Jain Family Institute

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Mineral Wealth and Electrification: A Producer-Country Perspective

Jonah Allen, Lead Researcher, Energy Transition Value Chains

Paul Katz, Vice President and Lead Researcher, Social Wealth

Sina Sinai, Research Associate

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Executive Summary

The energy transition represents a significant opportunity for countries producing the materials critical to electrification. In this report, we look at eight such materials: aluminum, cobalt, copper, natural graphite, iron, lithium, manganese, and nickel. As demand for so-called “critical minerals” grows, producer countries must develop robust strategies for effective value capture to transform a temporary windfall into an opportunity to grow shared wealth and climb the value chain.[1] Doing so demands both institutional capacity and political will.

View this report as an interactive web page.

Key takeaways

- Electrification is driving a growing demand for critical minerals, creating new opportunities for producer countries rich in these materials, as represented in our interactive online Transition-Critical Minerals Map.
- While criticality is often considered in light of the needs of countries consuming these materials as inputs of higher value-added products, we adopt a producer-country perspective centered on the potential for wealth creation and public value capture and investment.
- Sovereign wealth funds and other revenue management strategies can play a vital role in managing volatile commodity revenues, providing stability and promoting long-term investment.
- The Jain Family Institute has developed and continues to refine a set of tools to aid producer countries in seizing the opportunities afforded by the changing profile of these key commodities. These include the accompanying interactive Transition-Critical Minerals Map, a heuristic affording users a high-level perspective on this opportunity space.

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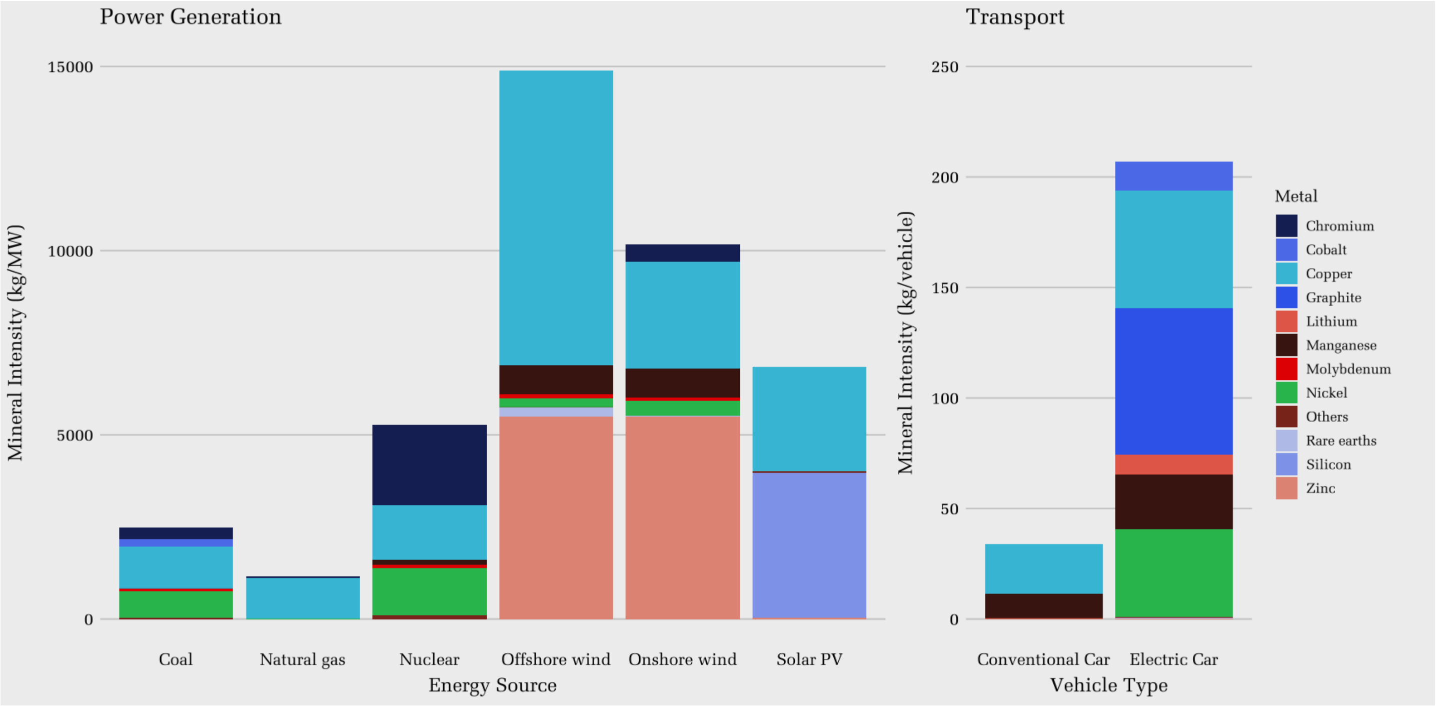
[1] We recognize that Al and Fe are technically chemical elements, not minerals—naturally occurring compounds with specific chemical structures (like bauxite for aluminum or hematite for iron). However, it is common to loosely refer to resources as "minerals," particularly with regard to the discussion of critical minerals, a practice we adopt throughout this report.

The promise of electrification

Decarbonization is electrification; the International Energy Agency's Net Zero Emissions Scenario sees electricity's share of final energy consumption growing from about 20% today to more than 50% in 2050. The technologies necessary to electrify our energy systems expand both the scope and scale of mineral demand. Technologies to produce renewable electricity are more materially complex than fossil incumbents (Figure 1), and the networks used to transport this electricity need to be established, expanded, and upgraded, requiring vast quantities of copper, aluminum, and steel. The batteries that will store much of this energy and power sustainable transport demand lithium, graphite, nickel, manganese, cobalt, iron, and other materials. Altogether, mineral demand growth will be unprecedented, though the pace of this growth depends on the speed and scale of both global development and the energy transition.[2]



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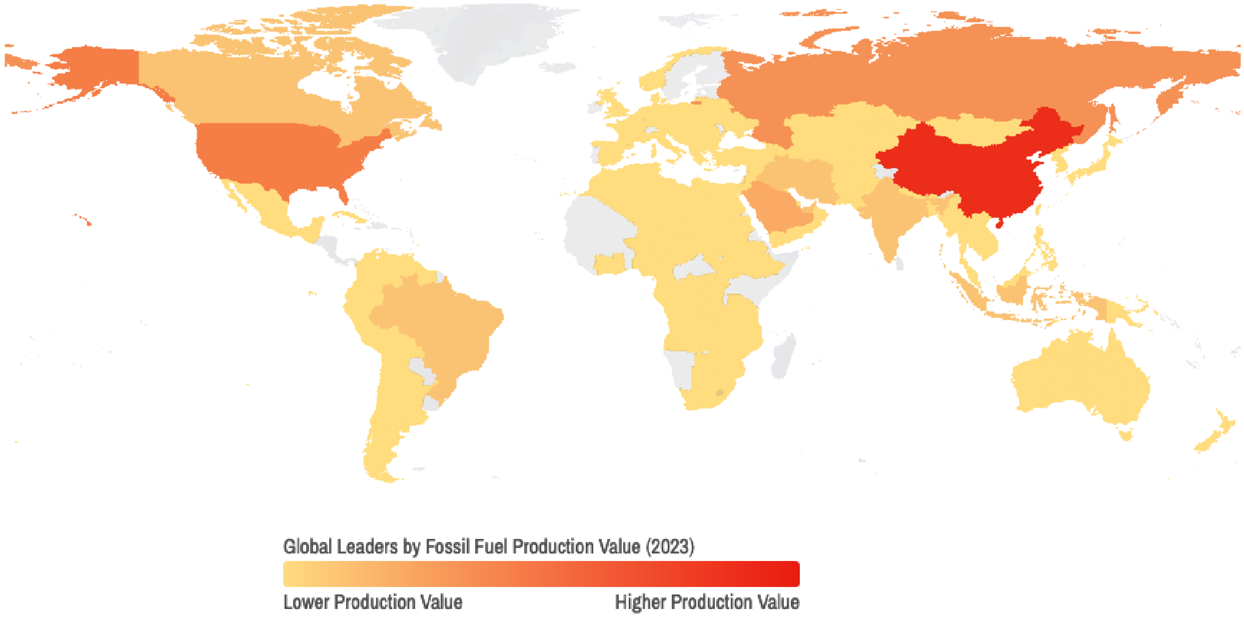
[2] The pace of demand growth will also be influenced by advancements in energy efficiency and manufacturing, which are expected to reduce the mineral intensity of demand and may shift demand toward substitutes for certain minerals. For instance, cobalt has constituted a decreasing share of battery chemistries, while lithium iron batteries and other emerging technologies are projected to reduce the proportion of battery demand currently met by lithium-ion technology.

Figure 1 (above): Mineral demand of typical power generation and transport technologies, from IEA, 2021. IEA analysis excludes steel and aluminum demand.[3]

These minerals are distributed differently across the globe than the fossil fuels responsible for powering the prior century of economic growth, creating new challenges and opportunities for both countries that produce and consume these materials. Some countries with unusually high fossil fuel production, like China, are just as well positioned to capitalize on major mineral resources.[4] Others, like the United States, hold comparatively less important positions as producers of critical materials than of fossil fuels. A third group of countries with relatively limited fossil production are endowed with minerals likely to increase in demand. These countries, which include Australia, Brazil, Chile, Guinea, and Peru, face a positive challenge: to transform the revenues generated by the one-time extraction of these transition-critical mineral deposits into durable solutions for driving long-term investment, growth, and prosperity.



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[3] Method notes from IEA: "Steel and aluminum are not included [in either figure]. The values for offshore wind and onshore wind are based on the direct-drive permanent magnet synchronous generator system (including array cables) and the doubly-fed induction generator system respectively. The values for coal and natural gas are based on ultra-supercritical plants and combined-cycle gas turbines. Actual consumption can vary by project depending on technology choice, project size and installation environment. The values for vehicles are for the entire vehicle including batteries, motors and glider. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode. The values for offshore wind and onshore wind are based on the direct-drive permanent magnet synchronous generator system (including array cables) and the doubly-fed induction generator system respectively.

[4] This is of course a simplification of regional imbalances between coal, oil, and natural gas. For example, China is abundant in coal but a structural importer of oil and natural gas. Countries in the Middle East have abundant oil and gas but lack domestic coal, while the US and Russia have abundant deposits of all three.

Figure 2 (above): Heat map of global leaders in oil, coal, and gas production in 2023.[5]

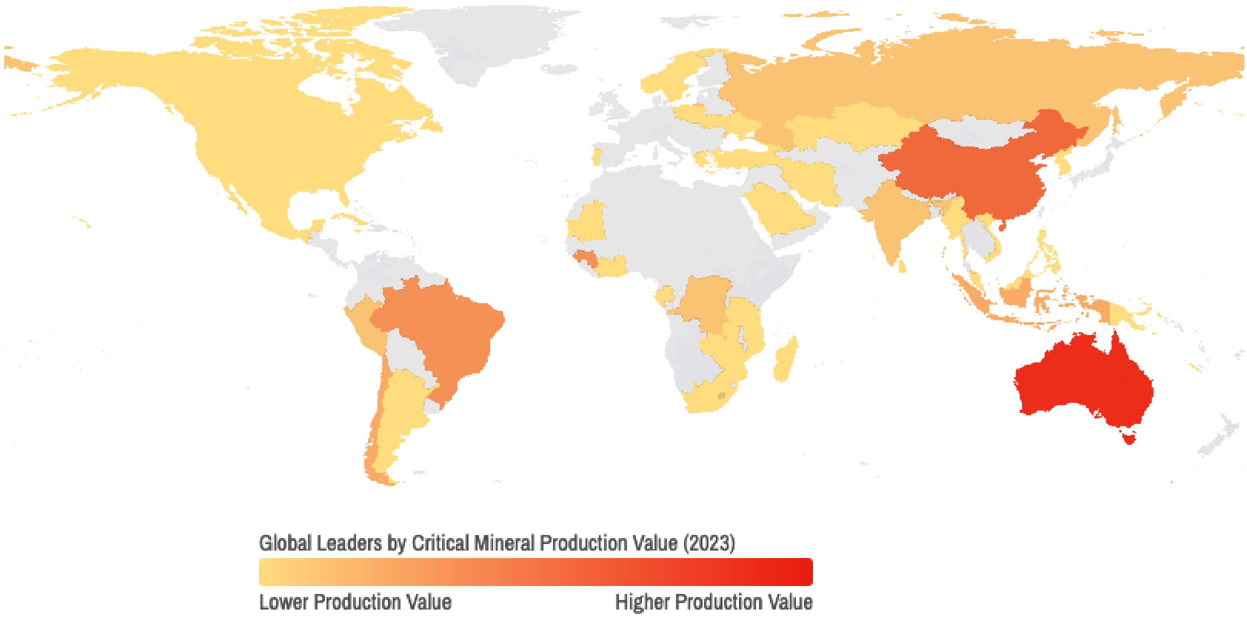

Figure 3: Heat map of global leaders in transition-critical mineral production in 2023.[6]

Unsurprisingly, critical minerals have moved to the center of global geoeconomic discussions. Yet the debate thus far is largely organized around consumer countries, which are especially concerned about supply chain resilience and security, often from an explicit national-security angle. While diverse definitions of the concept circulate, Hotchkiss et al. (2024) point to shared elements: "[c]ritical minerals typically have few substitutes, are essential to modern technology and economic development, and are susceptible to short- and long-term supply chain risks." Consumer countries tend to use these minerals as inputs to higher value-add technologies, and they seek easier access to these materials by diversifying supply chains and developing new sources in politically aligned countries, and, to a lesser extent, domestically.

Adopting a producer-country perspective centers the critical minerals discussion on the economic opportunities that the production of these materials may afford, rather than

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[5] Data sourced from the EIA using most recent annual production figures (2023 for petroleum and 2022 for coal and dry natural gas) and market prices as of October 9, 2024.

[6] Includes aluminum, cobalt, copper, natural graphite, iron, lithium, manganese, and nickel. Production data from USGS 2024 Mineral Commodity Summaries and market prices from Bloomberg on October 7th, 2024. This is the same as the "Current Value of Production" visualized and described in the Transition Critical Minerals map.

security considerations like supply chain concentration. And from this perspective, critical minerals are far from equal—either when compared to fossil fuels or to one another.

Mineral fuels, oils, and products together represented nearly four trillion in global trade value in 2022—compared to less than $300 billion in total across the eight minerals we study (about 7% of fossil fuels' value). And while 94% of fossil fuels are burned for fuel consumption, transition-critical mineral extraction is just the first step along complex supply chains for products that last decades, with potential for recycling and reuse. The World Economic Forum estimates that in 2030, lithium, nickel, and cobalt mining together will account for only 3% of the total sales value across the lithium-ion battery value chain.

Compared to one another, critical minerals can represent low economic importance at the point of extraction, as shown in Figure 4, which charts the total global trade value of select resources against their inclusion in selected lists of critical minerals:

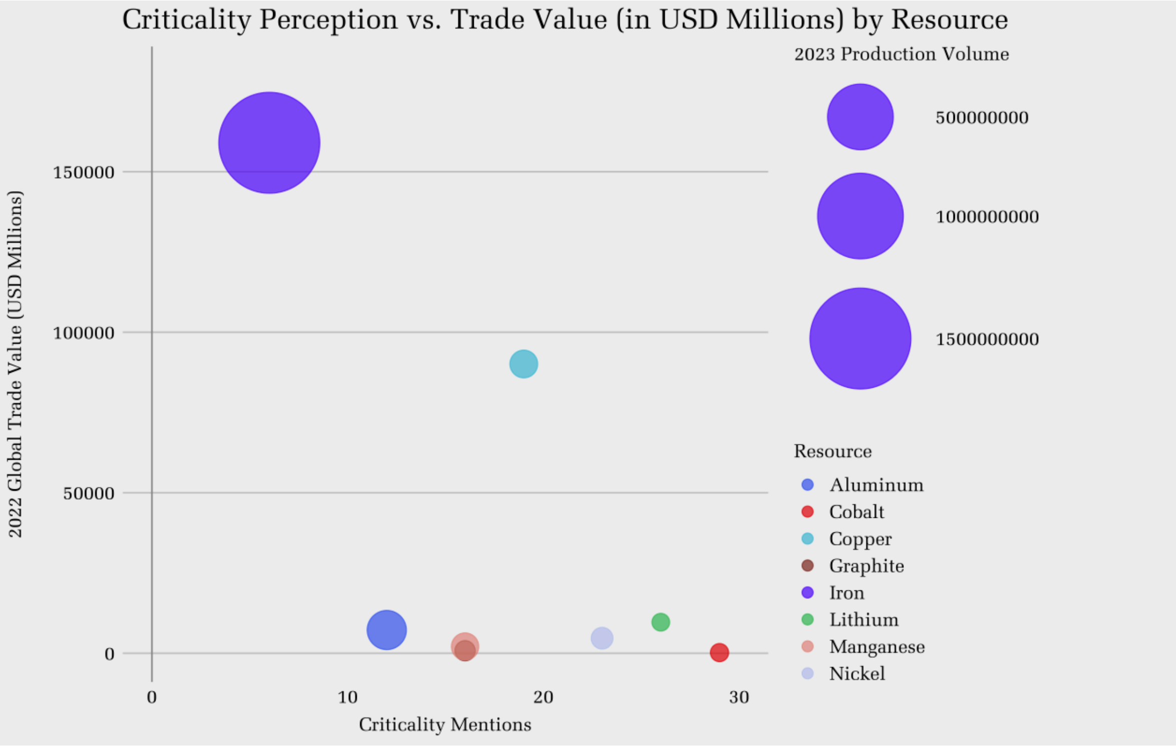

Figure 4: Count of critical mineral lists globally that include a mineral vs. the 2022 trade value of the mineral (the most recent available). Bubbles sized by 2023 production volumes. Sources: Ernst & Young, 2023, OEC, 2024, and USGS 2024 Mineral Commodity Summaries.

Of the eight materials considered in Figure 4, iron is the least often included in lists of criticality, but it is also the resource with the highest trade value and the highest production volume. In contrast, cobalt is the most frequently included in such lists but its trade value in 2022 was *only 0.13%* of iron's. Production volume and trade value are critical considerations for producer countries, because they represent local economic activity and determine the pool of value available for capture, structuring, and investment by the state.[7]

This is precisely the framework we adopt in our analysis. We approach the economic benefits of mining through the lens not of consumers but of host countries in order to identify opportunities that support their sustainable development. We believe that such an approach holds the greatest promise for the alignment of incentives between producer and consumer countries, laying the strongest foundation for durable economic partnerships.

Our exploration therefore focuses on a set of eight minerals that are critical to the energy transition and that have comparatively large market sizes. These materials present comparatively significant potential for host country value capture and thus could provide resources for national development, social investment, and public spending. We focus on the materials with the largest market sizes from among the Department of Energy's electric eighteen, i.e., aluminum, cobalt, copper, lithium, natural graphite, nickel, and iron.[8] We choose to also include manganese but exclude silicon (given its abundance) and rare earth elements with small market sizes.[9] Additionally, we utilize the Transition Metals Data Hub from Bloomberg New Energy Finance (BNEF) to obtain supply growth factors out through 2030, which are based on BNEF's mine-level analysis.[10] These eight minerals have a variety of important energy transition applications:

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[7] In practice, gross value add (GVA) will vary across metals, and factors such as specialized capital equipment and skilled labor requirements will influence contribution to the national economy. We hope to explore these factors more critically in a following work.

[8] Listed as electrical steel by DOE; 98% of iron is used for steel production and electrical steel is up to 97% iron by weight.

[9] We include manganese due to its use in EV batteries and electrical steel, its listing by the USGS as critical, and its potential strategic importance to Brazil, where we are heavily engaged. Silica deposits used for solar PV cells are relatively abundant. The ultra-high purity silicon required for semiconductors in AI and defense applications involves much more rigorous refining processes than the silicon used for solar PV cells. Further, silicon is not a USGS critical raw material, and is considered critical to DOE due to Chinese dominance of supply chains, not material scarcity.

[10] The mine supply growth forecast is more conservative than the demand growth scenarios (discussed in the technical appendix). Importantly, supply will serve *all demand* (not just transition-related demand), which is important grounding for a producer-country perspective.

Table 1: Energy transition uses of studied minerals

Minerals	**Energy Transition Uses**
Aluminum	Electricity grid, EV frames, Solar PV, Wind
Cobalt	EV/Grid batteries, Bioenergy, Electrolyzers
Copper	Electricity grid, EV/Grid batteries, Solar PV, Bioenergy, CSP, Electrolyzers, Geothermal, Hydro
Natural Graphite[11]	EV/Grid batteries
Iron	Electricity grid, EV batteries (LFP), EV components, Geothermal, Hydro, Wind
Lithium	EV/Grid batteries
Manganese	EV/Grid batteries, CSP, Electrolyzers, Geothermal, Hydro, Wind
Nickel	EV/Grid batteries, Electrolyzers, Bioenergy, CSP, Geothermal, Hydro, Solar PV

CSP = Concentrated solar power
EV = Electric vehicles
PV = Photovoltaic

From Geopolitics of the energy transition: Critical materials (IRENA, 2023) and others.

Accordingly, transition technologies will constitute an increasing share of total mineral demand in the race to decarbonization, as represented for selected minerals in the IEA’s Net Zero Emissions by 2050 scenario:

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[11] Natural graphite deposits vary in quality; only high quality “flake” and “crystalline vein graphite” are used in lithium-ion batteries (along with synthetic graphite production). USGS does not distinguish the type of graphite in production and reserves in the mineral commodity summaries; lacking more granule data at this stage, we include all graphite production and reserves but recognize this limitation.

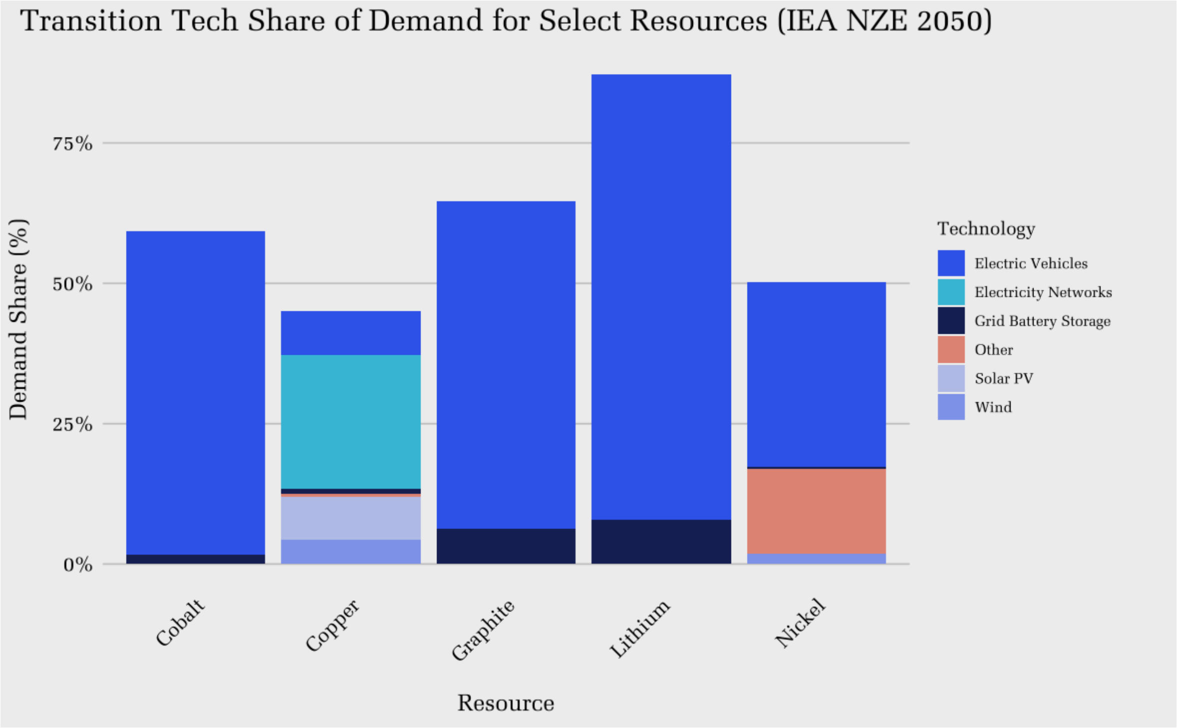
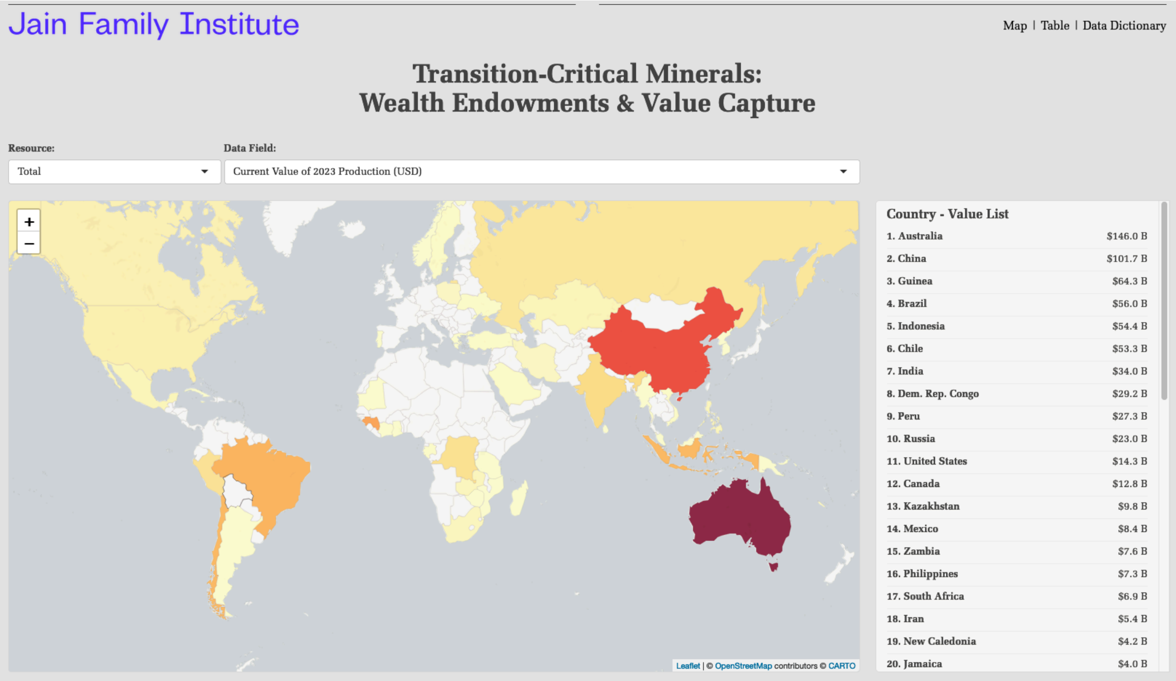


Figure 5: Transition technologies share of demand for selected minerals in IEA's Net Zero Emissions by 2050 scenario. "Other" includes hydrogen technologies and "other low emission power technologies."

To help frame the opportunities available for value creation, capture, and investment around these eight key materials, we have created an interactive online map, which readers are invited to explore:



Transition-Critical Minerals:
Wealth Endowments & Value Capture

Resource: Total

Data Field: Current Value of 2023 Production (USD)

Country - Value List

1. Australia	$146.0 B
2. China	$101.7 B
3. Guinea	$64.3 B
4. Brazil	$56.0 B
5. Indonesia	$54.4 B
6. Chile	$53.3 B
7. India	$34.0 B
8. Dem. Rep. Congo	$29.2 B
9. Peru	$27.3 B
10. Russia	$23.0 B
11. United States	$14.3 B
12. Canada	$12.8 B
13. Kazakhstan	$9.8 B
14. Mexico	$8.4 B
15. Zambia	$7.6 B
16. Philippines	$7.3 B
17. South Africa	$6.9 B
18. Iran	$5.4 B
19. New Caledonia	$4.2 B
20. Jamaica	$4.0 B

Figure 6: A static image of the Estimated Value of 2023 Production layer from our interactive Transition-Critical Metals map, available online at https://jfiresearch.shinyapps.io/transition-critical-minerals/

The map features six layers, each of which is available for the eight materials individually as well as their sum total, obtained by selecting "Total" in the resources menu at the top left. These six layers are explained in depth in our Technical Appendix. The first three of these layers hew closely to extant high-quality data sets from the U.S. Geological Survey (USGS), Bloomberg, and Bloomberg New Energy Finance (BNEF):

- *Current Value of 2023 Production* combines production quantities from USGS and current market values of commodities as obtained from Bloomberg on October 7, 2024. This layer is depicted in Figure 5 above.

- *Current Value of Reserves* combines recent market values of commodities from Bloomberg and reserve quantities from USGS.

- *Annual Reserve Utilization 2023* is first calculated for each country-metal pair. Each country's "Total" is obtained as an average across the metals it produces.

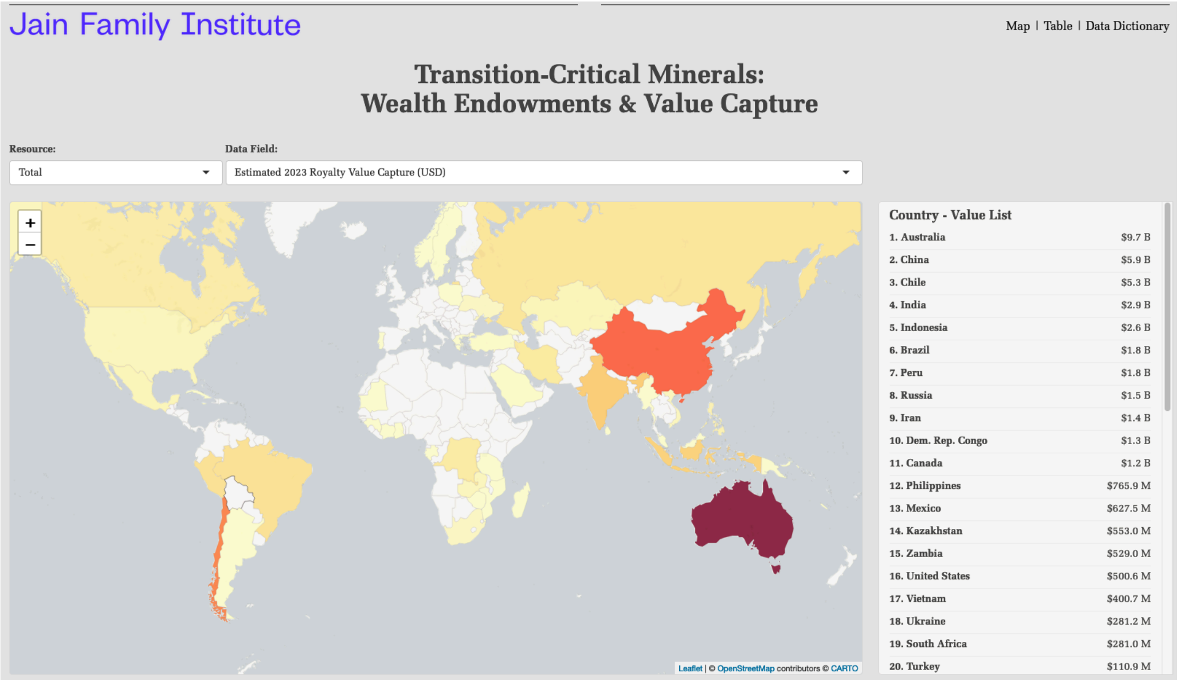
The last three layers make assumptions, some quite crude but all fully transparent, to provide a set of heuristics that can help readers take stock of the global opportunity set around the eight materials, and to explore national cases of particular interest:

- *Estimated 2030 Production Value* scales current production by BNEF's supply growth factor and multiplies it by the forecasted 2030 market price. This makes the unrealistic assumption that country-level production for a resource grows at the same rate everywhere; this figure is a thinking aid for global comparison, not a forecast.

- *Estimated 2023 Royalty Value Capture* offers a simplified estimate of direct value capture from royalties utilizing the royalty rate (midpoint if applicable), current market prices, and USGS reported production. Royalties are only one element of total value capture. We have not included taxation, even in stylized form as we did for royalties, due to its complexity.

- *Estimated 2030 Royalty Value Capture* provides a simplified projection of direct value capture from royalties, utilizing the royalty rate (midpoint if applicable), current market prices, and the BNEF supply growth factor uniformly applied to USGS reported production.

As the map makes clear, resource extraction for the energy transition has already opened the door to significant and growing value creation, and a share of this value stands to be captured and invested by producer countries, especially through royalty rates. Yet the relative size of this share depends on royalty and taxation schemes and is therefore a policy choice, illustrated in Figure 7 below.



Transition-Critical Minerals:
Wealth Endowments & Value Capture

Resource: Total

Data Field: Estimated 2023 Royalty Value Capture (USD)

Country - Value List

1. Australia	$9.7 B
2. China	$5.9 B
3. Chile	$5.3 B
4. India	$2.9 B
5. Indonesia	$2.6 B
6. Brazil	$1.8 B
7. Peru	$1.8 B
8. Russia	$1.5 B
9. Iran	$1.4 B
10. Dem. Rep. Congo	$1.3 B
11. Canada	$1.2 B
12. Philippines	$765.9 M
13. Mexico	$627.5 M
14. Kazakhstan	$553.0 M
15. Zambia	$529.0 M
16. United States	$500.6 M
17. Vietnam	$400.7 M
18. Ukraine	$281.2 M
19. South Africa	$281.0 M
20. Turkey	$110.9 M

Figure 7: A static image of the Estimated 2023 Royalty Value Capture layer from our interactive Transition-Critical Metals map.

The contrast between the relative position of many countries in *Estimated 2023 Royalty Value Capture* as depicted in Figure 7 above and the *Current Value of Production* as depicted in Figure 6 underscores the importance of royalty design. For example, even though Ghana only produces manganese across the studied minerals, a comparatively large royalty rate of 5% moves the country from 31st place in production up to 28th place in estimated value capture.[12] Much more strikingly, Guinea holds the third spot in terms of the relative value of its current USGS-identified production (due to its bauxite production), but stands in 25th place for 2023 royalty value capture. Guinea has the lowest royalty rate (0.075%) across all countries and commodities we study, though it does employ other tools for public value capture and investment, including significant state ownership of mining operations. Indeed, Australia is not just the only country to figure in the top five of both lists, but it stands at the very top of both and maintains these positions through to 2030.

Even when the state captures value on behalf of the public, building wealth from the mining of critical minerals is challenging, and in ways far beyond the more familiar case of fossil fuels. This is true not least because, as explored below, less value is represented by critical minerals at the point of extraction than is the case for oil production. To build truly transformative wealth from mining, revenues must be organized and invested into activities

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[12] There is also hard rock lithium mine under development in Ghana but it was not in production in 2023. Ghana is of course a leading gold producer; we do not include gold in this analysis.

that move producer countries up the value chain. In the following section, we discuss tools and structures that have been and are presently being developed to help producer countries manage and invest the proceeds of these time-limited opportunities.

Opportunities for value capture and investment

Resource curse or resource blessing?

The energy transition presents an enormous opportunity to rethink the current patterns of engagement between the Global North and South. Critical minerals are strategically important inputs for a wide range of high-value transition technologies and the sheer scale of the transition will continue to generate demand for decades to come. In a global context, where complex supply chains and partnerships are involved in the manufacture of these technologies, it has become crucial to ensure the resilience of these supply chains for sustained transition investment and deployment. As such, the Global North will need to strengthen partnerships with resource-rich countries in the Global South, offering robust incentives that align interests across the board in a constructive, equitable, and durable framework. The existing paradigm has at times exacerbated existing inequalities, contributing to social conflict, instability, deindustrialization, and the persistence of exploitative labor practices in host countries. Indeed, the relationship between a country's natural resource wealth and its state of development has been studied intensively since the time of classical economists.[13] The valences associated with the names given to this relationship over the years attest to its complicated nature: initially called "Dutch disease" (Cordon & Neary, 1982), subsequently "natural resource curse" (Auty, 1993), and even "natural resource blessing" (Lederman & Maloney, 2007).

The initial "Dutch disease" hypothesis proposed a mechanism in which new income generated by natural resource windfalls leads to relative price movements that reallocate non-resource sector investments toward resource sectors, causing a process of deindustrialization. Other theories have pointed to volatility and ensuing planning challenges, as well as institutional factors like political capture, rent-seeking, and corruption. In recent years, some commentators have begun to challenge the earlier negative consensus, suggesting that selective timeframes and omitted variables may limit the validity and applicability of earlier studies. As Badeeb et. al (2017) conclude in their survey, "It is fair to say that as a general conclusion, there is currently no consensus regarding the existence of a natural resource curse. If the curse is a relevant concern, the disparate literature certainly indicates that its ubiquity should not be exaggerated."

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[13] It's worth noting the distinction Adam Smith draws between "ruinous" prospecting for gold and silver and the implied more economical search for iron, copper, tin, and lead, a critique that took place in a specific historical context.

Table 2: Overview of natural resource curse literature

Study	**Finding**
Cordon & Neary, 1982	Natural resource wealth booms can distort relative prices and lead to de-industrialization and lower long-term growth
Auty, 1993	Natural resource wealth can distort internal capital allocation and lead to lower long term economic growth
Sachs & Warner, 1995	Countries with high natural resource “dependence” as defined by exports to GDP experienced lower rates of growth 1971–89
Gylfason, 2001	Natural resource wealth “crowds out” human capital investments, negatively affecting economic growth
Lederman & Maloney, 2007	Natural resources, when managed with good policy, can be a significant boon to development and growth
Brunnschweiler & Bulte, 2008	Natural resource “dependence” does *not* affect economic growth, while *abundance* enhances growth and institutions
Farhadi, 2015	Positive contribution of natural resource rents to economic growth mediated by institutional quality factors
Sharma & Paramati, 2022	Natural capital positively contributes to economic growth when controlling for institutional factors
Wang & Zhang, 2024	Natural resource rent volatility is related to economic growth, with positive/negative effects depending on a country’s development level

The literature makes it clear there is an acute need for robust institutional capacity in resource-rich countries that can transform temporary natural-resource windfalls into sustained multi-generational investment, economic diversification, development, and national wealth. This requires the implementation of well-designed structures for primary value capture, wealth management, and strategic investment capable of moving a producer country up the value chain.

Primary value capture

The potential for value capture begins at the point of extraction, where raw earth is mined and processed into transportable ores or refined into mineral commodities. Ultimately, retaining value from mining activity begins with the effective design of primary value capture mechanisms, i.e. how the State chooses to “take their share” of mineral extraction in their country, before any trade or industrial policies. Countries vary along their geological endowments, level of economic development, and institutional capacity—and thereby their use and preference for the tools available.

Table 3: Mining primary value capture mechanisms

Mechanism	Overview	Benefits	Critiques
Royalties	A percentage of revenue or unit-based charge paid to the state for extracting natural resources (usually 2–6% if applied).	Provides early and stable revenue for the government; easier to administer.	Can discourage investment if rates are high, can lead to inefficiencies in resource use, and distort production decisions.
Corporate Income Tax (CIT)	Tax levied on the profits of mining companies, usually at varying rates between 20% and 40%.	Fairly based on ability to pay; redistributes risk between government and companies.	Vulnerable to tax avoidance, profit shifting, and project timing; difficult to administer in developing countries.
State Ownership	Government retains 50% ownership or more in mining operations, typically via state-owned enterprises (SOEs).	Direct participation allows the state to retain profits, negotiate better contracts, and reinvest revenues.	Risk of mismanagement and inefficiency; revenues can be delayed and unpredictable.

Equity Stakes	The state holds shares in private mining companies, entitling it to dividends or a share of profits.	Enables the state to benefit from the profitability of the company without full operational control.	Dividends are dependent on profitability, which can be unpredictable or delayed.
Production Sharing Agreements	The state receives a portion of production instead of cash payments.	Provides a direct share of production, which can be sold for state revenue or utilized domestically.	Complicated to manage in terms of valuation and sales of the state's share of production.
Other Taxes	Includes taxes like VAT, import/export duties, land use fees, and withholding taxes.	Can provide diverse revenue streams and may encourage local procurement or employment.	Can complicate the tax environment, leading to inefficiencies or discouraging foreign investment. Also vulnerable to avoidance/profit shifting.
Local Labor/Sourcing Requirements	Mandates the use of local labor and materials in mining projects.	Promotes economic development and job creation within the host country.	Can increase operational costs for companies, particularly if local capacity is lacking.
Infrastructure Development Obligations / Community Investment Agreements	Companies are required to invest in public infrastructure (roads, schools, hospitals, etc.) as part of their license to operate.	Provides direct social and economic benefits to local communities, improves infrastructure, and boosts development.	Can lead to increased project costs for companies, implementation may be delayed, and communities may become overly dependent on company-funded services.

Informed by (IISD, 2020), (IMF, 2021), and (World Bank, 2006)

Each mechanism has multiple layers of complexity that determine effectiveness in practice. Proper utilization and design of these strategies depend on policy objectives, interaction with trade and industrial policy, and more. No one strategy alone determines the complete value capture picture; a low royalty rate does not guarantee a low effective tax rate, for instance.

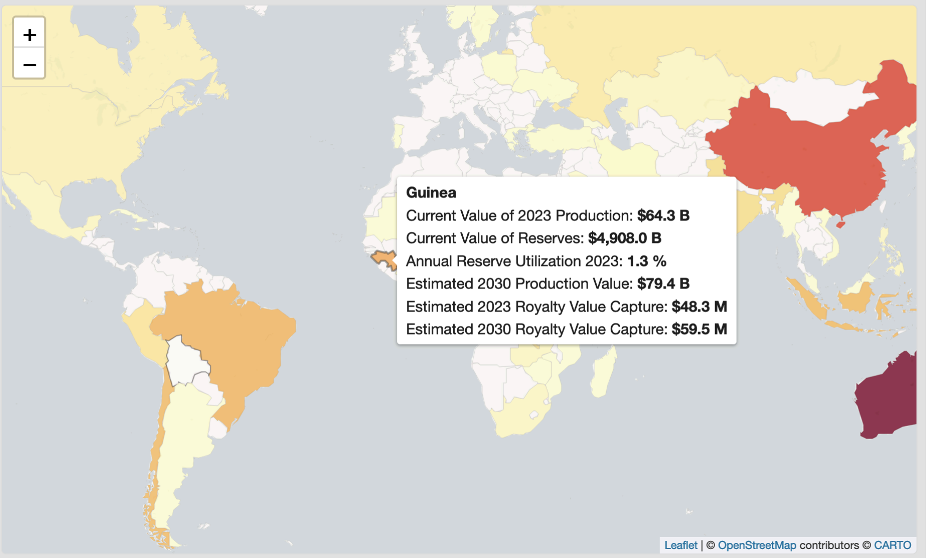
Royalties, for example, are generally classified as either unit-based or ad valorem (value-based). A unit-based royalty applies a fixed charge per unit of volume or weight and thus provides revenue certainty but fails to account for variations in the quality of mineral deposits, both across sites and over time. An ad valorem-based royalty, on the other hand, is (conventionally) calculated as a percentage of the mineral's market value at the point of sale, automatically adjusting to fluctuations in commodity prices and deposit quality. However, ad valorem royalty revenue can be vulnerable to price volatility, and in the absence of clear market exchanges, valuations can be subject to manipulation.

Both unit-based and conventional ad valorem royalties are considered *in rem taxes* (gross revenue based), while other royalty designs and taxes are considered *in personam taxes* (net revenue based). In a profit-based royalty, payment is determined based on the profits generated by the mining operation, rather than on the volume or value of the minerals extracted. The royalty is calculated after deducting operating expenses, capital costs, and sometimes other allowable costs, such as transportation and refining. Profit-based royalties are more difficult to administer and are of course vulnerable to reported expenses.

Box 1: Guinea's Royalty Rate for Bauxite

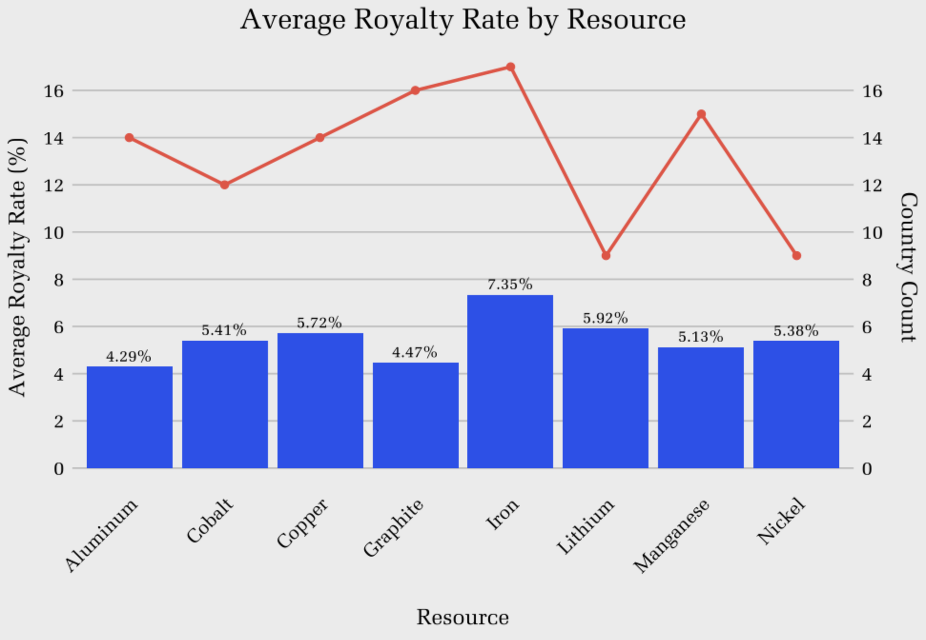
Royalty rate design has key implications for host countries, especially because it is one of the earliest and most direct forms of value capture from mining activity.

For example, Guinea is a global leader in bauxite production and is ranked third in the current value of 2023 production. However, with a royalty rate of only 0.075%, the Estimated Royalty Value Capture of $48.3 million is ranked 25th.



Guinea
Current Value of 2023 Production: **$64.3 B**
Current Value of Reserves: **$4,908.0 B**
Annual Reserve Utilization 2023: **1.3 %**
Estimated 2030 Production Value: **$79.4 B**
Estimated 2023 Royalty Value Capture: **$48.3 M**
Estimated 2030 Royalty Value Capture: **$59.5 M**

In fact, Guinea has the lowest royalty rate across *all countries and commodities* included in our analysis:



There are of course other mechanisms through which Guinea maintains value from mining, such as state ownership. Compagnie des Bauxites de Guinee (CBG), a joint venture between Alcoa, Rio Tinto, Dadco Investments, and the Government of Guinea, which has 49% ownership, maintains a significant share of production. Guinea has also been making strides to increase royalty revenue by implementing a reference price to counter underpricing and is also working with the Extractive Industries Transparency Initiative, the Natural Resource Governance Institute, and civil society to address corruption.

In practice, royalty rate design can vary across a range of characteristics with key implications for value capture. For example, Brazil takes its royalty on *net revenue*, i.e. the mineral sales revenue less taxes levied on revenue, insurance, and freight costs. Chile utilizes a blended ad-valorem component and an operating margin component specific to company size, according to their level of sales and the minerals exploited. In *Mining royalties: a global study of their impact on investors, government, and civil society*, Otto et al. (World Bank, 2006) built a representative nickel mine project and solved for the royalty rate that would generate $20 million in revenue across a range of designs, demonstrating both the complexities and implications for value capture:

Table 4: Rate applied to nine royalty bases that yield $20 million in royalty

Royalty Tax Basis	Rate (% unless noted otherwise)
Unit-based royalty	$0.19303 per pound nickel
Ad valorem—NSR times percentage	3.40
Ad valorem—metal contained in ore at mine mouth, valued at international reference price times percentage	2.75
Ad valorem—metal contained in concentrate at the mill, valued at international reference price times percentage	3.24
Ad valorem—metal contained in smelter product, valued at international reference price, times percentage	3.34
Ad valorem—gross sales, less transportation, handling, and freight, times percentage	3.45
Profit based—percentage of gross sales, less operating costs, transportation, handling, and freight	3.94
Profit based—percentage of gross sales, less capitalized costs, operating costs, transportation, handling, and freight	4.91
Ad valorem—sliding-scale percentages of NSR	1.17 / 2.67 / 4.17

World Bank, 2006; (NSR = Net Smelter Return)

While our stylized analysis of royalty rates is useful for high-level comparison, it presents a simplistic view of the complexities that inform the entire value capture picture.

Beginning in 2025, our *Country Profiles* reports will dig deeper into each mechanism within specific national contexts, as well as the current production and refining landscape down to the asset level. The reports will also delve into relevant policy and regulation, trade relationships, and socioenvironmental controversies.

Meanwhile, JFI will be building and deploying tools for policymakers to model and plan primary value capture scenarios within complex global market dynamics—beginning with a royalties calculator, which will forecast the range of royalty revenues at the national and subnational level, incorporating uncertainty in both future production and price.

Box 2: Ad valorem royalty rate examples

Royalty rate designs differ significantly across producer countries, with key implications for final capture (see Table 5 above). For example, Zambia, Chile, and Ghana—all included in our analysis—utilize Ad Valorem rates, but differ in how the royalty value is determined:

- **Ghana** applies a comparatively simple royalty rate between 3% and 5% depending only on the gross sales value of mineral production. The rate remains fixed regardless of market fluctuations, favoring straightforward administration and steady revenue. Ghana also maintains a 10% carried interest in large-scale mining operations (i.e. 10% of profits after all expenses, which can come out to very little).

- **Zambia** varies its royalty rate between 5.5% and 10% on the gross sales value of minerals, with the rate increasing as market prices rise. This design is well-suited for volatile copper markets, which Zambia is dependent on, and to balance the need to attract foreign investment. Lowering the rate during market downturns eases pressure on stressed operations. Also, the Zambian government already maintains minority stakes in several foreign mining companies, and recently announced a plan to establish production sharing of at least 30% of critical mineral output. It appears that this will only apply to future mines; mines currently in operation will be exempt.

- **Chile**, the world's largest copper producer, also utilizes a varying royalty rate but adjusts the rate depending on the taxed companies' *operating profits* (total income minus operating expenses) instead of gross revenues. The rate varies between 5% and 14% and is designed to capture windfall profits from companies (in a more targeted approach than Zambia's), while still lessening pressure during market stress. The royalty design is paired with significant state-owned operations under Codelco, which is the world's largest copper producer (though may soon be overtaken by BHP).

Thus, the specifics of royalty design are crucial, but it is the interaction of the entire portfolio of mechanisms, as outlined in Table 4, that ultimately shapes a country's complete value capture landscape.

Managing and investing volatile commodity revenues

Countries that depend on volatile natural resource revenues face inherent uncertainty in their planning and investment decisions. Studies have quantified the effects of this uncertainty across a range of commodities and have found statistically significant negative relationships. Thankfully, this uncertainty can be mitigated through a variety of innovative mechanisms that have proliferated in the past few decades. Foreign exchange stabilization facilities, commodity hedges, sovereign wealth funds, and countercyclical fiscal rules are a few examples of the tools resource-rich countries use to stabilize their planning and investment environment.

Table 5: Examples of countercyclical tools used by resource-rich countries

Tool	Description	Examples
Foreign exchange stabilization facilities	Funds or mechanisms that attempt to reduce large swings in a currency's foreign exchange rate, thereby stabilizing government budgets, incomes, and prices, which reduces risk and the cost of capital, enhancing long-term planning and investment	Brazil's FX hedging program launched in collaboration with the IDB
Commodity hedges	Funds or mechanisms that reduce the impact of commodity price volatility on revenue, which stabilizes government revenues and enhances fiscal planning processes	Mexico's petroleum hedging program

Sovereign wealth funds	Vehicles that invest natural resource revenues across a variety of asset classes for the long term, with mandates ranging from fiscal stabilization to national development	UAE's Abu Dhabi Investment Authority
Fiscal rules	Rules adopted by governments that set limits on public deficits, debt, expenditure, and savings that attempt to reduce the procyclical impact of natural resource revenues on their budget	Chile's fiscal surplus rule

Sovereign wealth funds in particular are dynamic vehicles with large pools of capital that can play this strategic role in the energy transition. There has been a growing awareness of the potential for SWFs with a focus on development, or "sovereign development funds," to play in this transformation. A strong commitment to good governance and transparency, like those enumerated in the Santiago Principles, enhances the ability of these entities to allocate their capital in the most efficient, impactful way in their economies. While other policies, like exchange rate and countercyclical fiscal management, have played a role in managing natural resource revenues, sovereign wealth funds represent active investment agents that can steward and restructure their economies during the transition.

Table 6: Examples of national sovereign wealth funds

Sovereign Wealth Fund	Country	Funding Source	AUM
Government Pension Fund	Norway	Oil & gas	$1.715 trillion
Abu Dhabi Investment Authority	UAE	Oil & gas	$993 billion
Public Investment Fund	Saudi Arabia	Oil & gas	$940 billion

Economic and Social Stabilization Fund	Chile	Copper	$4.7 billion
Pula Fund	Botswana	Diamonds	$4.1 billion
Revenue Equalization Reserve Fund	Kiribati	Phosphate	$930 million

It thus is imperative to identify tools, policies, and frameworks that both appropriately account for complicated historical contexts that are sensitive to the extractive legacies left by colonialism and enhance capacity to manage critical mineral wealth for the long term in line with national development objectives. Just as importantly, they must also create space for fostering productive discussions and arrangements that coordinate global resources needed for the transition, ensuring an equitable distribution of mining's economic benefits between host countries and foreign miners. The form that these distributive arrangements take will serve as important blueprints for signaling the good faith dealmaking and rapport that will be necessary for organizing a planetary energy transformation.

As part of this commitment to fostering constructive and equitable dialogue, the Jain Family Institute has pioneered new tools that empower public stewards to enhance their planning and investment decisions. Most notably, JFI, in close collaboration with subnational natural resource SWF managers, has created FeMCI, an investment management platform that is used by public investors across Brazil to construct portfolios and manage risks in the ways most closely aligned with their fiduciary obligations. JFI is also working on a new set of solutions that allow public officials to gain more certainty on anticipated natural resource revenues from petroleum and mineral extraction , enabling them to plan with greater foresight and enter negotiations with private operators on stronger footing.

Moving up the value chain

The energy transition will change not only the map of producer countries, but also the map of value creation across the supply chain; no mineral producer country will be able to replicate the wealth of fossil fuel producer countries like Norway, the U.A.E., and Saudi Arabia that have enriched themselves by managing and investing revenues from oil production, based on extraction and processing alone:

Table 7: Fossil fuels vs. transition minerals value capture landscape

Fossil Fuels	**Transition Metals**
Mineral fuels, oils, and products generated a global trade value of $3.88 trillion in 2022	The combined trade value in 2022 of all the metals we study (including iron) was only ~$274 billion, about 7% of fossil fuels' value
Short supply chains. Fuels are generally extracted, refined, and then consumed; 94% of fossil fuels are burned for energy consumption	Complex supply chains that accumulate value. Minerals are refined, processed, and along multiple steps, manufactured into products that last 10-30 years
No recycling potential	High potential for recycling and secondary use, especially in industries like electronics, EV batteries, and renewable energy components

Informed by (IRENA, 2023), and (OEC, 2024)

Iron and copper, which have broad infrastructure applications, currently represent 90% of the total trade value across the metals we investigate. Iron ore continues to generate the bulk of free cash flow for mining majors like BHP and Rio Tinto. Iron is a larger market with a broader demand base in infrastructure and manufacturing and is less sensitive than copper to fluctuations in sectors like electronics and renewable energy. Lithium trade value would grow to slightly over 10% of total trade value following BNEF's supply growth projection of nearly fivefold between 2022 and 2030:

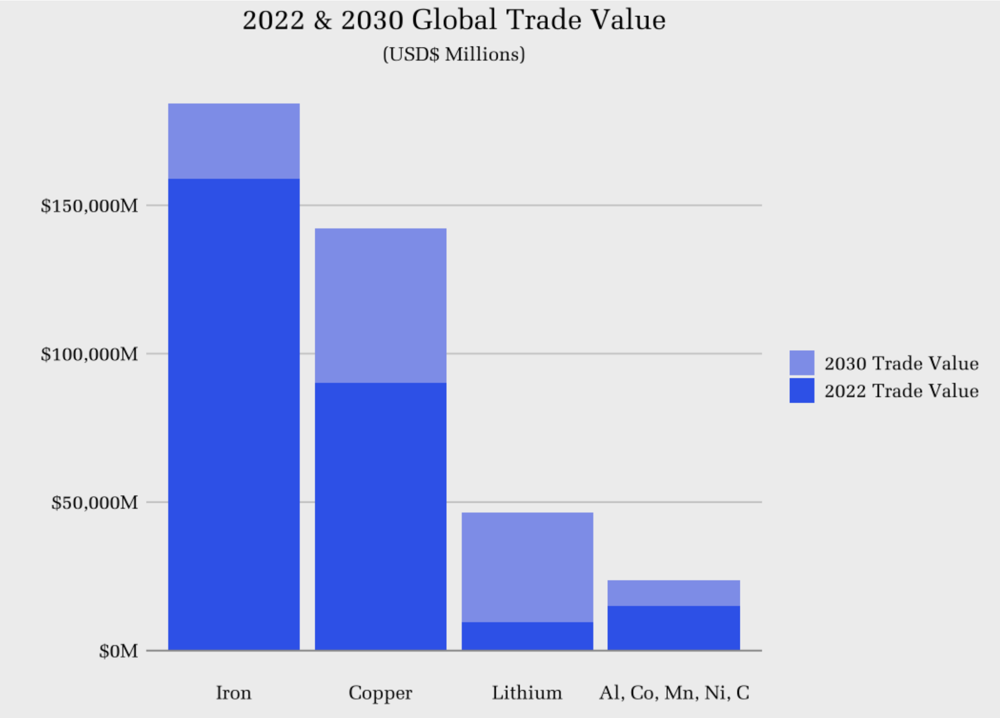


Figure 8: 2022 and 2030 Trade Value of Iron, Copper, Lithium, and the rest combined: Aluminum, Cobalt, Manganese, Nickel, and Graphite (Carbon). Sources: (OEC, 2024) and Bloomberg New Energy Finance.

On one hand, this implies that infrastructure metal extraction provides more “direct” value capture potential to producer countries. On the other, these markets are large and mature while critical mineral markets are comparatively nascent and structurally important in emerging high value-add industries. The structurally important role of critical minerals in emerging high-value add transition technologies creates space for producer countries to potentially negotiate the onshoring of higher value-add steps of supply chains onshore. Mineral products accumulate value as they “move up” the value chain, and countries seeking to retain long-term value from mining production in the country must progress past extraction and processing. According to estimates by the World Economic Forum and McKinsey, lithium, nickel, and cobalt mining together would represent only 3% of the total estimated sales value along the lithium-ion battery supply chain in 2030. Adding refining capacity increases the share to 30%—a significant jump, but noticeably short $220 billion of the total “revenue potential.”

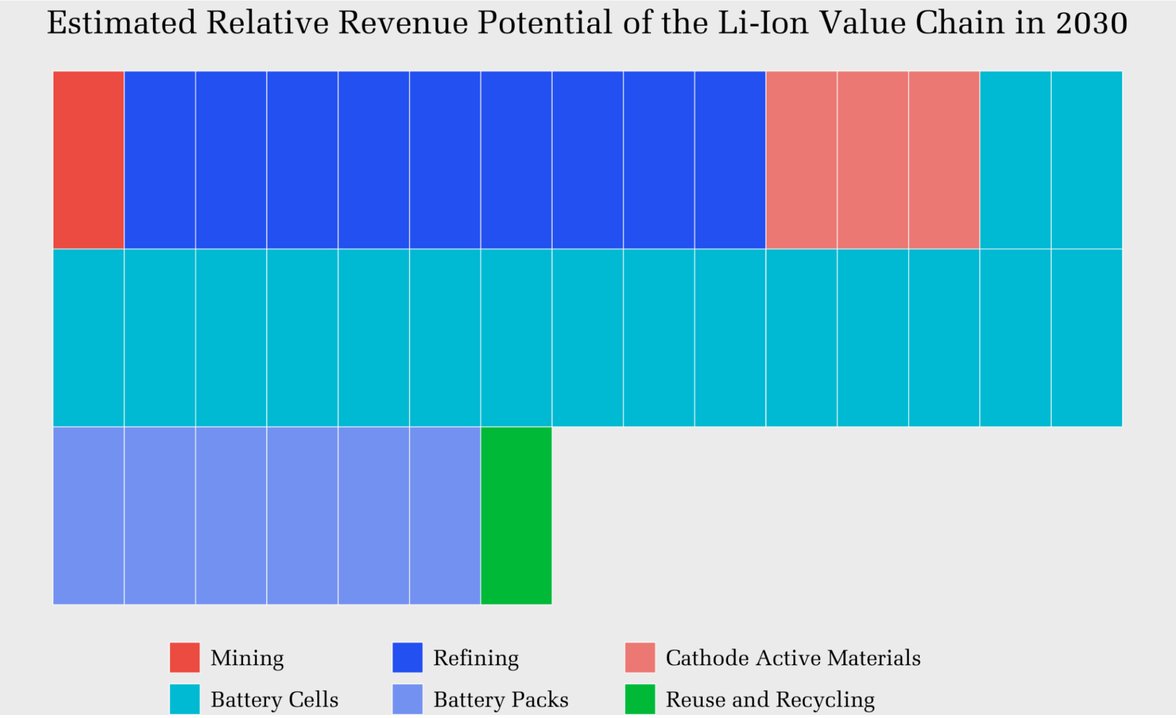


Figure 9: Estimated relative gross sales value ("revenue potential") of the lithium ion battery value chain in 2030, according to the [WEF and McKinsey.](#) "Calculated based on demand from mobility, energy storage and consumer electronics applications as well as battery pack prices for 2030 (not including lead-acid batteries)." Graphite, manganese, copper, and other minerals essential to manufacturing are of course missing. The estimated sales values are (in USD billions), 8, 74, 25, 137, 47, and 11, respectively.

The complex challenges of successfully moving up the value chain, however, cannot be overstated. Refining ores to purity standards requires costly, energy-intensive technology and stringent environmental controls. Processing these minerals into high-performance materials and manufacturing finished products demands specialized inputs, advanced techniques, and skilled labor. At each step along the value chain, increasingly diverse inputs are required and the need for robust supply networks grows. Additionally, many of the producer countries we highlight face interrelated challenges of large public debt burdens, high costs of capital, and currency volatility. [The Climate Vulnerable Forum](#) brings together many of these commodity export-reliant countries to address these barriers and enable members to unlock investments in climate adaptation and mitigation aligned with their national development objectives. Following our recent Memorandum of Understanding, the Jain Family Institute will partner with the forum to conduct research across a range of key workstreams.

In the global context, technical and institutional barriers intersect with complex geopolitical and market dynamics. China dominates both the supply and demand side across mineral markets and producer countries must navigate increasing trade restrictions. This influence is not always immediately visible; for example, Chinese companies have dominant shares in 90% of Indonesia's nickel processing facilities, according to the *East Asia Forum*. While Chinese investment was essential to scale refining capacity, Indonesia is now trying to pull back its influence to court Western trade partners; Inflation Reduction Act subsidies exclude firms with more than 25 percent Chinese ownership.

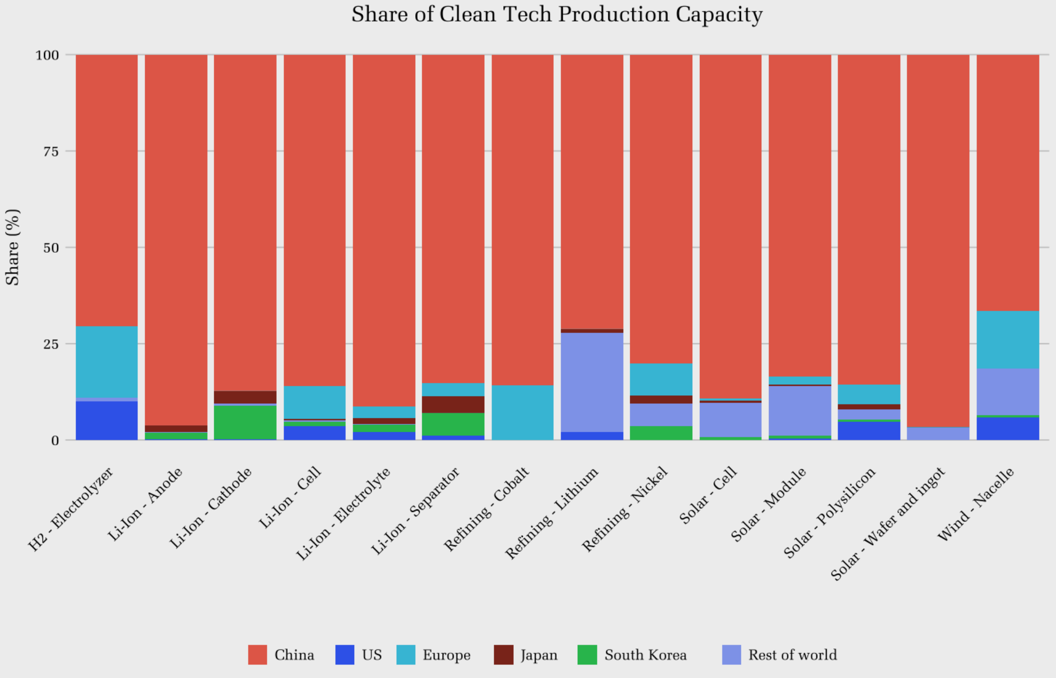


Figure 10: China dominates clean energy value chains, from refining to end-product. Share of global production capacity by product from Bloomberg New Energy Finance, 2024. Refining capacity specifically covers cobalt sulfate and nickel sulfate capacity.

Chinese processors and manufacturers benefit from economies of scale, an integrated supply network, and substantial state support, making it difficult for other countries to establish competitive refining and processing capacities. Even where new facilities emerge, securing reliable raw material supplies and downstream demand depends on elusive long-term agreements. Chinese off-takers can leverage market dominance to disrupt foreign partnerships by implicitly threatening to cut off access to other Chinese resources downstream. Meanwhile, new mines may struggle to secure offtake agreements outside of Chinese control, forcing reliance on volatile spot markets that might be subject to manipulation by China's dominant producers. China's central role in trade networks amplifies its influence over partner countries and deters investments in alternative processing capacity. Large incumbents are not immune to these dynamics—China is the largest consumer of steel (primarily iron, the metal generating the bulk of the majors' free cash flow), and stalled development from its distressed real estate sector continues to threaten industry profits.

Effective design and implementation of strategy is essential to success. Offtake and coordination between stakeholders, as well as the costs and benefits of policy design, need to be weighed carefully. For example, Indonesia's export ban on raw nickel ore has successfully established domestic refining and processing facilities.[14] Export revenues increased from $1 billion of raw nickel in 2014 to $20.8 billion of processed nickel by 2021, according to President Joko Widodo. This year, the first battery precursor plant entered production, moving Indonesia one step further along the value chain. However, inadequate regulation of new refining capacity has had serious socio-environmental impacts, including pollution, deforestation, frequent safety incidents, and labor rights concerns. Raw material export bans like the one implemented by Indonesia are an increasingly popular option to stimulate domestic processing (partially because they are "free" to implement) and eventual downstream investment (tracked and critiqued by the OECD, along with export taxes), and can have mixed outcomes.

Table 8: Recent critical mineral export bans

Country	Export Bans	Successes	Challenges
Indonesia	Ban on raw nickel (2020) and bauxite (2023)	Significant increase in nickel export revenue, the establishment of domestic smelting facilities with major investments. Recently moved further downstream to precursor production	Significant socio-environmental impacts; capacity to process all output initially challenged; more recently smelters in Indonesia have had to secure supply from the Philippines at higher costs to maintain capacity amidst tight domestic supply
Zimbabwe	Export ban on unprocessed lithium (2022) and chromium ore (2011, 2021)	Joint ventures established for battery metals processing; substantial foreign investments in chromium processing	Initial bans led to production declines and shutdowns; success contingent on developing sufficient processing capacity

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[14] See page 114 and 115 of Geopolitics of the Energy Transition (IRENA, 2023).

Namibia	Ban on unprocessed lithium, cobalt, manganese, graphite, and rare earth minerals (2023)	Still uncertain; could position Namibia to benefit from processing and downstream value capture	Infrastructure and financial capacity to support processing is uncertain
Ghana	Export restrictions on raw bauxite (2019), iron ore, and lithium (2024) to encourage local refining	Largely uncertain; prioritization of Ghanaian stakeholders in mining projects	Infrastructure and financial capacity to support processing is uncertain

Altogether, the challenges of coordinating effective industrial policy to develop and expand energy transition value chains globally are equal parts technical, economic, geopolitical, and socioenvironmental. Policymakers are underequipped to weigh complex and varied options amid innumerable challenges and uncertainties. JFI is continuing to develop resources to help close this knowledge gap and distill these uncertainties into manageable decision pathways. We will begin by building and disseminating tools to map prospective and proposed global value chains central to the green transition and identify different viable configurations of these supply chains—considering financing mechanisms, locations of intermediate supply chain stages, and tax, duty, licensing, and royalty schemes—and quantify the distribution of potential benefits to LMICs under the range of possible scenarios.