minerals	**Vanadium**	10	0
	Lanthanides	9	56
	Niobium	5	0
	Silver	70	30
	Palladium	4	14
	Platinum	43	0
	Uranium	57	0
	Total	141	100
Battery Minerals	**Lithium**	25	58
	Nickel	89	268
	Cobalt	7	318
	Graphite	13	41
	Manganese	44	109
	Total	178	794
Total		1858	4907

Caption: The list of minerals is taken from IEA 2021; mines are considered active when they have reached one of the production stages as defined by S&P; projects are those that have not yet reached the production stage.

3.3. Definitions of control

The definition of control over the production of a mine is crucial as it determines "who" can decide "how" the critical minerals may be used and traded. While it may seem trivial at first glance to consider the country in which the mine is located as the sole "controller" of its production, the complexity of the ownership structure of mines anchored in a globalized economy makes the definition of control much less straightforward. Thus, the assumptions underlying the choice of production control are essential for identifying a potential supply risk resulting from high market concentration among producers of essential minerals. However, as indicated in the literature review section, the definition of mining production control has been largely restricted to the geographical location of the producing mines.

In this study, we choose to analyze critical mineral production by defining three alternative sources of control. The aim is to go beyond simple measures of market concentration based on the geographical location of mines and make comparisons across the different levels of control. Following Leruth et al., (2022) and Prina Cerai, (2024) we define three levels of control as shown in Figure 3:

- **Geographical control:** Production of critical minerals is attributed to the country hosting the mine. The production of each country's mines is then aggregated to obtain the production controlled by the country. This is the level of production control most widely used in the existing literature.

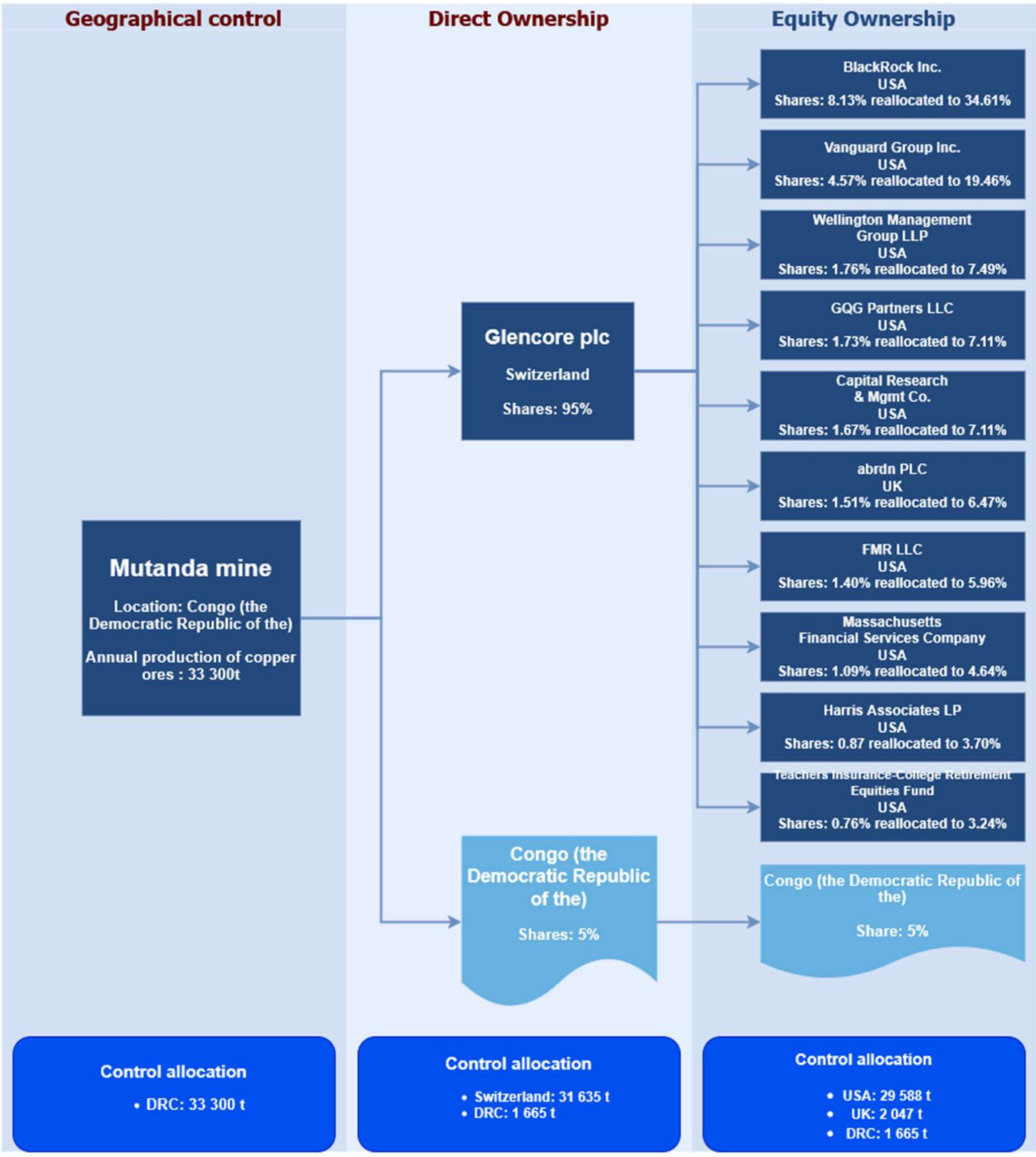
- **Direct ownership**: The production of critical minerals is divided between mining companies according to their share in each mining asset. The headquarters location of these companies is then used to attribute a nationality of the control of that production.

  Example: A mining asset in Zambia produces 1,000 tons of copper annually. Ownership is divided between Company A, holding a 70% stake, and Company B, holding a 30% stake. Company A, headquartered in the UK, is allocated control of 700 tons of copper, while Company B, headquartered in China, is allocated 300 tons.

- **Equity ownership:** The production of critical minerals is attributed to the institutional shareholders of the mining companies that control these mining assets. The share of production controlled by each shareholder is proportional to their ownership stake in the respective mining company. To approximate the influence of large shareholders, we restrict our analysis of control to the ten (or less, if less than ten are reported by S&P) largest shareholders. Therefore, ownership shares must be recalculated to determine the theoretical control over production.

Example: If equity owner 1 based in the US holds 40% of the shares and equity owner 2 based in China holds 20% of the shares in a mining company and no other shareholders are reported, then the US would theoretically control 66.6% of the production, while China would control 33.3% of the production managed by the mining company.

Figure 3: The three categories of mining asset controls



Caption: This figure shows three categories of control: the geographical control, which is defined by the location of the mine, the Direct ownership control, defined by the (main) owners of the mine, and the equity ownership, which can be defined by the owners of the owners of the mine. Most studies on critical minerals have focused on the first and second categories of control, the equity ownership remaining largely unexplored.

In this study, we assume that control is shared among shareholders in direct proportion to each shareholder's percentage interest. While this method of allocating control is widely used in the literature (see Sun et al., (2024) for example), it is nonetheless open to criticism. Indeed, it is questionable whether a shareholder with a small stake (say <5%) really has any control over mine production. Aware of this limitation, Ericsson et al., (2020) proposed to allocate production control only to shareholders with at least 10% of shares. Leruth et al., (2022) for their part, use a specialized software to allocate production control between shareholders according to the relative share held by each. Our analysis resembles Ericsson et al.'s approach by considering only the (up to) 10 largest shareholders.

3.4. Market concentration measures

Market concentration refers to the extent to which market shares are concentrated among a small number of firms. It can be used as a proxy for the intensity of competition[11]. A dominant position by a single producer, whether a company or a country, can influence commodity prices or lead to supply restrictions through export quotas or taxes. The increased risk of supply disruption may prompt changes in government policies or regulations and could affect decisions regarding the necessity of strategic reserves (T. Brown, 2018).

Herfindahl-Hirschman Index (HHI)

The Herfindahl-Hirschman Index (HHI) is widely recognized as the standard for measuring market concentration and is commonly used by institutions and researchers. In our study, we apply the HHI to assess the concentration of major producers of critical minerals, calculated as follows:

$$HHI_m = \sum_{i=1}^{N} S_i^2$$

With S_i^2 the squared number of shares of country i in the production of critical mineral m and N the total number of countries on that market. As defined in the previous section, the shares of minerals produced are calculated based on the country location of the mine, the country of the headquarters of private and public companies that control the production, or the ownership share of each institution controlling the mining companies.

According to the United States Department of Justice (2010), the level of this index, which determines whether a market is concentrated, is generally set at 2500[12]. A value between 1500 and 2500 represents a moderate market concentration and below 1500 no market concentration (T. Brown, 2018). Recent works such as Bucciarelli et al., (2024) have questioned this threshold in the case of critical minerals although they do not propose an alternative method. They argue that using a threshold may result in underestimating supply risks in less concentrated markets. Indeed, they find that low levels of HHI concentration generate on average more variations in the prices of critical minerals than higher levels. Therefore, in our

[11] See https://www.oecd.org/competition/market-concentration.htm

[12] In 2023, the US department of Justice lowered this threshold to 1800.

analysis, we are taking a cautious approach to the 2500 threshold which motivates us to extend the scope of HHI inside criticality matrixes using the Geopolitical distance as explained below.

Alternative measures of market concentration (tested for robustness check in appendix)

Although the HHI index is today the benchmark indicator for market concentration, alternative measures exist. According to Brown (2018) the entropy measures provide credible alternatives to the HHI. Entropy serves as a metric of uncertainty that spans between equity, where uncertainty is evenly distributed, and strong concentration on a single possible value. The most commonly used index, the Shannon entropy, is defined as the sum of the product of relative country shares and their logarithm, such that:

$$S = -\sum_{i=1}^{n} S_i ln S_i$$

3.5. Geopolitical distance (GPD)

To measure geopolitical distance between countries, we rely on observable foreign policy behavior, in particular their voting patterns in the United Nations General Assembly (UNGA). For this purpose, we use the UNGA roll-call voting dataset (Voeten et al., 2009, version 32), which covers sessions 1 to 77 and spans the period from 1946 to 2023. A range of approaches have been proposed in the literature to translate these voting records into indicators of geopolitical distance (Bailey et al., 2017; Häge, 2011).

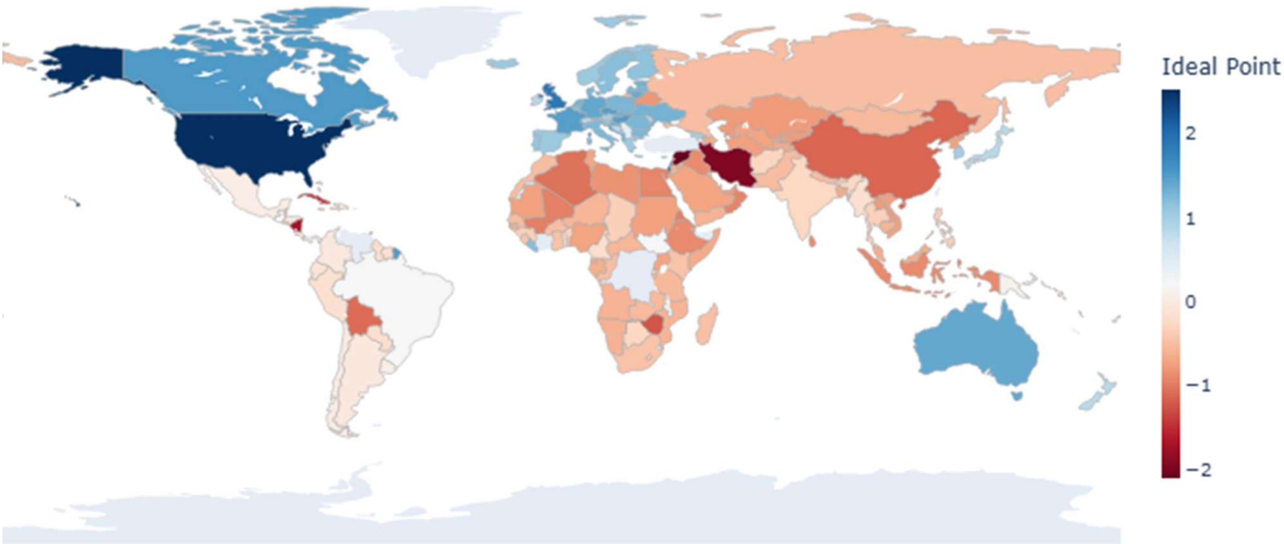
In this paper, we draw on the Ideal Point Distance (IPD) measure introduced by Bailey et al. (2017). This method estimates countries' relative positions in the UNGA by modeling each vote (yes, abstain, no) through an ordered logit framework, where observed voting choices are assumed to reflect an underlying latent preference parameter. These preferences are inferred using Bayesian estimation techniques, specifically a Metropolis-Hastings/Gibbs sampling algorithm. The bilateral distance between two countries in a given year is then calculated as the absolute difference in their estimated latent preference scores. The IPD thus provides a systematic way to capture geopolitical alignment and divergence as expressed in UNGA voting behavior.

Figure 4 presents the Ideal Point Index of countries, placing each nation along a geopolitical spectrum. The greater the distance between two countries' values, the more pronounced their geopolitical divergence. Several noteworthy patterns emerge. Most industrialized nations tend to align—though to varying degrees—with the United States, which occupies one of the extreme ends of the scale. Conversely, a second bloc, led by China and joined by several other nations, generally positions itself in opposition to the U.S., although China's stance is not as sharply antagonistic. Notably, Syria and Iran exhibit the widest geopolitical distance from the United States. Interestingly, many BRICS countries—Brazil, India, South Africa, and to a lesser extent, Russia—maintain a relatively neutral position between the U.S.

and China, albeit with a slight tilt toward the latter. Finally, most countries in Latin America, Africa, and Southeast Asia tend to adopt a moderate and balanced stance between the two blocs, with a subtle preference for alignment with the China-led group.

While the Ideal Point Index offers a structured approach to quantifying geopolitical alignment, it is not without limitations. Most notably, it reduces the complex, multidimensional nature of international relations to a single latent preference score. This simplification can obscure the nuanced motivations behind countries' voting behavior, which is shaped by a mix of diplomatic entanglements, economic dependencies or genuine ideological (mis-)alignments. Voting convergence may reflect external pressures as much as political agreement. Moreover, while historical voting data from 1946 to 2023 is valuable for identifying long-term trends, its use can obscure contemporary geopolitical dynamics—particularly due to the lingering influence of Cold War-era voting patterns. However, Airaudo et al., (2025) demonstrate that these historical alignments do not significantly distort estimates of geo-economic fragmentation, suggesting that the impact of legacy voting behavior may be less consequential than previously assumed.

Figure 4 – Ideal Point Index of countries



Caption: Figure 4 ranks countries worldwide according to their average Ideal Geopolitical Point. Nations with extreme values occupy sharply opposing geopolitical positions. The greater the difference between two countries' ideal points, the larger their geopolitical *distance. Conversely, an Ideal Point near 0 reflects a more nuanced stance, suggesting alignment or moderation in voting behavior relative to the countries at either extreme.*

4. Results

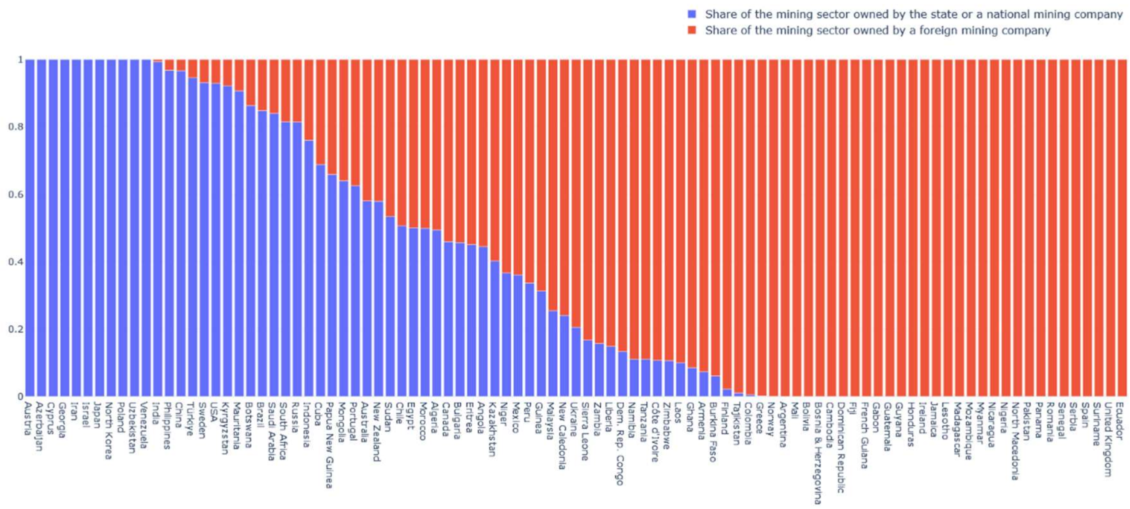
4.1. Analyzing Control Across direct and equity ownership dimensions by country

We start by analyzing control in all three dimensions by country, where geography is by definition 100% controlled by the county itself. Figures 5 and 6 compare the average share of the mining sector controlled by foreign entities (whether companies or states) with the share controlled by domestic entities. Figure 5 considers foreign entities based on the Direct ownership control, while Figure 6 defines foreign entities according to the Equity ownership (EO) definition. The proportion of each mineral controlled by foreign entities is aggregated using a simple average, meaning the economic size associated with the production of each mineral is not considered.

Both Figures 5 and 6 reveal contrasting patterns between national and foreign control. Notably, around two-thirds of the countries producing critical minerals have more than 50% of their mining sector controlled by foreign entities. Additionally, about one-third of these countries have no control at all over their critical mineral production. This lack of domestic control is even more pronounced when foreign entities are defined according to the EO definition.

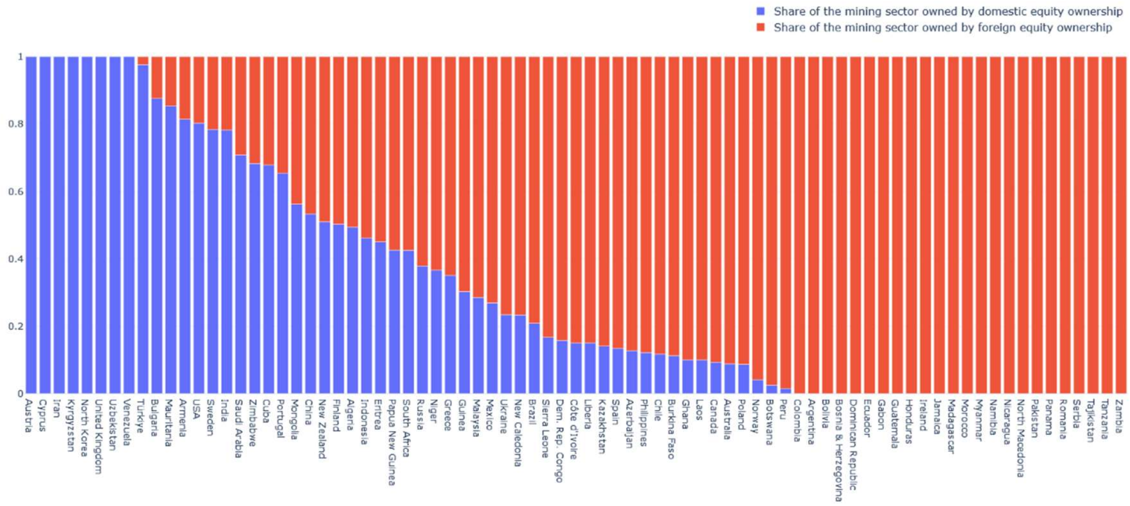
In contrast, only a few countries have managed to maintain significant control over their critical mineral production. Among them are nations under U.S. sanctions, such as Venezuela, Iran, and North Korea. Also included are major economic powers like the United States and China, which have been proactive in securing the supply of critical minerals. It is important to note that a significant portion of the foreign entities involved in China's mining sector are based in Hong Kong. Countries such as Cyprus, Japan, and Israel possess minimal domestic reserves of critical minerals, which likely accounts for the subdued involvement of foreign actors in their mining sectors. In contrast, the limited foreign engagement in Azerbaijan and Uzbekistan may be more indicative of their constrained economic openness and regulatory environments.

Figure 5 – Direct domestic ownership share in each country's mineral sector.



Caption: This graph shows the share of domestic Direct ownership (in blue) in each country's mineral sector of our dataset.

Figure 6 – Equity domestic ownership share in each country's mineral sector.



Caption: This graph shows the share of domestic Equity ownership (in blue) in each country's mineral sector of our dataset.

4.2. Market concentration of critical minerals production

In this section, we present the results of the HHI scores by mineral across the three different levels of production control. HHI (geographic) reflects market concentration based on geographic distribution of mines, HHI (Direct) represents market concentration based on the direct ownership, and HHI (EO) indicates market concentration based on the nationality of the institutional owners of mining companies (Equity Ownership). For all three measures, a value of 10,000, the maximum possible HHI, means that the market is entirely dominated by a single country.

On average, the concentration scores for critical minerals are high, but they vary significantly depending on the level of control. Among the 20 critical minerals analyzed in table 2, 11 exceed the 2500 market concentration score threshold for the geographic control hypothesis, reinforcing previous findings of high geographical concentration among critical mineral producers. Specialty minerals generally exhibit the highest levels of market concentration, with the notable exception of silver. Graphite, iron, and tin also approach this high concentration threshold. In contrast, base minerals such as copper, nickel, and zinc tend to have the lowest concentration levels. The entropy measure of market concentration, used as a robustness check in appendix 3, yields results consistent with the HHI concentration for all three ownership types.

Direct ownership concentration tends to reduce the concentration of mineral producers across countries. For example, Lithium and Cobalt, known for their high geographical concentration, have particularly diversified ownership structures. This observation supports Sun et al. (2024), who argue that foreign direct investment (FDI) from countries without native deposits of a critical mineral can effectively mitigate the supply risk for that mineral. Legal constraints, such as mandatory government participation — either directly or through state-owned mining companies — can foster this diversification in mining ownership. Additionally, the large investments required to develop mining projects often lead to a multi-stakeholder structure.

Conversely, analyzing market concentration using the Equity ownership (EO) often tends to increase the concentration observed through the Direct ownership measure for certain industrial minerals, such as copper and nickel, while reducing it for other types of minerals. For the minerals emerging with the energy transition, diversified Equity ownership could reflect ongoing efforts to secure and advance the development of new critical minerals, like those used in batteries (Cobalt, Graphite...). It could also point to the fragmented and still-evolving nature of these markets, which have only recently gained geopolitical and economic prominence. In contrast, base minerals typically exhibit a concentrated ownership structure, often dominated by major financial institutions such as trust funds, which tend to lock in and maintain high levels of control.

Table 2 - HHI production scores for the three control levels

	Mineral	HHI (geographic)	HHI (Direct)	HHI (EO)	Diff Direct/GEO	Diff EO/GEO
Base minerals	**Bauxite**	3060	1577	3422	-48%	11%
	Tungsten	6191	6829	2624	10%	-57%
	Chromite	3078	2762	2572	-10%	-16%
	Iron Ore	2459	1405	2410	-42%	-2%
	Copper	1109	844	2403	-23%	116%
	Lead	1768	1733	2250	-1%	27%
	Tin	2354	2827	2171	20%	-7%
	Zinc	1246	1333	1967	7%	57%
	Average	2658	2414	2477	-9%	-7%
Specialty minerals	**Vanadium**	5007	3697	5631	-26%	12%
	Lanthanides	5163	5316	5073	2%	-1%
	Niobium	10000	10000	3701	0%	-62%
	Silver	1222	899	2877	-26%	135%
	Palladium	3754	5458	2280	45%	-39%
	Platinum	6095	7068	2128	15%	-65%
	Uranium	2278	1495	1374	-34%	-39%
	Average	4726	4847	3294	3%	-30%
Battery Minerals	**Lithium**	3470	2283	4608	-34%	32%
	Nickel	988	1050	2163	6%	118%
	Cobalt	5641	1490	2020	-73%	-64%
	Graphite	2458	4317	1854	75%	-24%
	Manganese	2231	1292	1566	-42%	-29%
	Average	2958	2086	2442	-29%	-17%
Average		3479	3184	2755	-8%	-21%

Caption: This table presents HHI production scores across the three control levels. White cells indicate scores below the concentration threshold; light grey denotes moderate concentration (HHI > 1,500); and dark grey indicates high concentration (HHI > 2,500). "Diff Direct/GEO" shows the percentage difference between HHI values for direct control and geographic distribution. "Diff EO/GEO" reflects the percentage difference between institutional ownership and geographic HHI. Positive values indicate higher concentration under direct or institutional ownership compared to geographic distribution; negative values indicate the opposite.

Figure 7: Geographical concentration of ownership by critical minerals and by country (production):

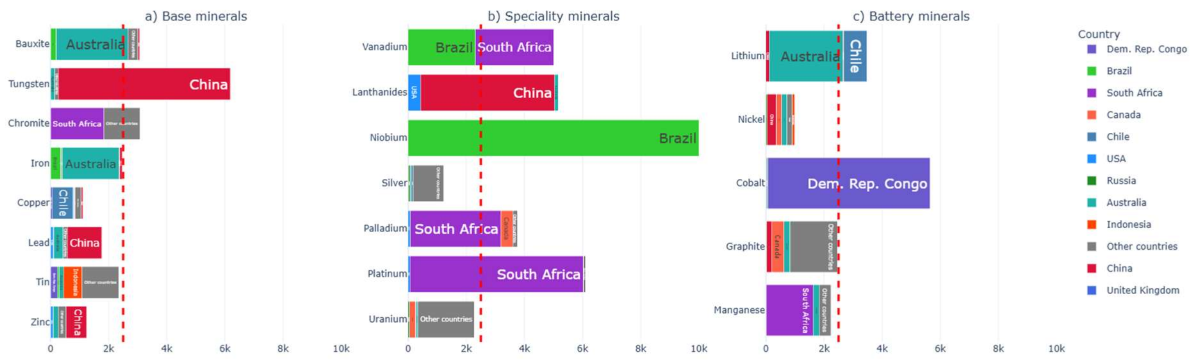


Figure 8: Direct ownership concentration by critical minerals and by country (production):

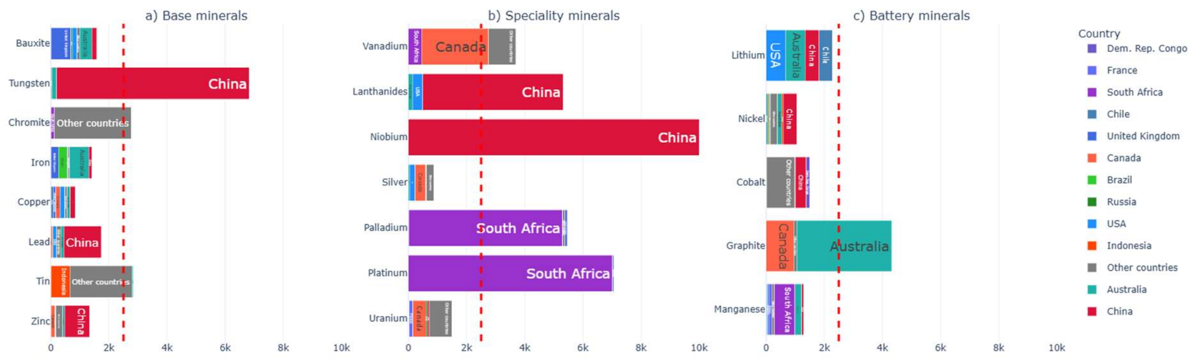
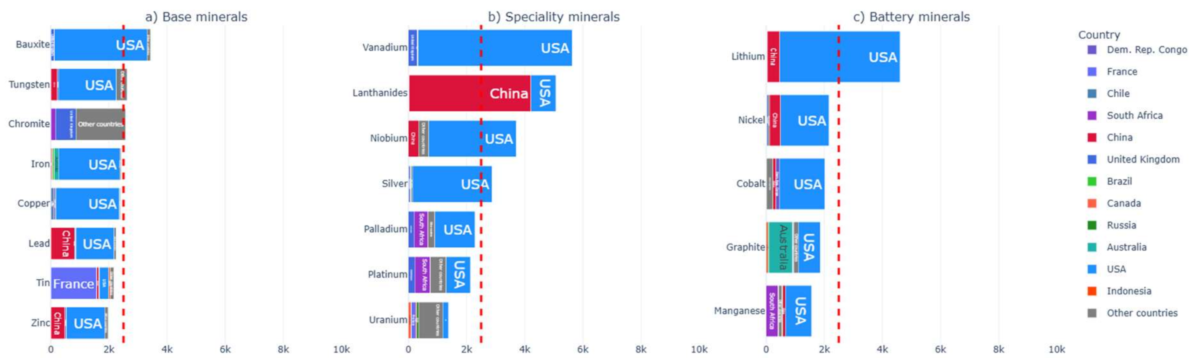


Figure 9: Equity ownership concentration by critical mineral and by country (production):



Caption: In Figures 7, 8, 9, we decompose the market concentration indicator (HHI) by analyzing the respective weight of each controlling country. This allows us to identify which countries dominate each critical mineral market. The HHI index, as shown in Table 2, is derived from the sum of the shares controlled by each country. To clarify the contribution of each region, we further disaggregate the market concentration indicator (HHI) by examining the relative weight of the OECD, China, and the Rest of the World, as illustrated in Figures 13, 14, and 15 in Appendix 2.

The direct ownership (DO) concentration reveals that a few countries dominate the critical mineral mining industry in this dimension. These countries—Australia, Canada, China, Russia, South Africa, the United Kingdom, and the United States—share a common trait: they are major mining powerhouses with well-established ecosystems of mining companies. Each hosts the headquarters of some of the world's most influential mining firms. Australia, Canada, China, Russia, and the United States are among the largest countries in the world, which has enabled them to develop strong domestic mining industries thanks to their vast geological potential. Although South Africa is smaller in size, it possesses some of the world's richest deposits of palladium and platinum, positioning its mining companies as natural leaders in these commodities. The UK, while somewhat distinct, has inherited powerful mining companies as a result of its colonial period (Humphreys, 2024).

The equity ownership (EO) concentration reveals that an even smaller set of countries control critical minerals production in this dimension. Australia, China, France, South Africa, the United Kingdom and the United States have the largest ownership share in at least one mineral. But it is notable that the United States has this largest share in 16 minerals, providing it with control over a substantial portion of global critical mineral production in the equity ownership dimension. This owes to the larger financial market than any other country and the concentration of the global asset management industry in the United States, leading to substantial holdings in listed mining firms around the world, including in Chinese ones. Consequently, the OECD region emerges as the clear leader in EO share, while the Rest of the World remains largely absent or marginal across most minerals (see Figure 15).

The case of tin, and France's apparent dominance in terms of equity ownership, highlights one limitation of applying the approach highlighted in Figure 3 to small-scale markets. In our dataset, the leading tin producing company is Minsur SA, a Peruvian based company. The only recorded equity holder in Minsur SA by S&P is AXA Investment Managers SA, a French investment firm, which holds 0.1% of the company's capital. Other investors are listed, but their individual shares fall below 0.1% and are therefore reported as 0% by S&P. As a result, following our approach, France appears to hold 100% of the reported equity ownership in Minsur SA, giving it the highest apparent level of control among all countries—an outcome that likely overstates its actual influence due to data granularity and reporting thresholds. This outcome however appears to be a unique artifact of the tin market, shaped by both its limited size and the specific equity structure of Minsur SA reported by S&P, and does not generalize to other minerals.

4.3. Geoeconomic fragmentation (GEF)

The breakdown of the ownership structure of mining assets by country reveals that a limited number of countries holds significant shares over the production and reserves of critical minerals. As we ascend the ownership hierarchy, it becomes increasingly evident that the current trend in geoeconomic fragmentation may play a driving role in countries' critical mineral strategies. The geoeconomic risk to critical mineral supplies cannot be directly captured by the Herfindahl Hirschman index alone. The geoeconomic fragmentation of the global economy—exacerbated by recent events such as COVID-19, the war in Ukraine, and the Israel-Palestine conflict—has become a focal point of numerous studies (Aiyar et al., 2023). This geopolitical tilt among major economies is raising concerns about the resilience of global supply chains, particularly for strategic common goods like critical minerals. The control over the means of production of these minerals could provide a significant advantage to one of the world's major geopolitical players. Given the strategic importance of critical minerals in supporting the global energy transition, this geo-economic fragmentation could pose a serious threat to global efforts toward a low-carbon development.

In Figure 10 and 11, we use the Geopolitical Distance (GPD) in conjunction with the Herfindahl-Hirschman Index (HHI) to provide a new perspective on market concentration for critical minerals. High market concentrations can present varying levels of risk to a country's supply, depending on whether the dominant producers are aligned with or opposed to the country's geopolitical stance. In the Figures, each mineral is associated with its three concentration measures of control over production (three different associated colors). The size of the dots indicates the value of the corresponding HHI score. The X axis represents the normalized average geopolitical distance of the producers on each mineral market according to the different levels of controls in Figure 10. Figure 11 shows the same data but as deviation of the distance for geography.

Figure 10 – HHI concentration and average Geopolitical Distance

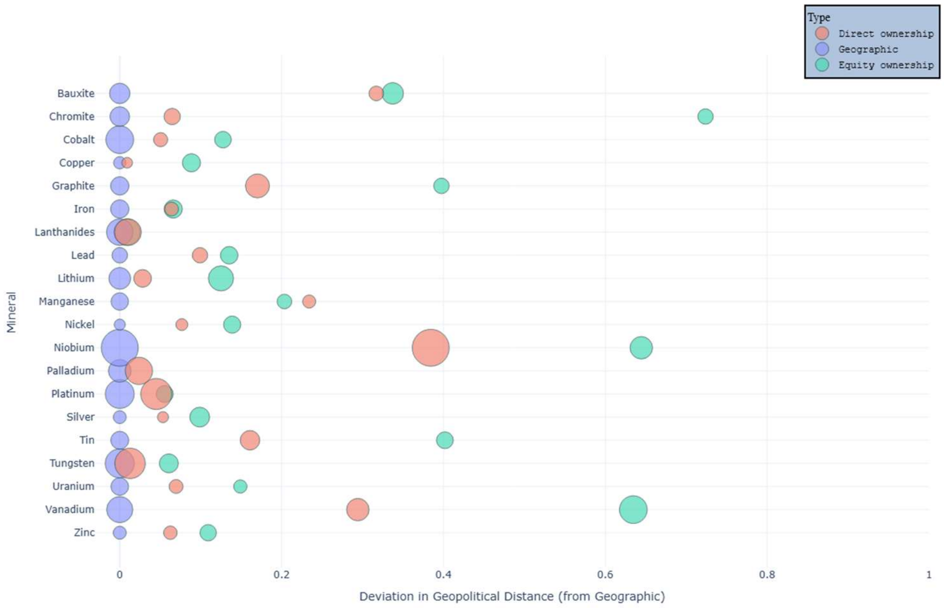
Caption: This graph compares the HHI concentration of critical minerals and the average Geopolitical Distance of countries that control the production. In this graph, the size of the bubbles is proportional to the HHI concentration score of each mineral.

Lanthanides (rare earths) stand out as the most exposed minerals due to geopolitical distance. These minerals are predominantly extracted in China, and to a lesser extent the United States, and Australia. The direct and equity owners of lanthanide mines are predominantly in China and the United States, and the main institutional owners of the companies exploiting these minerals are also in China and the US. These two countries have effectively locked down the production ownership structure of these minerals. Although China has only moderate geopolitical distance, the inclusion of the United States—considered a high geopolitical risk—and the absence of third-country participation in the ownership structure make lanthanides the most geopolitically exposed group of minerals.

The next three most exposed minerals are Chromite, Graphite and Niobium, but only in the equity ownership dimension. Two of these rank among the geopolitically least concerning minerals in the geography dimension, showing that the ownership dimension adds a degree of complexity also to the problem of how geoeconomic fragmentation impacts mineral criticality. In fact, for many minerals, different control dimensions can have widely average geopolitical distances, highlighting the differences in dimensions also according to this criterion.

For all minerals, producers identified by direct and equity ownership (DO and EO) have a higher average Geopolitical Distance (GPD) from the rest of the world compared to geographic producers (Fig 11). This suggests that the host countries of critical mining assets are generally less geopolitically distant than the institutional owners. These host countries often include nations in South America and Africa, which have some of the lowest GPD scores. Conversely, high levels of production control frequently involve a significant proportion of countries aligned with specific geopolitical blocs, which tend to have higher average GPD values relative to the rest of the world.

Figure 11 - HHI Concentration and Average Geopolitical Distance Deviation (Relative to Geographic Control)



Caption: This graph compares the market concentration (HHI) of critical minerals with the average geopolitical distance of the countries controlling their production. Bubble size is proportional to the HHI score for each mineral, while the position reflects how geopolitical exposure deviates from a baseline based on geographic control.

4.4. Market concentration of owners of critical mineral reserves for undeveloped mining assets

In this section, we analyze the reserves identified in currently operating mining assets and the ones from not yet active mining projects (for a full analysis of reserves concentration see appendix 4). The shift between both types of reserves may provide an idea of future trends in the production of critical minerals. It would also help to identify actors (old or new) that would be able to capture a dominant position on a given market. Figure 12 (left) indicates the HHI concentration of reserves for geographic ownership of currently operating mines on the X axis and for mining projects on the Y axis. Figure 12 (right) investigates in a similar way the HHI concentration of reserves according to direct ownership concentration definition. The color bars show the level under which the market concentration is considered acceptable according to the 2500 threshold.

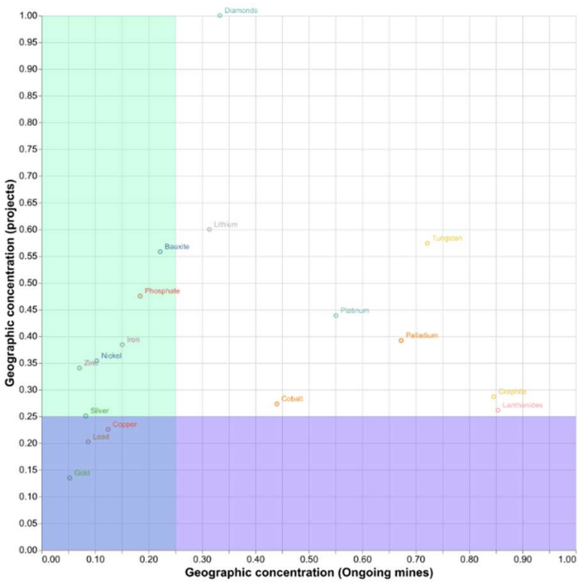
The market concentration resulting from future mining projects is likely to be significantly higher than that based on current reserves for a wide range of minerals—including bauxite, nickel, and zinc (see Figure 12, left). However, some minerals experience a notable decrease in market concentration, although they still remain above the 2500 threshold. This trend is particularly evident for Lanthanides and Graphite. In both cases, the relatively low geographic concentration of new mining projects suggests that additional countries are beginning to invest in the development of Lanthanide and Graphite resources. However, this diversification appears constrained, likely due to limited geological endowments. Meanwhile, the persistently high concentration in direct ownership indicates that a small number of mining companies originating from the same countries continue to dominate production. This may be driven by China's prevailing control over the refining processes for these elements, which creates significant barriers to entry for new producers (IEA, 2025).

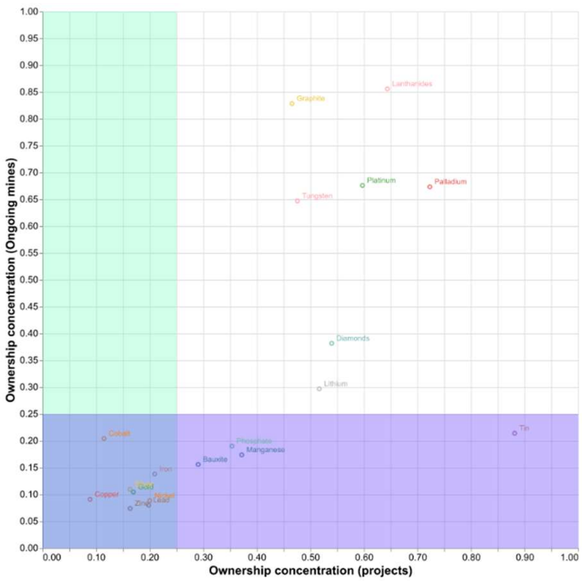
The direct ownership concentration of critical minerals shows only marginal changes between the reserves of currently operating mines and those of upcoming projects (Figure 12, right). This suggests that while there may be shifts in the countries where these minerals are exploited, the entities involved in their extraction are likely to maintain similar market shares as they do today. Implicitly, this also suggests that the main players currently dominating the critical minerals market will remain largely unchanged as new mining projects come to the market.

Figure 12 - Difference in HHI concentration between reserves located in active mines and those under development.

A) Geographic concentration of Reserves – Active mines vs mining projects

B) Direct Ownership concentration of Reserves - Active mines vs mining projects





Caption: The graph on the left shows the HHI concentration (geographical) for active mines (x axis) and for mining projects (y axis). The graph on the right shows the HHI concentration (Direct ownership) for active mines (x axis) and for mining projects (y axis).

5. Concluding discussion

This study of the market concentration of the main producers of critical minerals complements the analyses traditionally carried out based on the geographical location of mining assets. Varying the assumptions made about production control revealed significant heterogeneity between critical minerals. The results first confirmed previous studies that market concentration based on the geographic location of mining assets was high on average. Besides the well-known case of rare earths minerals (lanthanides), we confirm here also that minerals critical to batteries, such as cobalt and lithium, are produced in particularly concentrated ways. More common minerals (copper, iron, etc.) have a more diversified production basis.

The switch of focus to other definitions of control, based on the ownership structure of mining assets, alters the classical discourse of market concentration based on the location of the mining assets. First, the use of direct owners' control leads to an average decrease in the market concentration of critical minerals markets compared to the geographical concentration. This is particularly notable in the case of cobalt, where the concentration of producers has been considerably reduced by this change in the definition of control. Second, analysis by equity ownership shows that some minerals that do not make the headlines are much more concentrated than expected. This is particularly true of certain minerals such as copper, nickel and silver, where production is controlled by a small number of ultimate owners, highlighting a rarely raised risk for the supply of these minerals.

The decomposition of concentration indicators by country across additional dimensions of production control reveals that the same few countries dominate critical minerals, while developing economies play only a marginal role. Unlike the geographic distribution of mineral production—which varies significantly across countries—direct and equity ownership tend to be concentrated within a consistent set of countries, reflecting a more uniform pattern of control.. This implies that, beyond the supply risk associated with concentration in individual minerals, there is also cross-mineral concentration of control in more indirect dimensions. Such patterns become particularly salient under conditions of geoeconomic fragmentation, especially when these dominant countries are geopolitically distant from key importers. Notably, the countries exerting such control are primarily developed and industrialized economies. By contrast, developing countries, despite their dominance in the geographic production of several minerals (e.g., cobalt, manganese, vanadium), remain significantly underrepresented in these higher-order control dimensions, raising questions about their ability to capture the benefits of the resources extracted from their territories.

Confronting market concentration with geopolitical distance between suppliers and importers highlights the vulnerability of certain critical minerals to geoeconomic fragmentation. Even if, on average, direct and equity ownership concentrations are lower than geographic concentration, the composition of these higher levels of concentration can be risky under conditions of geoeconomic fragmentation. The geopolitical analysis revealed a large geopolitical distance between some of the main direct and equity owners of certain critical minerals and (potential) importers. As such, there is a significant geopolitical risk lurking in the ownership structure of mining assets.

This risk is especially pronounced for minerals such as bauxite, chromite, graphite, niobium, tin, and vanadium, whose average geopolitical distance of their producers —based on the countries hosting their mines—is relatively low. Yet analyses of market concentration based only on the geographical location of mining production miss this risk.

Multilateral efforts to keep certain levels of supply available via 'safe corridors' to all importers, including developing countries, are important for a smooth energy transition and economic development more broadly. The proliferation of bilateral and multilateral agreements such as the Mineral Security Partnerships and those under the Belt and Road Initiative could lead to the formation of trading blocs for minerals. The friendshoring of critical mineral production by these blocs could reduce access to critical minerals for non-aligned countries, a situation that applies to many developing economies (see Figure 4). For all countries, aligned or not, price increases and the risk of supply interruptions would become more likely, and slow down the development of low-carbon industries. Multilateral efforts to establish 'safe corridors' for certain floor levels of trade in minerals, as suggested by Aiyar et al. (2023), would be important to mitigate the worst supply and price fluctuations. By ensuring that a minimum volume of key minerals continues to flow across borders regardless of geopolitical alignment, such mechanisms would support both the stability of the energy transition and broader goals of sustainable economic development.

The concentration of foreign control in direct and equity ownership dimensions could lower supply reliability also through the local impact of mining activities. Aside from the geopolitical angle, concentration of direct and equity ownership could also be relevant for critical minerals supply through the local impact of mining, notably through increasing the likelihood of conflict in the mining country. Foreign owned mining has been found to be associated with conflict, likely through its propensity to finance militias (Berman et al., 2017). Foreign mining can also drive conflicts more implicitly. It can favor very substantial illicit capital outflows (capital flight), which in turn undermines economic development (Ndikumana & Boyce, 2022, 2025). And unregulated mining activity can create substantial environmental and social impacts, exacerbating conflicts with and between local communities, including indigenous people (Luckeneder et al., 2021; Spash, 2017). The bargaining power of a state with foreign mining companies is often limited (Kuswanto et al., 2017), which undermines its ability to mitigate capital outflows or regulate local pollution. More concentrated control over foreign mines reduces the bargaining power of the state further, all else equal, including in conflict areas via conditionalities on access to resources in exchange for military support. These problems all matter deeply for local communities and economic development, a well-documented fact in the cited literature. The present analysis highlights how such local conflict links up with the risks of concentrated control for global critical mineral supplies.

Participation in existing and emerging international initiatives aimed at promoting fairer production and trade of critical minerals can help developing countries better leverage their mineral endowments, particularly in a context of significant foreign control. For instance, the Extractive Industries Transparency Initiative (EITI) plays a key role by fostering disclosure of mining asset ownership structures—a participation shown to have significant positive effects on economic growth (Pafadnam, 2024). However, such initiatives often have a limited scope when it comes to integrating developing countries into the broader green value chain. New supranational frameworks are beginning to take a stronger stance on this issue. For example, the seven Guiding Principles developed by the UN Secretary-General's Panel on Critical Energy Transition Minerals call for a greater share of value added in the green value chain to remain within resource-rich developing countries, encouraging all partners in mining projects to promote benefit sharing, value addition, and economic diversification (United Nations, 2024). The African Green Mineral Strategy, developed by the African Union, takes an even stronger stance on green industrialization through critical minerals, promoting *Equitable Resource-Based Industrialization (ERBI)* as a pathway to transform resource wealth into sustainable economic development (African Union, 2024). It promotes intra-African cooperation to pool efforts in developing nationally owned mining assets and green value chain projects, such as the transboundary battery and electric vehicle Special Economic Zone between Zambia and the DRC[13].

Finally, it is important to mention some of the limitations associated with this exercise. First, control over production is difficult to determine. It is not only defined by the ownership structure, but by a complex set of factors, ranging from management to the binding contracts that the company may face. For example, mining companies of Chinese origin but listed on US or UK financial markets may be subject to a degree of control even if no Chinese entity holds a significant stake. Second, the extent to which a government can exert direct influence over the behavior of multinational companies, which many of the mining and financial companies in sample are, may be limited. Lastly, our study comes up against the limitations of the S&P database, particularly relevant regarding smaller mining assets and/or mines located in countries with low transparency, but also equity ownership reporting and how ownership shares translate into actual control.

[13] https://www.uneca.org/stories/zambia-and-drc-to-implement-an-innovative-transboundary-battery-and-electric-vehicle-special

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7. Appendix 1 – China refining capacities

Table 3 – Share of China refining capacities

Material	Product	Share (%)
Cobalt	Refined cobalt	77.0
Copper	Refined copper (primary & secondary)	42.0
Iron & Steel	Crude steel	53.9
Rare Earth Elements	Refined REE	87.8
Lead	Refined lead (primary & secondary)	51.3
Lithium	LCE	69.2
Manganese	Mn ferroalloys (FeMn & SiMn)	69.5
Nickel	Refined nickel (Class I incl. salts & oxide, pr…	23.3
Tantalum	Refined Tantalum	45.5
Tin	Refined tin (primary & secondary)	52.3
Tungsten	Refined Tungsten	44.3
Vanadium	Refined vanadium	59.0
Zinc	Refined zinc (primary & secondary)	46.9

Caption: This table shows China's share (%) in the refining of 13 critical minerals, highlighting its dominant position in the global critical mineral value chain.

Source: Raw Materials Information System (RMIS)

8. Appendix 2 – Disaggregating Ownership Concentration by Economic Region: OECD, China and ROW

Figure 13: Geographical concentration of ownership by critical minerals and by economic region (production)

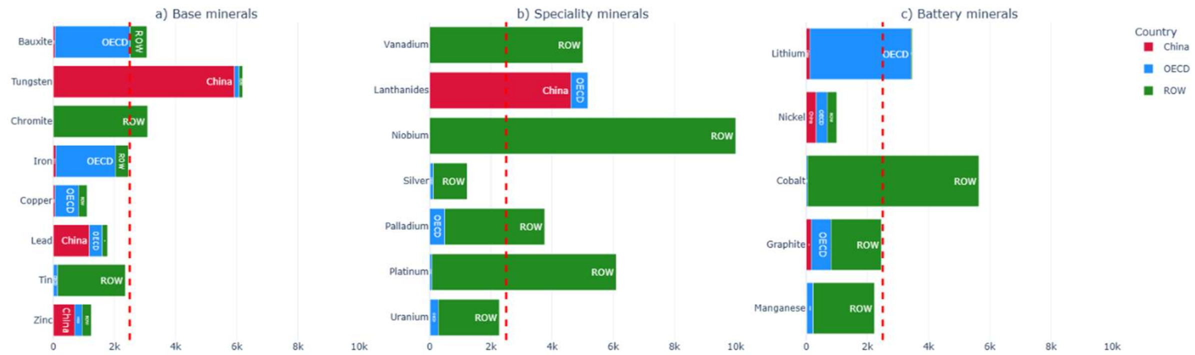


Figure 14: Direct ownership concentration by critical minerals and by economic region (production)

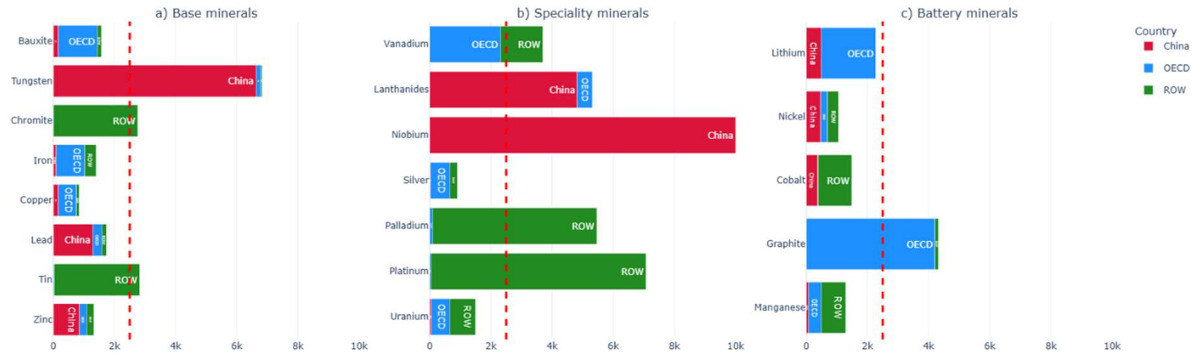
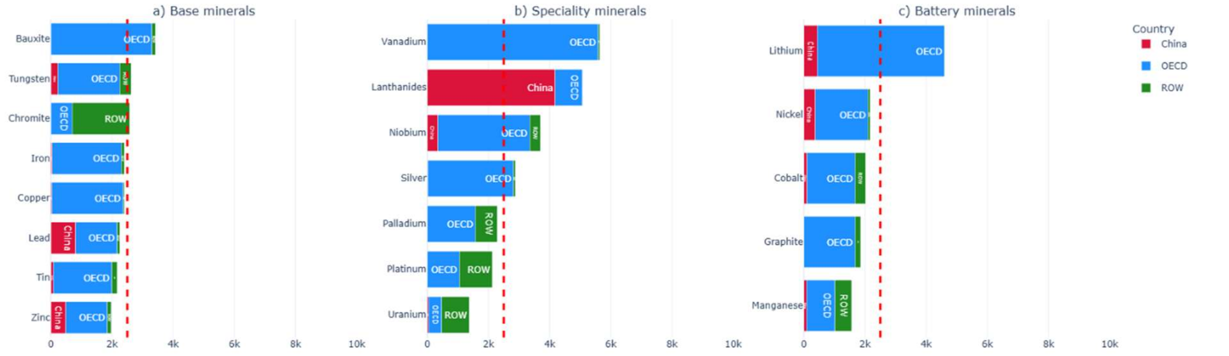


Figure 15: Equity ownership concentration by critical mineral and by economic region (production)



9. Appendix 3 – Other concentration indicators

Figure 16 - Entropy of production by mineral (Geographic ownership)

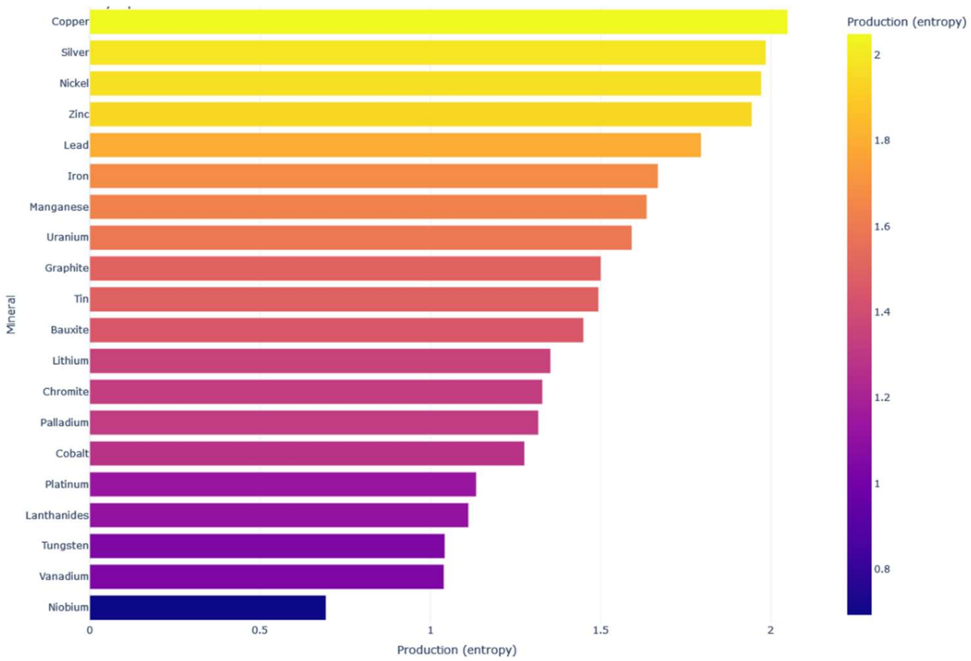


Figure 17 - Entropy of production by mineral (Direct ownership)

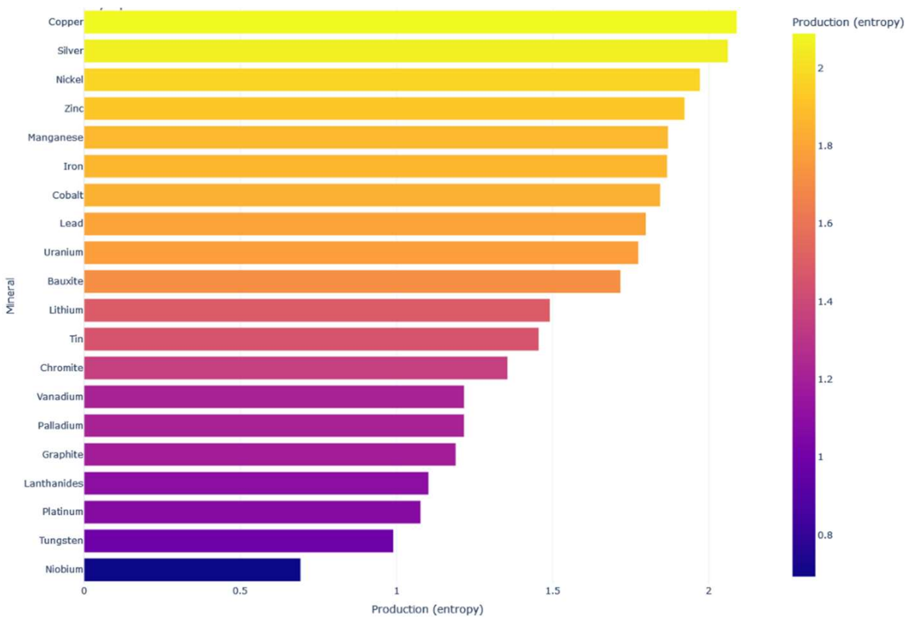
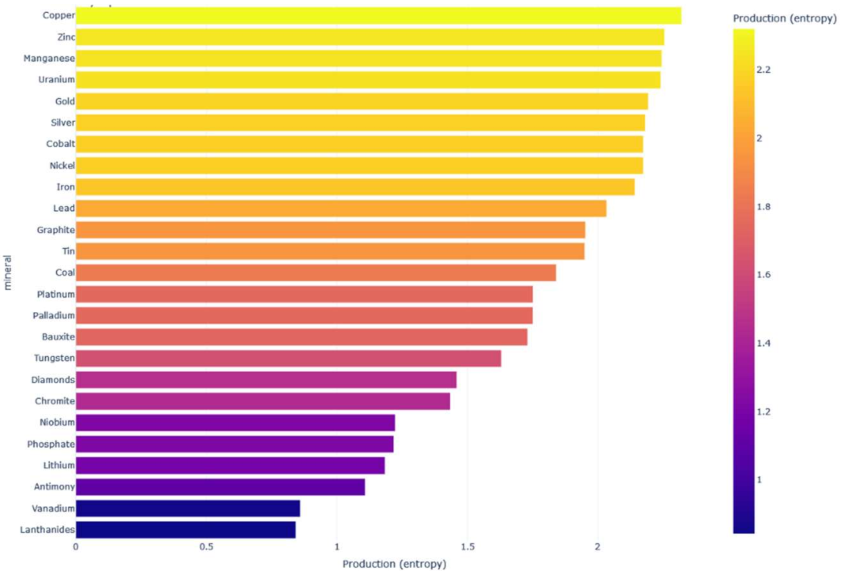


Figure 18 - Entropy of production by mineral (Equity ownership ownership)



10. Appendix 4 – Market concentration of critical mineral reserve owners

Table 4 – HHI reserves scores for the three control levels

	Mineral	HHI (geographic)	HHI (Direct)	HHI (EO)	Diff Direct/GEO	Diff EO/GEO
Base minerals	**Tungsten**	7079	6470	5831	-8%	-17%
	Copper	1183	907	2671	-23%	125%
	Bauxite	2209	1557	2605	-29%	17%
	Iron Ore	1491	1379	2023	-7%	35%
	Lead	797	798	1871	0%	134%
	Tin	1640	2139	1420	30%	-13%
	Zinc	697	738	1450	5%	107%
	Average	2157	1998	2553	-7%	18%
Specialty minerals	**Lanthanides**	7765	8559	6990	10%	-9%
	Palladium	6300	6733	4059	6%	-35%
	Silver	772	1095	2731	41%	253%
	Platinum	5441	6759	2236	24%	-58%
	Average	5069	5786	4004	14%	21%
Battery Minerals	**Lithium**	3814	2967	4029	-22%	5%
	Graphite	3377	8285	2803	145%	-16%
	Cobalt	3869	2041	2361	-47%	-38%
	Manganese	3120	1737	1922	-44%	-38%
	Nickel	1039	882	1592	-15%	53%
	Average	3545	3757	2779	6%	22%
Average		3564	3365	3081	-6%	-14%

Caption: This table presents HHI reserves scores across the three control levels. White cells indicate scores below the concentration threshold; light grey denotes moderate concentration (HHI > 1,500); and dark grey indicates high concentration (HHI > 2,500). "Diff Direct/GEO" shows the percentage difference between HHI values for direct control and geographic distribution. "Diff EO/GEO" reflects the percentage difference between institutional ownership *and geographic HHI. Positive values indicate higher concentration under direct or institutional ownership compared to geographic distribution; negative values indicate the opposite.*

In Table 3, we analyze the reserves of critical minerals using the same approach as for production, distinguishing between the three levels of control. This analysis includes reserves from both currently active mines and future mining projects. It is important to note that not all mining projects in our dataset have reserve estimates, as these estimates are typically associated with more advanced projects in the later stages of development.

We observe slightly higher concentration levels of reserves compared to production, along with significant heterogeneity across different minerals. Notably, battery minerals like Graphite, Lithium, and Manganese, as well as cross-cutting technology minerals like Lanthanides (rare earth elements), exhibit considerably higher concentration levels in reserves compared to production. Conversely, some minerals, such as Bauxite and Tin, show a lower concentration levels of reserves compared to production.

The decomposition of the ownership structure of reserves in Figures 19, 20, and 21 reveals shifts in key players as ownership concentration increases. At the geographic level, major players in production maintain their strong positions, largely due to their extensive geological capabilities. However, significant changes in ownership emerge when considering direct and equity ownership (DO and EO). In terms of direct ownership, we observe China's growing share over Cobalt and Lanthanides reserves. Australia takes the lead in Graphite reserves, while Russia becomes dominant in Palladium. Regarding equity ownership, the US share remains unmatched. Nevertheless, Chinese control over Tungsten reserves is higher than over production, and Bolivia emerges as a key player in Lithium reserves, holding significant shares in every foreign firm involved in mining projects within its vast Lithium deposits. The regional decomposition of equity ownership, as depicted in Figure 24, underscores the pronounced dominance of OECD countries across the majority of minerals, with the Rest of the World largely absent or playing only a marginal role.

The shift in countries' shares for certain minerals can be attributed to several factors in the current structure of the global production system for critical minerals. First, the current race for critical minerals has incentivized many countries to pursue new mining projects, even if they are not currently exploiting those minerals. For example, countries with large reserves, like Bolivia with its significant Lithium reserves, may not yet be actively producing these minerals. Additionally, in the earliest stages of mining projects, many junior companies are involved. These companies specialize in developing uncertain or speculative mining projects. Since the majority of junior companies are Anglo-Saxon, this naturally reinforces the shares of countries like the US, Canada, and the UK in the global mining landscape.

Finally, this analysis of mining projects could be viewed as an indication of future ownership scenarios for critical mineral production, although this comes with some words of caution. A mining project may never reach the production stage due to various economic, technical, and socio-environmental factors, which can lead to its cancellation. Even if a project progresses to active mining, large reserves do not always translate into large-scale production. The same factors—economic conditions, technical challenges, and social or environmental concerns—can limit the development of a mine's productive capacity. Additionally, reserves in currently active mines may not be economically viable to extract if the mineral's price drops or if other socio-technical issues arise that affect the mine's operations.

Figure 19: Geographical concentration of ownership by critical minerals and by country (reserves):

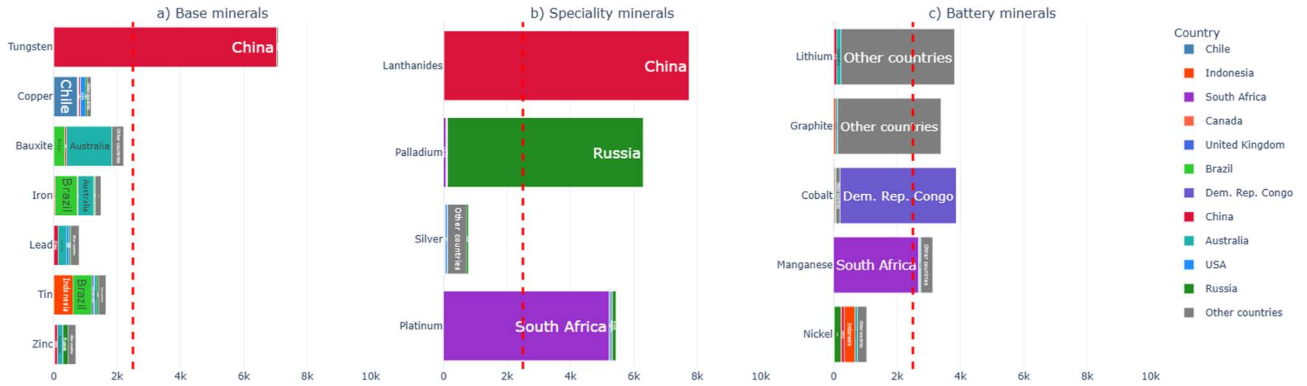


Figure 20: Direct ownership concentration by critical minerals and by country (reserves):

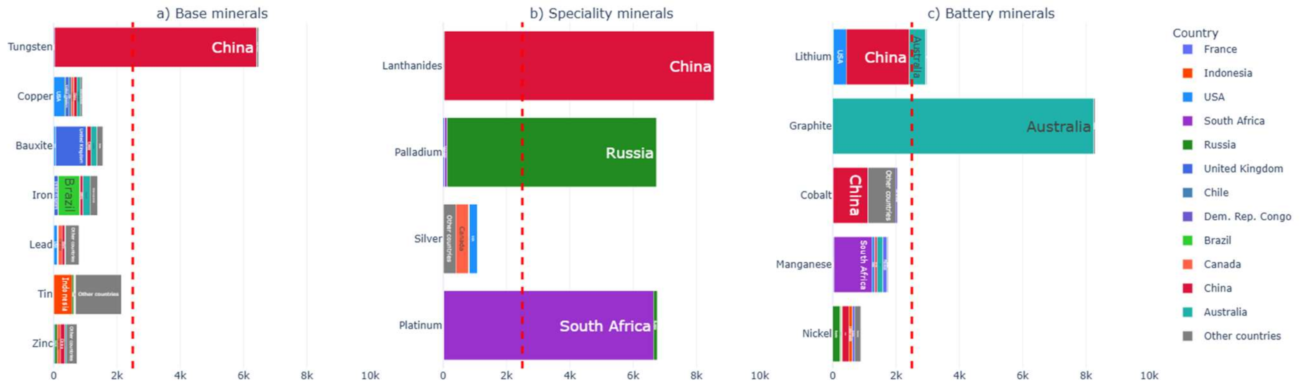


Figure 21: Equity ownership concentration by critical mineral and by country (reserves):

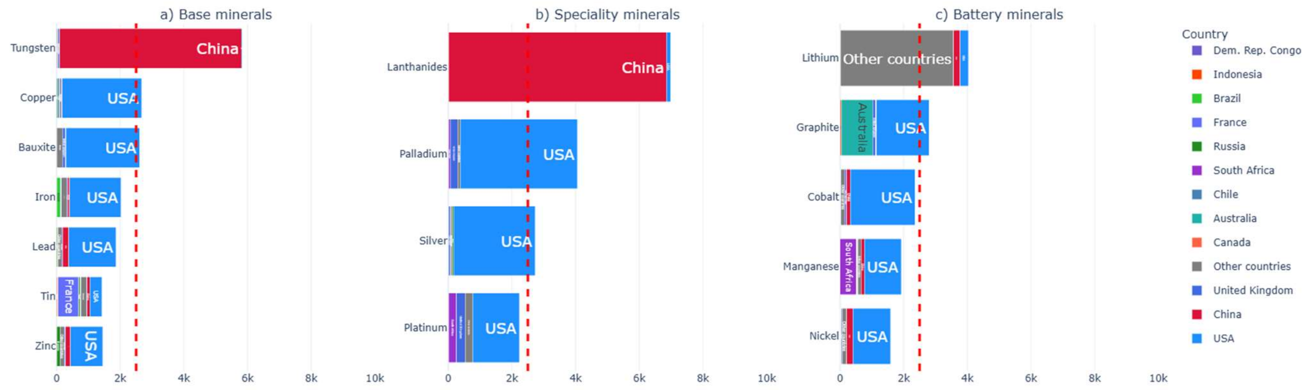


Figure 22: Geographical concentration of ownership by critical minerals and by economic region (reserves)

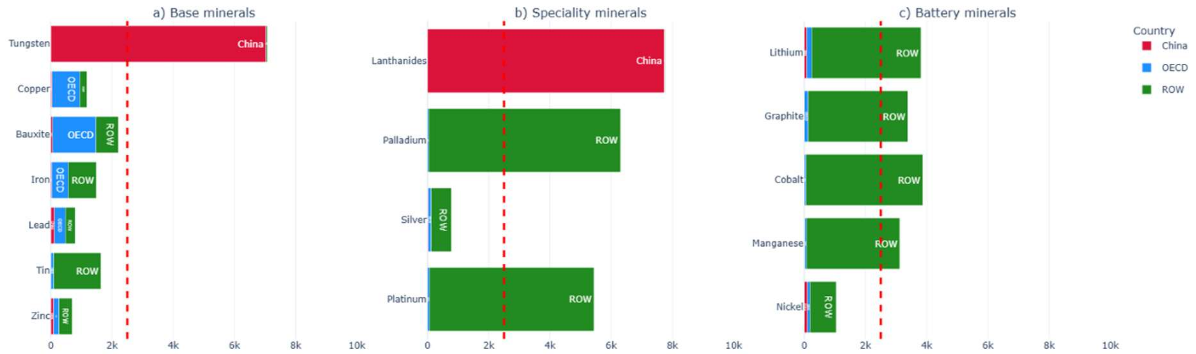


Figure 23: Direct ownership concentration by critical minerals and by economic region (reserves)

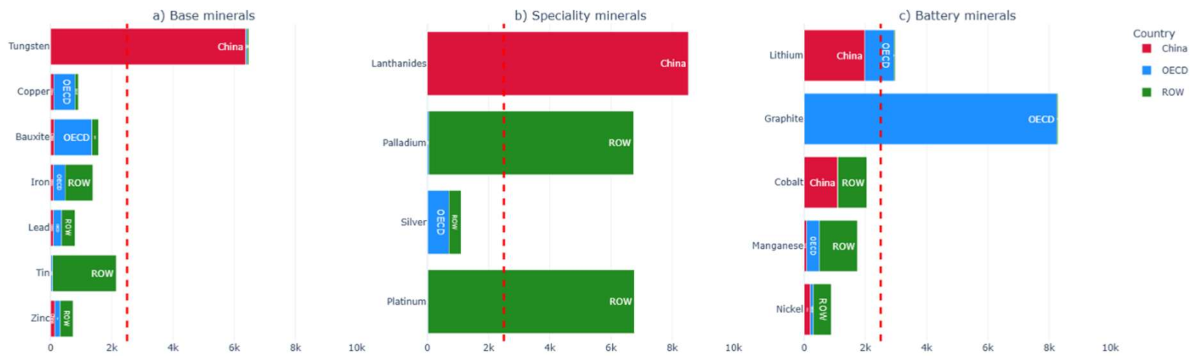
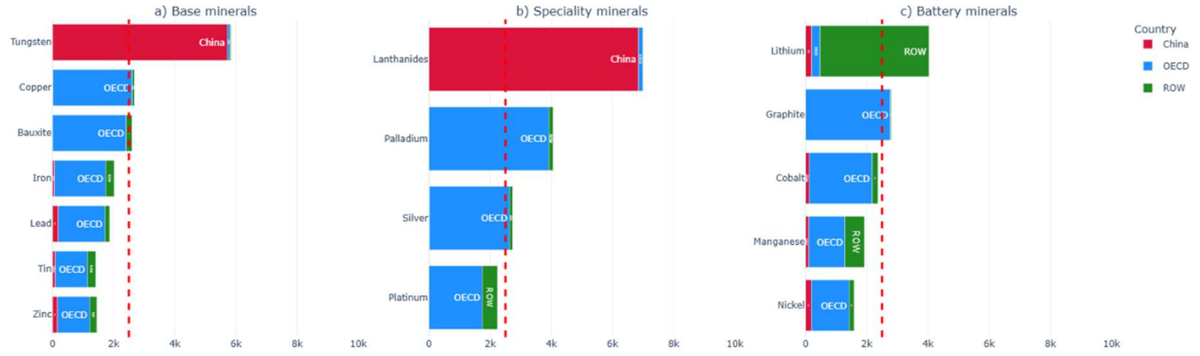


Figure 24: Equity ownership concentration by critical mineral and by economic region (reserves)



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