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Critical Mineral Development:
Opportunities and Challenges for Resource-Rich Countries in the Global South

Supported by funding from

The Payne Institute for Public Policy
AT COLORADO SCHOOL OF MINES

Introduction

The Payne Institute for Public Policy at the Colorado School of Mines welcomes you to its inaugural London Critical Minerals Symposium! We give thanks to the generous sponsorship of Quadrature Climate Foundation (QCF) to make this event possible and to our gracious hosts, Anglo American PLC.

As we convene, we look forward to an enriching day of conversation that brings different perspectives to the vast opportunities presented by the growing demand for critical minerals. At its core, taking advantage of these opportunities involves developing complex global supply chains. Our event will keenly focus on how to ensure developing economies are both a key part of such solutions and a beneficiary of the tremendous investment that must accompany them.

This compendium includes work produced largely by some of the representatives at today's event that are being supported by QCF. Its articles illustrate considerations, challenges and tools as 'global south' communities seek to leverage their mineral resource for socioeconomic development.

The first paper provides some context setting. TMP assesses the risk to demand and supply of clean technologies, homing in particularly on China and including the potential impact of the outlook for erratic economic U.S. policy. The piece argues that China's structural challenges threaten a climate technology shortage with wide-ranging impact.

The compendium then turns more specifically to developing economies and the potential to benefit from — and challenges for — critical mineral development. These are illustrated in an article from Natural Resource Governance Institute (NRGI) summarizing a recent listening/learning session with Indonesia stakeholders. Indonesia has been an economic success story, in part driven by Nickel development. These stakeholders speak to the complexity of ensuring that such success translates to socioeconomic development; this includes managing the country's emphasis on value addition, *i.e.* developing value chains for mined materials including mid- and downstream processing. The article also addresses the imperative to address Environmental, Social & Governance (ESG) concerns and it considers a general challenge of forward planning. For the latter, the stakeholders reveal some unease about the demand outlook, in part due to the rising popularity of Lithium-Ion-Phosphate (LFP) batteries vs. a Nickel-Manganese-Cobalt (NMC) design.

Next, the topic of Artisanal and Small Mining (ASM) is introduced. ASM is an economic foundation in many resource-rich communities and, in some cases, a more important contributor to mineral production volumes than is commonly realized. An article from the Payne Institute provides color on the ASM landscape and argues that better management of ASM represents a significant opportunity for these communities to realize socioeconomic gains and contribute to countries' mining development ambitions.

The compendium then pivots to consider more specific issues, including, in different ways, knowledge gaps that make policymaking difficult. A second contribution from NRGI provides a survey of the evolution and nature of policies related to value addition. The article also addresses the benefits to high income

countries in supporting value addition in developing economies, while cautioning all actors that design choices matter and that on a country- and project-specific basis, investments must be underpinned by clear strategies and economic/cost-benefit analysis.

A piece by the Jain Family Institute (JFI) highlights the pitfalls for local and national governments when overly optimistic projections can result in far less government "take" than was expected when projects are approved. The article describes a JFI suite of tools it is developing to assess and manage such market risks.

And finally, also related to knowledge gaps, a second article by the Payne Institute considers the lack of information related to ASM activity/output in Indonesia. The piece attempts to derive Indonesian ASM contribution to Nickel production by looking at smelter output vs. recorded mining production. In the process, it hints at the risk of unintended consequences of policies to promote value addition, in this case that individual smelters "ended up" with considerable market power over miners.

Again, we welcome you to the Symposium and thank you for taking time out of your busy schedules to join us. We wish all of you a productive and thought-provoking day!

Sincerely,

The Payne Institute for Public Policy team

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June 2025

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By the Payne Institute for Public Policy team

This compendium has been produced for the Payne Institute's inaugural London Critical Minerals Symposium. The event's generous sponsor is the Quadrature Climate Foundation (QCF), and the Symposium's gracious host is Anglo American PLC. This compendium includes work produced largely by some of the representatives at the Symposium that are being supported by QCF. This volume's articles illustrate considerations, challenges and tools as "global south" communities seek to leverage their mineral resource for socioeconomic development.

Breaking Point?
Why China's Emerging Manufacturing Crisis Matters for Renewables, Electric Transport …and Climate Change Itself **4**
By TMP, which is a consulting group dedicated to understanding and solving complex climate, environmental, social, and security problems

Cleantech supply chains remain highly-concentrated in China and are more fragile than commonly understood. President Trump's aggressive and unpredictable trade policies threaten to compound deep-seated structural challenges facing China's economy, including overreliance on exports, weak consumption, ideological dogma, financial opacity, and a property crisis. Consequent supply chain disruptions could lead to a climate technology shortage that ultimately delays global decarbonization efforts.

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By Matthieu Salomon, Lead, Anticorruption, Natural Resource Governance Institute; Frenky Simanjuntak, Consultant, Natural Resource Governance Institute; Amir Shafaie, Legal and Economic Programs Director, Natural Resource Governance Institute; and Patrick Heller, Chief Program Officer, Natural Resource Governance Institute

As the global demand for clean energy technologies rises, nickel — and other critical transition minerals — has become central to Indonesia's economic strategy. The country is leveraging its significant nickel reserves, key for electric vehicle (EV) batteries and stainless-steel production, to secure a growing share of the global market. At a macroeconomic level, there is a rich debate on the role of mining and mineral value addition in a broader national strategy for economic diversification and broad-based economic development. Indonesia's experience — both successes and challenges — can serve as a valuable model for other low- and middle-income mineral-producing countries as they develop and implement their own strategies to manage their transition minerals sustainably and equitably.

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By Clarkson Kamurai, Critical Minerals Program Manager and Research Associate, Payne Institute for Public Policy at the Colorado School of Mines; Isabel Guajardo, Researcher, Payne Institute for Public Policy at the Colorado School of Mines; Grace Akinyi, Mining and Energy Economics, Colorado School of Mines; Brad Handler, Program Director of the Energy Finance Lab and Researcher, Payne Institute for Public Policy at the Colorado School of Mines; and Ian Lange, Ph.D., Associate Professor, Mineral & Energy Economics Program, Colorado School of Mines

It is expected that a significant increase in the supply of dozens of so-called "critical minerals" will be needed in the coming decades, for uses ranging from defense to no- and low-carbon energy. Mineral endowment and production capacity have therefore become crucial assets for developing economies. Achieving this supply growth will depend on multiple stakeholders across governments and the private sector. Yet one set of the stakeholders — artisanal and small-scale mining (collectively referred to here as ASM) — tends to be overlooked and may prove to be crucial. The Payne institute is initiating a research study to consider how ASM can be leveraged most effectively to support the complementary ambitions of growing critical minerals supply and promoting social and economic development. The research will address the role ASM-supplied minerals have in current value chains. It will also explore the value of governmental oversight/regulation for practitioners, ASM's relationships with large-scale mining (LSM) and the community, and industry economics.

Leading Economies' Industrial Policies Risk Reinforcing Inequities in Mineral Value Chains **28**

By Thomas Scurfield, Africa Senior Economic Analyst, Natural Resource Governance Institute; and Annalena Brokering, Mercator Fellow, Stiftung Mercator

To support policymaking on mineral value addition in mineral-producing countries, including providing a better understanding of the competitive landscape, the authors have surveyed the policies that governments have adopted in recent years. This article has focused on the copper, lithium and nickel value chains and identified 123 policies adopted by different countries up to April 2025 that target these value chains. Under current conditions, most low- and middle-income countries will struggle to meaningfully reduce the inequities in copper, lithium and nickel value chains. Despite the recent turn inwards of some high-income countries and China, they should provide support to low- and middle-income country efforts to develop mid- and downstream mineral-based industries, where this aligns with mineral producer countries' priorities and economic circumstances.

Benchmarking Opportunity in Transition-Critical Mineral Markets **33**

By Jonah Allen, Ph.D., Lead Researcher, Energy Transition Value Chains, Jain Family Institute; and Eduard Nilaj, Senior Research Associate, Jain Family Institute

Producer countries seeking to turn transition-critical mineral booms into lasting development outcomes must navigate market volatility, complexity, and uncertainty. The recent rise and crash of
(Continued on the next page.)

lithium prices underscore how quickly market realities can outpace expectations; in Brazil and Ghana, overoptimistic projections and plans have translated into deflated public revenues and challenged downstream ambitions. Given these challenges, the Jain Family Institute (JFI) is developing a suite of tools to reduce information asymmetries and support policymakers in assessing and managing market risks. JFI has begun with the *Mineral Market Dashboard*, which benchmarks varying projections for transition-critical mineral market growth and maps the distribution of historical production and current estimated resources and reserves to enable more grounded discussions on the scale and distribution of opportunity.

Analysis on ASM Role in Indonesian Nickel Production **48**

By Matt Lee, Researcher, Payne Institute for Public Policy at the Colorado School of Mines; Clarkson Kamurai, Critical Minerals Program Manager and Research Associate, Payne Institute for Public Policy at the Colorado School of Mines; and Brad Handler, Program Director of the Energy Finance Lab and Researcher, Payne Institute for Public Policy at the Colorado School of Mines

Indonesia now dominates the global supply of nickel, an essential raw material for lithium-ion batteries and stainless steel. Nickel production in the country has more than doubled in the last 4 years, fueled by the government's "value chain" strategy that drove domestic development of smelting/refining capacity. The supply chain of raw nickel ore is characterized by a blend of large- and small-scale mining. The contribution of artisanal and small-scale mining (ASM) to Indonesian nickel production is unclear, although we believe it might be as much as 25% of recent production. This sizeable impact raises the imperative for Indonesia to understand ASM's contribution to and the nature of domestic nickel production. This can set the basis for optimizing the economic benefit for local communities and the country as a whole.

Breaking Point?

Why China's Emerging Manufacturing Crisis Matters for Renewables, Electric Transport…and Climate Change Itself: A Commentary by TMP

Chinese cleantech manufacturing is more precarious than commonly understood. Despite the recent détente in the trade war with the U.S., ongoing uncertainty around trade relations and the global economic outlook stands to aggravate China's structural challenges, threatening to create a climate technology shortage that could critically impact renewable energy and automotive supply chains, as well as delay global decarbonization efforts. Our analysis identifies multiple compounding risks that China's current leadership will struggle to contain, placing this critical supply infrastructure in jeopardy:

1. ***Economic Crisis: China faces a $18 trillion property collapse*** *(122% of 2020 GDP) coupled with deflation and slumping consumer confidence—reliable estimates place* ***actual GDP growth at just 1.5-2.8%****, far below official claims.*

2. ***Governance Failure:*** *Xi Jinping's consolidation of power has* ***weakened economic policy-making****. His reported statements reveal concerning economic naivety ("What's so bad about deflation?"), while ideological opposition to demand-side solutions is* ***paralyzing effective intervention***.

3. ***Manufacturing Vulnerability:*** *Chinese cleantech manufacturers* ***operate with razor-thin margins****, minimal capitalization, and mounting debt. Key players and much-touted success stories like BYD and Tongwei Solar are* ***already showing signs of financial strain****.*

4. ***Financial Opacity:*** *China's* ***opaque financial system****—with trillions of hidden debt in local government financing vehicles (LGFVs) and other mechanisms—creates conditions for failures that could* ***cascade rapidly through manufacturing supply chains****.*

5. ***Trump Administration Impact:*** *While the recent climbdown from triple-digit tariffs brings temporary breathing room,* ***uncertainty continues*** *to cloud the longer-term outlook and* ***the duties remain substantial*** *relative to historical levels—Trump's levies on China currently stand at 30%, on top of pre-existing duties. This is already destabilizing an export sector that contributed ~20% of China's GDP in 2024.*

6. ***Climate Technology Bottleneck:*** *A manufacturing collapse would* ***dramatically constrain global access to affordable solar panels, batteries, wind turbines****, and other essential climate technologies, just as accelerating climate impacts increase demand.*

7. ***Strategic Unpreparedness:*** *Most institutional planning* ***incorrectly assumes*** *China's manufacturing dominance will continue uninterrupted and that its leadership can effectively navigate economic challenges.*

The views expressed in the *CID* are those of the individual authors.

1. Why Does China Matter So Much for Climate Change?

Many scientists have become concerned that global warming is accelerating dramatically.[1] We anticipate this will reverse the current trend away from climate action before the end of the decade. Consequently, TMP's base case sees demand for renewables, clean transport and associated technologies rapidly accelerating by 2030.

In that context, China matters in two ways. First, Chinese firms dominate supply chains for many products and materials that are crucial for renewable energy and clean transportation. Despite U.S. and European efforts to challenge this dominance, China continued to expand its share of global production capacity across 12 key clean energy sectors in 2023, spanning solar panels, battery components, minerals and power generation (see Table 1).[2]

Table 1
China's Share of Global Manufacturing Capacity

Sector	Product	Share
Solar	Solar Module	84%
	Solar Cell	89%
	Solar Wafer/Ingot	97%
	Polysilicon	86%
Batteries	Battery Cell	86%
	Battery Cathode	87%
	Battery Anode	96%
	Battery Electrode	91%
	Battery Separator	85%
Minerals	Lithium	71%
	Cobalt Sulfate	86%
	Nickel Sulfate	80%
Electricity	Wind Turbine Nacelles	67%
	Hydrogen Electrolyzer	70%

Note: Share of capacity located in China, excludes capacity operated by Chinese companies in other countries. Lithium refers to lithium hydroxide and carbonate.
Table: TMP Public • Source: BloombergNEF

Second, China is by far the largest source of carbon emissions globally. The country produced 11.9 gigatons of CO2 in 2023, accounting for ~31.5% of the global total—more than double the amount produced by the second-largest emitter, the U.S. (4.9 gigatons).[3] Given our base case for the pace of decarbonization, we anticipate China's dual carbon goals of peaking emissions by 2030 and reaching carbon neutrality by 2060 will require rapid acceleration.[4]

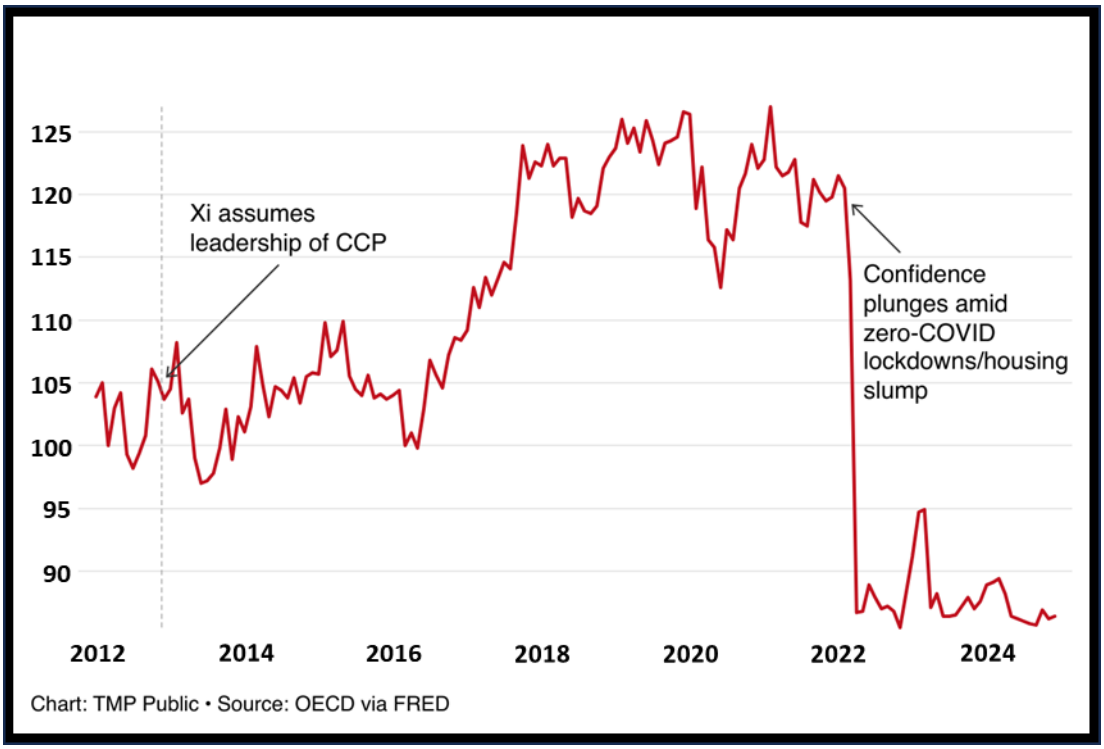
For these reasons, the health of China's economy—particularly its manufacturing sector—is vitally important for the clean energy and transport sectors specifically, as well as the broader need to address climate change.

2. What is the Situation with China's Economy?

In 2005, China's government began creating[5] the largest property bubble in history, then deliberately popped it in 2020 without a viable plan for managing the fallout. This vaporized over $18 trillion in property value,[6] equivalent to 122% of its 2020 GDP.[7]

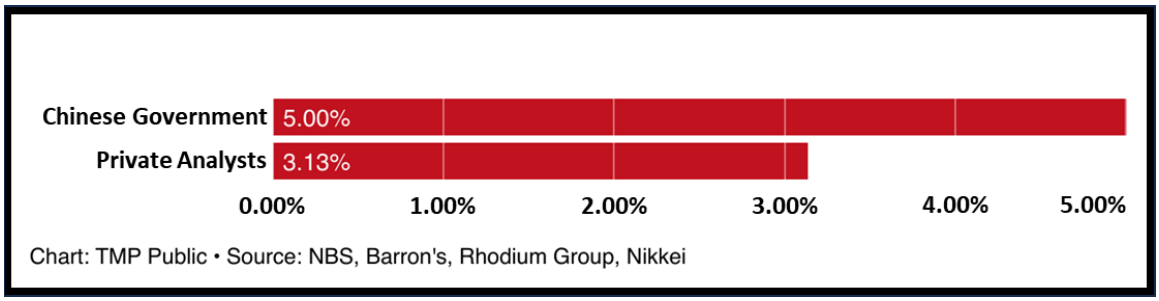
That alone would have been the largest economic crisis since the Great Depression,[8] but to make matters worse, Beijing followed this with a draconian crackdown on the coronavirus that crushed consumer confidence and created significant social discontent.

Figure 1
China Consumer Confidence Index



The result has been a hard landing. In December 2024, Rhodium Group calculated China's growth at a paltry 1.5% for 2023 and 2.4-2.8% in 2024,[9] while Gao Shanwen (高善文), former chief economist at state-owned SDIC Securities, estimated as low as 2%.[10] Official statistics show China's GDP grew 5.2% in 2023 and 5% in 2024[11] —but these are likely to have been concocted as part of Beijing's broader suppression of negative economic news.[12]

Figure 2
China GDP Growth Estimates (2024)



A stock rally last September gave investors some reason for hope but sentiment has since weakened. The CSI 300 hit a six-month low amid escalating trade tensions sparked by Trump's "reciprocal tariffs" and the index remains ~10% below its early-October peak, despite a slight boost from recent tariff reductions.

Both sides agreed on May 11 to reduce duties by 115 percentage points for 90 days (until August 14). This lowered U.S. tariffs on China to 30%, on top of existing duties and with exceptions for certain sectors, while China's levy on the U.S. fell to 10%.[13] However, uncertainty continues to cloud the long-term outlook, and even at this level the tariffs pose a major challenge for China, adding to a host of structural economic issues that the country will struggle to overcome.[14]

3. Why Does TMP Think This Could Get Worse?

Two specific characteristics of China's economy make us especially worried: how little room manufacturing firms have for error, and how opaque its financial system is—particularly with regard to debt.

An overcrowded market,[15] intense price competition[16] and rising labor costs[17] have decimated profit margins for "the factory of the world." Manufacturing in China is dominated by private firms which have limited access to state support, leaving them little to fall back on in a financial crunch. Even leading players in key growth areas such as the "new three"[18] are under pressure: EV maker BYD is thought to rely heavily on financing from working capital, hiding surging debt levels.[19] Price cuts announced recently stand to decimate its profit margins and spur consolidation in the sector.[20] Leading solar panel makers like Tongwei Solar are also struggling to maintain profitability, as prices have cratered amid an industry-wide supply glut.[21] Less competitive players and legions of small upstream suppliers are likely in worse predicaments.

As the crisis worsens, the fundamental opacity of China's financial system will start to matter more. The sheer size of China's economy and low transparency of state-owned banks makes debt burdens hard to assess.[22] The IMF estimates that murky local government financing vehicles (LGFVs) hold hidden debts of 60 trillion yuan, though official estimates are worryingly low at 14.3 trillion yuan.[23] Chinese economists have highlighted other little-known types of debt such as unpaid VAT receipts, pension contributions and historical debts to farmers, which in aggregate add up to trillions of yuan.[24]

As a result, many crucial manufacturers could simultaneously experience a capital crunch and default on debts, missing payments to suppliers and sending defaults cascading through the supply chain. At that point, the financial system may well freeze up due to uncertainty about who owes what to whom, leaving those firms with little option but to dramatically cut back production at best, and at worst, fold entirely.

4. What is the Government Doing about the Crisis?

Not nearly enough. The problem begins with Xi himself, who appears to have a very limited understanding of how market economies work. The most famous example of this comes from *Wall Street Journal* reporter Lingling Wei:

[Xi's advisors] warned that China could slip into a deflationary spiral—the kind of disaster that befell the U.S. during the Great Depression—if more urgent steps weren't taken to rejuvenate growth. Xi was unperturbed. "What's so bad about deflation?" he asked his advisers, according to people close to Beijing's decision-making. "Don't people like it when things are cheaper?"[25]

Whereas his predecessors Hu Jintao, Jiang Zemin or even Deng Xiaoping might have considered a wider range of crisis responses, concentration of power under Xi has made his doctrine of Xi Jinping Thought (XJT) the dominant factor in policy decisions. This has significant implications for the kind of measures China can actually pursue.

For example, economists generally agree that China's problem is insufficient consumer demand. This directly conflicts with how XJT explains Chinese economics:

If demand management is likened to "Western medicine," then the supply-side management emphasized by New Supply-Side economics is more akin to "traditional Chinese medicine." "Western medicine" can provide quick relief, but often with significant side effects. In contrast, traditional Chinese medicine uses a slow, comprehensive approach that requires careful balancing, resulting in a richer, more nuanced effect.[26]

The underlying reason for this is Xi's ideological opposition to promoting consumer demand by strengthening social safety nets, which he believes encourages laziness through "welfarism."[27] As he explained in a 2022 speech on the economy:

In promoting common prosperity, we cannot adopt a "welfarist" approach. In the past, some Latin American countries that pursued populist policies and high welfare levels ended up nurturing a class of "idlers" and free riders, leading to unsustainable fiscal burdens and falling into a "middle-income trap." When welfare levels rise, it is difficult to lower them; excessive welfare beyond one's capacity is unsustainable and inevitably leads to serious economic and political issues!

In addition, most CCP leaders want to maintain control over the economy and are wary of the shift to consumer-led growth.[28] In their eyes, any reduction of state power over the economy could pitch China from stability to chaos, playing into Xi Jinping's fears of China becoming a second Soviet Union, with him a latter-day Mikhail Gorbachev.[29]

For all of these reasons, we think it likely that China will stick to its current slate of insufficient policy responses. The Two Sessions ("两会") meetings, which set the economic roadmap for the coming year, produced little of note beyond stronger rhetoric on stimulating consumption.[30] Key measures remained incremental, stopping short of direct payments to households advocated by many economists.[31] Moreover, implementation of many policies was left in the hands of debt-ridden local governments, raising further doubts over the impact.[32]

More recent reports suggest China is also determined to maintain the share of GDP contributed by manufacturing. Policymakers are thought to be drawing up a new version of Xi's "Made in China 2025" plan to boost the country's high-end manufacturing sector. Drafts of the 15th Five-Year Plan (2026-2030) are also rumored to target steady GDP contribution from manufacturing in the mid- to long-term.[33]

These ideological constraints are hampering efforts to address systemic economic problems, placing China on a weak footing at the precise moment it faces its biggest external challenge in decades: Donald Trump and the U.S. anti-trade movement.

5. What Impact Will Trump Have?

Trump's erratic policies and shake-up of global trade have cast a shadow over the outlook for China and raised fears of recession in the U.S. and globally.[34] The recent climbdown in tariffs brought some cheer following a rapid tit-for-tat escalation in the wake of "Liberation Day" on April 2. However, uncertainty prevails, with the prospects for a more lasting deal still far from clear.

Analysts surveyed by Bloomberg expect Trump's duties to remain at around 30% throughout 2025, while a slim majority predict they will edge down to a final level of ~20%. This comes on top of existing tariffs estimated to average ~12%, and excludes certain sectors such as smartphones and semiconductors—though Trump has since said these will be subject to separate tariffs. While substantially lower than the 145% proposed previously, the current duty is still high enough to eliminate ~70% of China's exports to the U.S. in the medium-term.[35]

The levies are already stoking fears of job losses in China and dampening the outlook for consumer spending.[36] Moreover, Trump's flip-flopping and unexpectedly aggressive assault on trading norms have created global economic uncertainty that is paralyzing business and consumer activity.

The chances of a recession in the U.S. and globally remain significant following a 0.3% contraction of U.S. GDP in Q1 2025.[37] J.P. Morgan says the probability of a U.S. recession in 2025 is now below 50% but still elevated, down from 60% prior to the détente.[38] Goldman Sachs sees a 35% chance,[39] while betting platform Polymarket put the odds at 37% at time of publication.[40]

Political constraints and big egos make it unlikely that either Trump or Xi will back down completely.[41] Even if the two sides manage to negotiate further reductions and the tariffs jolt China into implementing more aggressive fiscal and domestic consumer spending policies, this might not be enough to pull its economy

back from the brink given Trump's shake-up of global trade. Despite his 90-day pause on "reciprocal tariffs" for other countries, they are still regarded as the worst trade shock in history.[42]

While the U.S. remains China's largest trading partner, over 80% of China's trade is conducted with other countries.[43] Trump's weaponization of trade for diplomatic purposes and China's efforts to find new markets to absorb its overproduction means nations the world over may become more inclined to protect their markets from Chinese imports,[44] particularly as weak consumer spending reduces the impact of losing access to the China market. From the perspective of China's manufacturers, U.S. actions have instilled lasting uncertainty over future access to global markets for Chinese products.

This wave of uncertainty hits them at exactly the wrong time. Chinese exporters accounted for ~2% of GDP growth in 2024[45] and rely on overseas markets for their profits, as margins are razor-thin domestically due to weak consumer demand. In short, they are poorly positioned to weather the significant disruption of global trading patterns likely to result from Trump's tariffs, with daunting consequences for renewable energy and clean transportation.

6. If This Happens, What Would it Mean for Climate?

To reiterate: global warming is accelerating at a dramatic pace, and we expect this to override the current trend of retreating from climate action. As a result, we anticipate a rapid surge in demand for renewables, clean transport, and related technologies by 2030. In this scenario, China plays a critical role.

We have explained how China's macroeconomic problems and misguided governance overlap with its manufacturers' weak financial condition, and how China's broader financial system might freeze up. This would almost certainly impact Chinese companies which supply the essential elements for solar, batteries, wind turbines and other cleantech solutions—and supply them at the prices needed to foster their deployment.

While many individuals are aware of these patterns, typical strategic planning for a wide range of institutions tacitly relies on outdated assumptions that (1) Chinese manufacturers will maintain their export dominance, (2) global markets will continue accepting this arrangement, and (3) China's centralized leadership can effectively navigate major economic challenges.

Our reading of the evidence suggests all three are incorrect, and that preparations for a Chinese cleantech manufacturing crisis must be made. This is even more true for those concerned about whether we are to respond to the impending climate crisis effectively.

7. Can This Risk Be Managed?

Yes. There are significant, concrete, and above all feasible solutions for this problem. It is therefore not something that can simply be pushed aside with the attitude that "whatever happens, happens."

Specifically, we recommend that organizations of all stripes prepare for potential supply chain disruptions by developing alternative sources wherever possible, or by strengthening existing Chinese supply chains wherever diversification is not feasible. Most importantly, they should review their strategic planning and remove any expectation that China's political and financial system would respond adequately to the crisis scenario we outline above.

Doing this effectively requires precise and actionable analyses of the specific risks different stakeholders face. Because TMP advises a wide range of organizations with different needs and goals, from government ministries to corporates to philanthropies, our specific advice on which actions need to be taken will depend on your institution.

Endnotes

TMP can deliver specific advice on how to assess, prepare for and manage the risks noted in this commentary. To request more information, please contact Orlando Bowie at orlando.bowie@asktmp.com.

1 https://insideclimatenews.org/news/04022025/james-hansen-research-documents-global-warming-acceleration/

2 https://www.bloomberg.com/news/newsletters/2024-04-16/china-extends-clean-tech-dominance-over-us-despite-biden-s-ira-blueprint

3 https://emissions.globalcarbonatlas.org/index.php#

4 In addition to this, TMP's research has found that China is highly exposed to a wide range of climate risks, and Chinese suppliers of many clean energy and transport products are particularly vulnerable. Disruptions of these firms' operations could create a vicious cycle, reducing the availability of technologies and materials necessary to decarbonize, in turn further exacerbating climate change.

5 https://en.wikipedia.org/wiki/Chinese_property_bubble_(2005%E2%80%932011)

6 https://www.wsj.com/world/china/china-economy-excess-debt-gdp-46c69585

7 https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CN

8 The next closest in size was the 2008 U.S. subprime crisis, during which the U.S. suffered $6.5 trillion in property losses during its housing market collapse, equivalent to 44% of U.S. GDP. In other words, the Chinese crisis is roughly three times as large by comparison.

9 https://rhg.com/research/after-the-fall-chinas-economy-in-2025/

10 https://www.wsj.com/world/china/xi-jinping-muzzles-chinese-economist-who-dared-to-doubt-gdp-numbers-2a2468ef

11 https://www.stats.gov.cn/xxgk/sjfb/zxfb2020/202501/t20250118_1958363.html

12 https://www.nytimes.com/2024/01/31/business/china-censorship-economy-markets.html.
Despite the censorship, government bond yields reached record lows in September 2024 and the yuan hit a 15-month low against the dollar in January, all while Chinese stock exchanges made the extraordinary move of asking fund managers to restrict selling in an effort to shore up collapsing share prices.

13 https://www.reuters.com/world/us-china-tariff-live-updates-bessent-greer-announce-details-constructive-geneva-2025-05-12/

14 Shanghai's minimum wage, the highest in China, flatlined for three years running from 2022 and increased only slightly in 2025. Unemployment is elevated, especially among the youth demographic—the government recently started excluding students from its data, reflecting its concerns over the statistics. This has led to numerous instances of factories withholding wages from workers, sparking public protests.

15 https://www.ccn.com/news/business/china-electric-vehicle-markegrowth-western-restrictions/

16 https://www.scmp.com/economy/china-economy/article/3292901/sectors-distress-chinas-intense-competition-demands-action-economic-official-warns

17 https://www.sciencedirect.com/science/article/abs/pii/S0167268121000329

18 Batteries, electric vehicles and solar products—"新三" in Chinese.

19 https://www.bloomberg.com/news/articles/2025-01-19/byd-s-supply-chain-financing-masks-ballooning-debt-gmt-says

20 https://asia.nikkei.com/Business/Automobiles/Electric-vehicles/BYD-price-bombshell-raises-specter-of-wider-China-EV-consolidation

21 https://www.bloomberg.com/news/articles/2025-01-20/chinese-solar-stocks-fall-after-gloomy-initial-results-for-2024

22 https://www.bloomberg.com/news/articles/2024-10-24/record-defaults-hit-800-billion-chinese-municipal-debt-market

23 https://www.elibrary.imf.org/view/journals/002/2024/050/article-A003-en.xml

24 https://mp.weixin.qq.com/s/S4e-RzwRkXMtUSk-XLdVvw

25 https://www.wsj.com/world/china/china-xi-debt-economic-plan-13aaeec1

26 http://www.xinhuanet.com/politics/2015-11/19/c_128445566.htm - the original Chinese text is:
如果将需求管理比喻为"西医"，新供给所强调的供给管理更像是"中医"。"西医"可以救急，但副作用大。中医疗法如文火慢煮，综合施治，需要把握火候，引出的味道也更浓。

27 http://www.qstheory.cn/dukan/qs/2022-05/15/c_1128649331.htm - the original Chinese text is:
促进共同富裕，不能搞"福利主义"那一套。当年一些拉美国家搞民粹主义，高福利养了一批"懒人"和不劳而获者，结果国家财政不堪重负，落入"中等收入陷阱"，长期不能自拔。福利待遇上去了就下不来了，搞超出能力的"福利主义"是不可持续的，必然会带来严重的经济和政治问题！

28 https://www.foreignaffairs.com/china/why-china-wont-give-failing-economic-model

29 https://www.economist.com/china/2024/09/30/worries-of-a-soviet-style-collapse-keep-xi-jinping-up-at-night

30 https://www.reuters.com/world/china/more-words-than-deeds-china-consumption-keep-deflation-play-2025-03-06/

31 https://www.chinadailyhk.com/hk/article/590469

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33 https://www.bloomberg.com/news/articles/2025-05-26/xi-plans-new-made-in-china-effort-even-as-trump-aims-to-boost-us-manufacturing

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35 https://www.bloomberg.com/news/articles/2025-05-16/trump-s-china-tariffs-seen-staying-at-30-through-late-2025

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Indonesia's Energy Transition Ambitions: Nickel Downstreaming and Beyond

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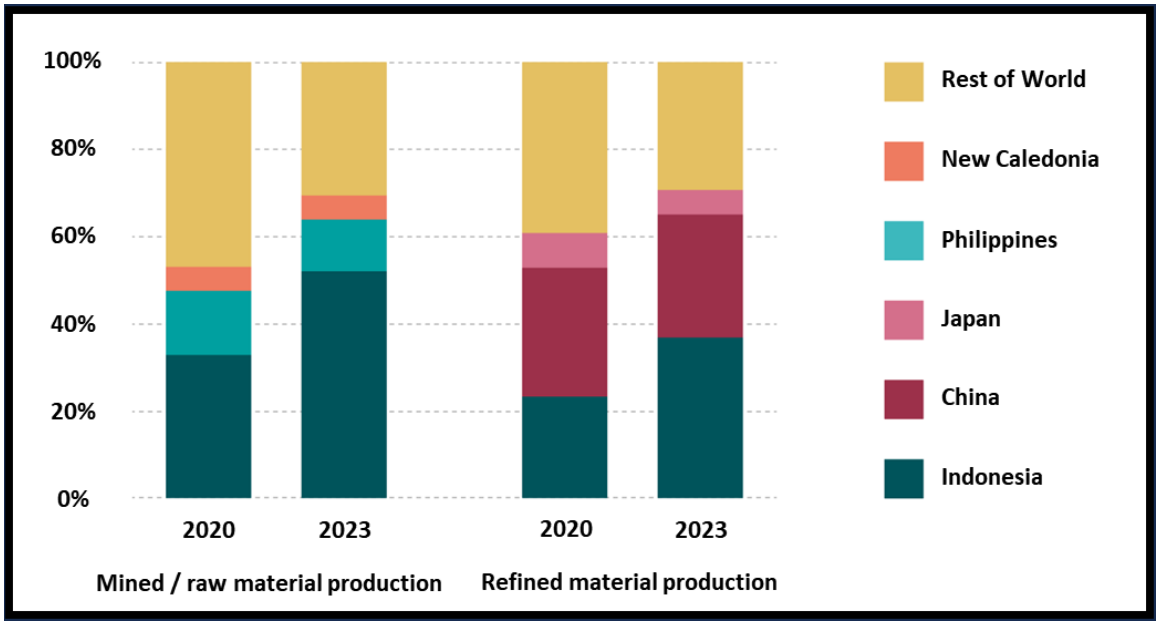
Credit: Kukuh Napaki.

As the global demand for clean energy technologies rises, nickel—and other critical transition minerals—has become central to Indonesia's economic strategy. The country is leveraging its significant nickel reserves, key for electric vehicle (EV) batteries and stainless-steel production, to secure a growing share of the global market.

This economic success story, promoted by the Indonesian government and showcased in various media outlets, has contributed to the country's overall economic growth, which remains at about 5 percent in 2024, and to growth in nickel-producing regions. For instance, North Maluku has been the best performing

province, with an average economic growth of 20.1 percent from 2021 to 2023, driven largely by the nickel industry. Central Sulawesi, the second-best performing province, has similarly benefited from the nickel industry. Building on the successes of his predecessor, President Joko Widodo, the newly elected President Prabowo Subianto plans to further strengthen policies promoting exploitation and value addition of transition minerals, including through a possible revision of the mining law.

Figure 1
Share of Nickel Production (Mined / Raw Material and Refined Material) by Country



Source: The International Energy Agency's Global Critical Minerals Outlook 2024.

However, significant questions remain about how this growth will contribute to sustainable development outcomes for Indonesians, particularly in tackling poverty, unemployment and inequality in mining regions. Additionally, concerns around the socio-environmental impacts and the corruption risks associated with both mining and value addition continue to pose significant challenges. At a macroeconomic level, there is a rich debate on the role of mining and mineral value addition in a broader national strategy for economic diversification and broad-based economic development.

The world's attention is increasingly focused on how Indonesia will tackle the next phases of its transition minerals story. Researchers and officials from a wide range of countries are looking to learn from Indonesia's nickel story. At a recent Natural Resource Governance Institute (NRGI)-organized gathering at the Rockefeller Bellagio Center, leading thinkers from Africa, Asia and Latin America discussed innovations in the transition minerals space and options to implement recommendations from the UN Secretary-General's Panel on Critical Energy Transition Minerals. However, some analysts have expressed skepticism about the viability of the government's stated ambitions to further advance downstreaming— which include achieving full coverage of the EV nickel battery value chain in Indonesia, producing EVs in Indonesia

and expanding downstreaming to other minerals and sectors in coming years. These differing perspectives underscore the ongoing clash of narratives around mining and value addition ambitions in Indonesia.

Credit: Rakhmat Sobirin.

On December 10-11, 2024, NRGI, in collaboration with ViriyaENB, gathered more than 30 Indonesian experts to discuss how Indonesian citizens can further benefit from opportunities related to their country's transition minerals wealth. The workshop focused on how to think through key governance challenges around Indonesian transition minerals, with NRGI experts contributing international experience and perspectives. This event marked a significant step in NRGI's reengagement in Indonesia, which started in 2024. NRGI's renewed engagement is part of its global priority to support the fair and sustainable management of the global race for transition minerals, including through successful value addition and equitable development policies.

The discussions at the workshop revealed several key present and future issues of relevance to the country's transition minerals: the need to move beyond polarized narratives of downstreaming; the impact of technology and geopolitical uncertainty on the window of opportunity; the necessary ambition to improve environmental, social and governance (ESG) performance; and the importance to connect and bridge the gaps between Indonesian stakeholders.

Downstreaming: Moving Beyond Polarized Narratives

Workshop participants discussed how views on Indonesia's nickel downstreaming risk becoming polarizing—either focusing too heavily on "success" (*e.g.*, growth in production and government revenues, progress along the nickel battery value chain) or on "failure" (*e.g.*, social and environmental impacts, inequitable sharing of benefits.) They noted that this lack of nuance can hinder constructive dialogue and improvements. A recurring theme was the need for better metrics for evaluating downstreaming policies beyond production and revenues. Participants highlighted the importance of building on existing research that analyzes both benefits and costs, helping understand how much value addition policies are benefiting Indonesians, particularly those living in mining-affected areas.

On the benefits side, participants indicated that metrics should include the issue of equitable distribution (*e.g.*, at the subnational provincial and regency level) and various kinds of benefits (*e.g.*, not just growth in production, revenues or GDP, but also the impact on unemployment and poverty reduction.) Such metrics would also need to measure the tradeoffs that can result from downstreaming growth (*e.g.*, negative impacts in the agriculture sector and agrarian conflicts, deforestation, pollution and emissions, etc.) Developing such metrics and integrating them more consistently into policy discourse was viewed by participants as particularly useful and timely given the new Indonesian government's stated aim to continue and extend the downstreaming approach as referenced above.

These discussions aligned largely with NRGI's recent briefing: Six Keys to Unlocking Equitable Value Addition in Mining (now available in Bahasa Indonesia.) The briefing emphasizes that governments need to set clear goals around their value addition strategies, analyze trade-offs and costs—not just benefits—and implement these strategies transparently to enable assessment by citizens and continuous improvement.

Window Of Opportunity: Impact Of Technological and Geopolitical Uncertainty

Participants expressed interest in deeper research and public discourse around the impact of various market and geopolitical scenarios. Indonesia's nickel progress has been shaped by contextual factors such as rising global demand for nickel in clean energy applications like EV batteries. However, battery technologies are constantly evolving, with factors ranging from price and performance to supply and reputational risks (*e.g.*, concerns around child labor and human rights in the sourcing of cobalt from the Democratic Republic of Congo or emissions and deforestation around nickel in Indonesia.)

One issue raised was whether the window of opportunity for Indonesia's nickel downstreaming is shrinking due to the projected growing market share of lithium iron phosphate (LFP) batteries, at the expense of nickel-based batteries (NMC). The government is aware of this challenge and is taking steps to mitigate it, including by managing nickel supplies to balance government revenues in the short term and lowering NMC battery costs to extend their viability.

Geopolitical tensions, particularly the potential for a U.S.-China trade war, were also discussed as a potential significant obstacle to Indonesia's downstreaming ambitions. Chinese companies are major

nickel mine owners in Indonesia, with around 40 percent of production, while Indonesian companies account for just 10 percent. Government industrial policies have also pushed Chinese investors to expand from nickel mining to refining, but this substantial involvement means rising trade tensions between the U.S. and China could be a barrier for Indonesian nickel reaching American markets—especially given how provisions in U.S. legislation discourage the use of minerals tied to Chinese companies. While geopolitical competition could attract more non-Chinese investment, the change in U.S. administrations have reduced the likelihood of a U.S.-Indonesia free trade agreement that could be catalytic for such investments.

ESG: Ambition to Improve Performance

The workshop also focused on how Indonesia can enhance its ESG performance in the mining sector. Participants emphasized that the current polarized environment means that civil society often has to raise issues by "shouting" to get attention on serious social and environmental, as well as governance and corruption concerns.

View of nickel mining activities in Sulawesi, Indonesia. Credit: Nanang Sugi.

For example, corruption in mineral licensing—both upstream and downstream—is a significant barrier to equitable development in transition minerals supply chains globally, and Indonesia is no exception. This can significantly impact the success of downstreaming efforts. Workshop participants focused on ways to reduce corruption risks, emphasizing the risks around strong ties between politicians and the mining industry, and the lack of serious anticorruption commitments from many mining companies. Transparency International-Indonesia recently assessed 121 mining companies and found an average anti-corruption compliance score of only 0.31 out of 10, with only 6 companies having clear anticorruption policies.

Participants discussed initiatives launched by the government to improve ESG performance. The PROPER standard, managed by the Ministry of Environment and Forestry (KLHK), assesses company performance in environmental management. Separately, the Indonesia Sustainable Finance Taxonomy, previously the Indonesia Green Taxonomy, was also developed through an interministerial effort. Meanwhile, the SIMBARA system, managed jointly by the Ministry of Energy and Mineral Resources, the Ministry of Transportation, the Ministry of Industry and the Ministry of Trade and Ministry of Finance, was designed to strengthen commodities traceability. Initially used for coal, SIMBARA now also applies to nickel, and is expected to expand to more minerals.

Participants expressed cautious optimism about the potential of these initiatives to meet the growing demand for improved ESG in Indonesia, driven in parts by concerns from affected communities near mine sites. However, they still need to prove their effectiveness. These efforts could build on Indonesia's commitment to the EITI (Extractive Industries Transparency Initiative), which includes a pilot community engagement in Morowali to ensure a just transition. Government-led initiatives could also learn from market-driven global standards like IRMA (Initiative for Responsible Mining Assurance), which is already gaining traction in Indonesia, with some companies committing to IRMA audits. These efforts can help encourage companies to adopt more responsible mining practices. The discussion also emphasized the need for Indonesian stakeholders to consider ESG standards within the global geopolitical context. As Western actors push for stronger ESG Standards, especially in competition with Chinese companies, Indonesian leaders must balance these dynamics while prioritizing the needs and rights of people.

Connection: Bridging the Gaps Between Stakeholders

A key takeaway from the workshop was the need for stronger connections and collaboration between the diverse range of stakeholders involved in the governance of nickel, other transition minerals and processing. Participants highlighted that while Indonesian stakeholders have substantial expertise, collaboration is limited, impeding progress on equitable development. Deeper dialogue and coordination among various stakeholders is important, including among:

- *Government entities* (central and local), researchers, civil society and local communities.
- *National and local actors*, focused on national policy opportunities and risks at the local level near mining sites projects.

- *Indonesian policy experts and geopolitics and global market analysts*, to provide nuanced perspectives on ongoing reforms within the broader global context.

- *Stakeholders working on equitable development in Indonesia* and those focused on international mineral equity and governance initiatives.

- *Experts on downstream products and markets* (batteries, EVs) – and those focused on mining, to strengthen policy recommendations and connect mineral development with supply chain development and diversification.

The richness of the workshop underscored the depth of expertise in Indonesian civil society organizations, think tanks and academics on transition minerals. These voices must be amplified and included in policymaking to ensure that Indonesia's people benefit from the opportunities provided by transition minerals while managing the associated risks.

Indonesia's experience—both successes and challenges—can serve as a valuable model for other low- and middle-income mineral-producing countries as they develop and implement their own strategies to manage their transition minerals sustainably and equitably.

Author Biographies

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Based in France, Matthieu supports NRGI's work on anticorruption, EITI and civil society partnerships, with a focus on francophone Africa and the Middle East and North Africa. In addition, Matthieu is alternate member of the EITI board.

Matthieu has worked on governance and anticorruption for 15 years, including more than 10 years based in Southeast Asia. From 2012 to 2015, based in Jakarta, he supervised a three-year USAID-funded partnership project on extractive industry governance in the Asia-Pacific region. He led on project administration, coordination and strategy, providing technical assistance to Indonesian co-implementing partners and regional partners from Cambodia, Malaysia, the Philippines, Timor-Leste and Vietnam. In parallel, he also led NRGI's involvement in Myanmar, relocating to Yangon in 2015. He was in charge of NRGI's Myanmar activities, engaging with local civil society, government, parliamentarians and media. From October 2022 to September 2023 Matthieu also served as NRGI's acting governance programs director.

Matthieu was previously the international senior advisor for Vietnam's Towards Transparency (Transparency International's official Vietnamese affiliate). Prior to that, he served as the anticorruption advisor for the Embassy of Sweden/SIDA in Hanoi. He also worked as a program officer for Transparency International France in Paris and for the National Democratic Institute in Algeria.

Matthieu graduated from Sciences Po and from the Sorbonne (University Paris I) with a degree in history and political science. There he published on contemporary Vietnamese politics and society.

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Based in Indonesia, Frenky is both a consultant for NRGI and a co-founder & managing director at Randu Consulting (PT Randu Rambate Gawi). Randu Consulting, in turn, is a public policy consulting firm built on the 20+ years of experience of its founders in development projects, good governance, and civil society in Indonesia. He is skilled in project management, monitoring and evaluation, social research (qualitative and quantitative), and policy analysis. Frenky's prior appointments include serving as a Project Manager for the World Bank's Extractives Global Programmatic Support (ESPS) Grant to bring technical support for the EITI Indonesia Secretariat and also as a Manager in the Economic Governance Department of Transparency International Indonesia, amongst other professional and research positions.

Frenky has a bachelor's degree in anthropology from the University of Indonesia and a master's degree in public policy from the Victoria University of Wellington in New Zealand.

AMIR SHAFAIE
Legal and Economic Programs Director, Natural Resource Governance Institute

Based in London, Amir leads the legal & economic programs team at NRGI responsible for the organization's portfolio of research, policy analysis, technical assistance, capacity development and advocacy related to legal and economic issues. Amir has contributed significantly to NRGI's country programs, including in the Democratic Republic of Congo, Ghana, Mongolia, Senegal and Tunisia.

Amir has facilitated courses on the oil, gas and mining sector with partner institutions including the Catholic University of Central Africa (Cameroon), Columbia University, the Extractive Industries Transparency Initiative, the International Monetary Fund and the Lebanese Center for Policy Studies.

Amir writes about a wide range of natural resource-related subjects including governance challenges associated with European demand for African gas and critical minerals. He is active in international efforts to improve natural resource-based development, including contributing to the OECD's Principles for Durable Extractive Contracts and the African Development Bank's work on resource-backed loans. Amir has previously worked in NRGI's Beirut and New York offices.

Prior to joining NRGI, Amir was a managing associate in the energy, infrastructure and project finance team in the London and Dubai offices of a leading international law firm. Amir's *pro bono* experience includes assisting the International Senior Lawyers Project.

Amir has degrees in history and law, both from the University of California, Berkeley. He also studied international relations at Sciences Po in Paris. He is fluent in English, French and Farsi.

PATRICK HELLER
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As chief program officer, Patrick oversees NRGI's global program portfolio. He previously served as an advisor to NRGI, a position in which he managed the organization's work supporting equitable energy transition in resource-rich countries, including the governance of critical clean-technology minerals, reforms to domestic energy systems, and strategies to avoid excessive economic dependence on fossil fuel extraction. He also led NRGI's work on the governance of state-owned oil and mining companies. He is based in New York City.

Patrick has contributed extensively to NRGI's programs of technical assistance to governments and civil society organizations throughout the world, and to NRGI's capacity development efforts. He has facilitated courses on oil, gas and mining legal frameworks with partner institutions including the University of Oxford, Columbia University, Gadjah Mada University (Indonesia), the Catholic University of Central Africa (Cameroon) and the Universidad Externado de Colombia.

Patrick has supported legal reform and accountability in Africa, Asia, Latin America and the Middle East for more than 20 years for organizations including USAID, the U.S. State Department, the Asian Development Bank, Creative Associates International and the International Center for Transitional Justice. He is a non-resident fellow at the Center for Law, Energy & the Environment at the University of California, Berkeley.

Patrick holds a law degree from Stanford University and a master's in international relations from the Johns Hopkins School of Advanced International Studies.

Critical Minerals Supply Chain: The Role and Impact of ASM

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It is expected that a significant increase in the supply of dozens of so-called "critical minerals" will be needed in the coming decades, for uses ranging from defense to no- and low-carbon energy. Mineral endowment and production capacity have therefore become crucial assets for developing economies. Achieving this supply growth will depend on multiple stakeholders across governments and the private sector. Yet one set of the stakeholders — artisanal and small-scale mining (collectively referred to here as ASM) — tends to be overlooked and may prove to be crucial.

ASM is most widely associated with stigma; it has generally been criticized for its environmental impact, illegal activities, and exploitative nature, including child labor and hazardous working conditions. Yet there is growing acknowledgment of the significance of ASM as both a contributor to global supply of critical minerals and as an economic growth driver in resource rich communities in developing economies.

With that said, ASMs' contributions to and integration with economies, communities and even mining value chains all remains poorly understood. Several studies have considered the social impact and community relationships of this sector, but data on ASM's production, workforce size, overall economic impact and the nature of its economic contribution is poor.

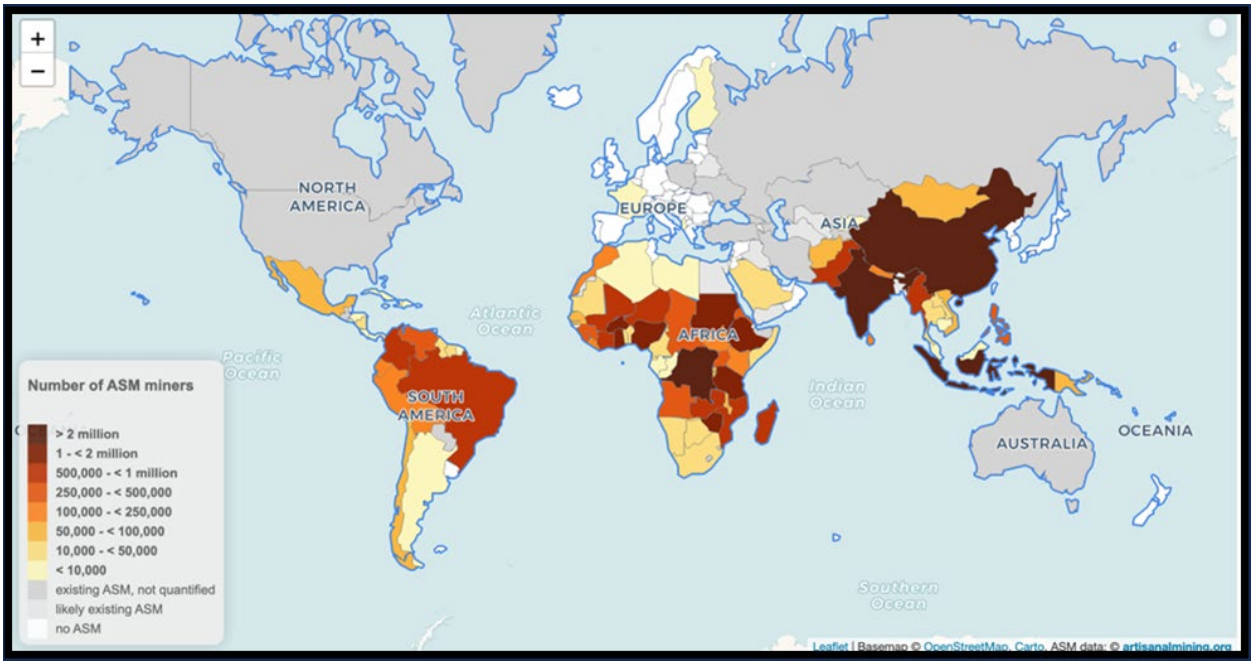
The Payne institute is initiating a research study to consider how ASM can be leveraged most effectively to support the complementary ambitions of growing critical minerals supply and promoting social and economic development. The research will address the role ASM-supplied minerals have in current value chains. It will also explore the value of governmental oversight/regulation for practitioners; ASM's relationships with large-scale mining (LSM) and the community; and industry economics.

ASM Information Gaps

The challenge of determining ASM's impact starts with defining it. Organizations including the United Nations, National Institutes of Health, UNICEF, the World Health Organization and individual countries' mining regulators all define ASM differently, viewing it through one or some of the following lenses: production scale, title holding, sophistication/mechanization, mining philosophy and technical capacity.

Further and related, there is a paucity of (reliable) data, which suggests that the economic contributions of ASM to countries' GDP are often underestimated. Said differently, the economic significance of ASM is often overlooked, primarily because of its informal nature and the absence of regulatory frameworks. Nevertheless, the World Bank and other institutions estimate that ASM supports the livelihoods of more than 40 million people directly and a minimum of 150 million indirectly. ASM makes significant economic contributions in many countries, as is suggested by estimates of the ASM population in many minerals-rich countries across Latin America, Africa and Asia. See Figure 1.

Figure 1
Population % Dependent on ASM Activity

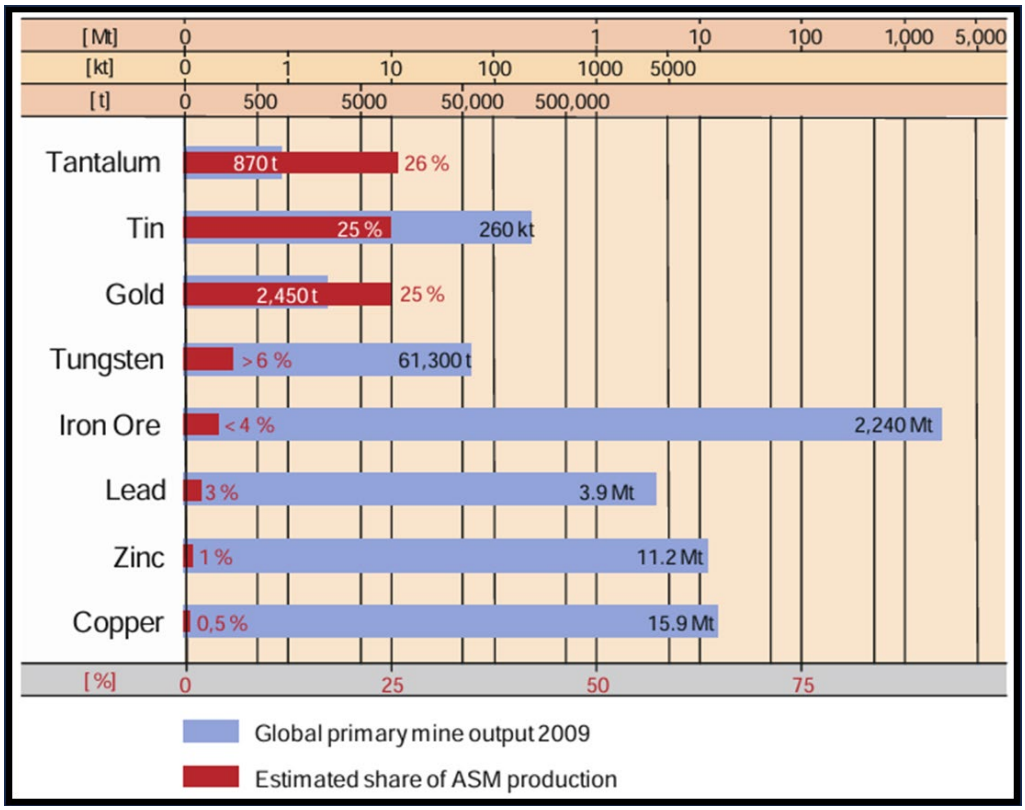


Source: ASM inventory-artisanalmining.org. The oldest data is from 1999; the newest data is from 2024. Last database update: 2025-01-30.

Several initiatives such as the global platform DELVE, developed by the World Bank and the international nonprofit PACT for human development, are trying to address the data gap by fostering collaborative efforts to collect ASM data and offer resources for enhancing mining practices. However, most of these studies tend to focus on gold mining, given ASM's clear relevance in that metal's global production.

Considered by mineral, the contribution of ASM to global supply can differ markedly. ASM is thought to comprise more than 20% of global cobalt production, with significant contributions from countries such as the Democratic Republic of Congo (DRC), Zambia and Indonesia. On the other hand, ASM's contribution to copper is thought to be only 0.5% of global supply. See Figure 2.

Figure 2
Estimated Share of ASM in Global Production of Select Minerals



Source: Dorner *et al*., 2012- POLINARES Working Paper N 19-2012.

Note: The figures in the chart above exclude production from ASM miners who are "contracted by 'large scale' mining or smelter consortiums." Nickel and Copper are examples of minerals with skewed production reporting towards formal or LSM mine production due to the existence of "contract mining" with ASM and direct selling of ore to private custom smelters.

Government Engagement

While ASM is, often by definition, informal, there is interaction between it and the government or other stakeholders. There are a variety of governmental programs that manage the legal rights (tenure), conduct and regulatory parameters of ASM. Separately but related, relationships between ASM and Large-Scale Mining (LSM) range from symbiotic to hostile. The linkages between these actors lead us to explore current formalization, sustainability and economic integration policies and opportunities, as well as to assess governments' role in balancing ASM's economic contributions with environmental protection and social welfare.

Our research will focus on the Global South, given the dependency on ASM activity and the valuable insights the "region" provides on economic resilience, policy challenges, environmental sustainability and social justice. We will focus on Chile, Zambia and Indonesia as they offer very different illustrations of government engagement and relationships in the sector and mine for some of the largest volume critical minerals (including lithium, cobalt, copper, platinum/palladium metals, and nickel).

Chile is characterized by policies and resources linked to the promotion and sustainability of ASM for more than six decades. The country's institutional framework, represented by ENAMI, a state-owned company, has enabled the ASM sector to access technical support and advice, as well as formal, sustainable and competitive market access. This model has demonstrated efficiency and efficacy, making it a valuable reference for analysis to compare and identify gaps faced by other producer countries' legal instruments. With that said, we intend to examine the potential for ENAMI and its model to be even more effective.

Zambia's critical minerals policy promotes and formalizes the small-scale mining sector, particularly through initiatives to encourage local, private sector participation as well as value addition via domestic processing (which should improve artisanal miners' access to buyers). Examples include a country-wide aeromagnetic mineral mapping project to be conducted by a private exploration company, X-Caulibar, and, in its strategy to ramp up national copper production to three million tonnes per year from the current 800,000, an expected contribution from ASM of 50,000 tonnes. However, currently there is no government direct engagement or oversight in the ASM sector other than the policy pronouncement. Noticeable ASM custom milling/smelting and trading is instead supported by private and NGO efforts — especially with respect to copper and high-grade manganese.

Indonesia has a commodity-specific policy banning export of raw nickel ore and encouraging onshore midstream and downstream beneficiation. The country has also upgraded its processing capabilities and thus can export higher-value nickel goods. Despite the government setting up policies to regulate the ASM sector, unforeseen challenges have emerged. One such challenge is lack of price support for ASM-mined ore sold to smelter operators. The government sets a floor price, but, as competition has risen to sell ore domestically — because it can no longer be exported — smelter operators have offered lower prices; compounding the challenge for ASM operators, in some cases these same smelter owners have ties to LSM nickel mines or own LSM licenses through their subsidiaries.

The Payne study is borne out of a view that ASM can be harnessed. As is suggested by the country examples above, countries' policies for critical mineral development and export do not just have significant bearing on their ASM sectors; they also impact ASM's ability to contribute to country goals. Further, institutional structures supporting ASM appear to be important for ASM to operate with necessary environmental and health safeguards as well as to realize its productive and economic potential. If successful, we will offer recommendations for policy and institutions/governance that provide the "win-win" that helps the social and economic development for ASM communities and, in so doing, optimizes countries' critical minerals development.

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Clarkson Kamurai is a Critical Minerals Program Manager and Research Associate for the Payne Institute at the Colorado School of Mines. Clarkson is a mining engineer with over 18 years of mining engineering experience, in which he holds a Master's degree. He has experience in precious and energy metal development and extraction. Clarkson's experience in these areas is drawn from numerous mining operations and project developments across much of Sub-Saharan Africa and South America. He is currently enrolled in the Energy and Mineral Economics Division at the Colorado School of Mines and about to start his Ph.D. studies related to critical minerals supply chain, an area for which he has a deep passion.

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Leading Economies' Industrial Policies Risk Reinforcing Inequities in Mineral Value Chains

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The last few months have seen a flurry of actions by countries aiming to capture more economic activity within their borders, including in relation to the mid- and downstream of mineral value chains. The U.S. has announced an investigation that could lead to tariffs on processed mineral imports. In response to U.S. tariffs on other imports, China has restricted rare earth mineral exports. The EU has announced the first tranche of strategic mineral processing projects in Europe that will receive support under its Critical Raw Materials Act. Given the flurry of activity, a casual observer may get the impression that these government policy actions around mineral value chains are new and only the result of recently increasing trade conflicts. But they are also the latest in a series of actions by various countries aimed at establishing or strengthening their position within mineral value chains.

To support policymaking on mineral value addition in mineral-producing countries, including to provide a better understanding of the competitive landscape, we have surveyed the policies that governments have adopted in recent years. We have focused on the copper, lithium and nickel value chains and identified 123 policies adopted by different countries up to April 2025 that target these value chains (see below for further details on our methodology.)

High-Income Countries are Using More Tools to Support Mineral Value Addition

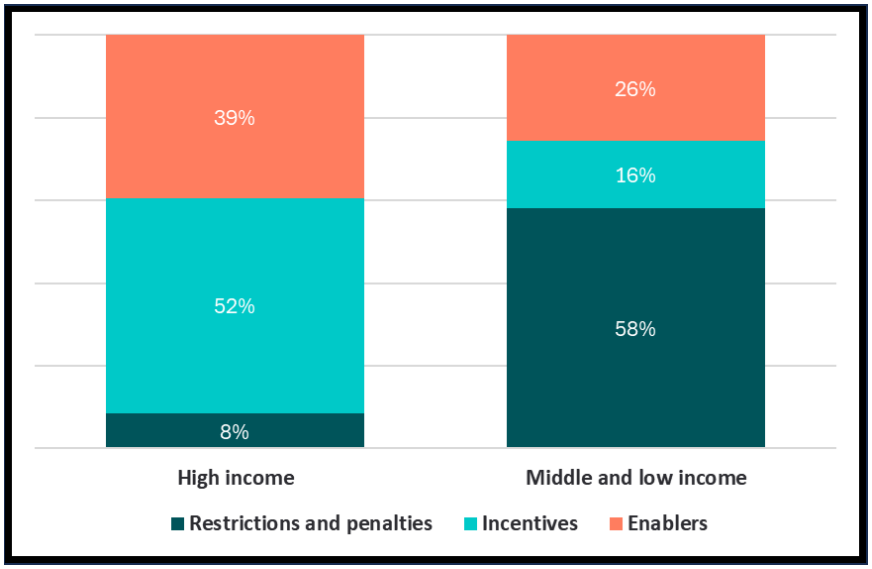
High-income mineral-producing countries—including Australia, Canada, European Union (EU) member states and the U.S.—have adopted considerably more value addition policies than low- and middle-income countries. The average high-income producer country has introduced five policies during the surveyed period, while the average middle-income country (excluding China) has introduced two policies and the average low-income country has introduced only one. China's policy toolkit is difficult to fully assess due to information challenges, but the country has implemented active industrial policies to support its mineral value chains since the 1980s. High-income non-producing countries have also been active in the past five years. Countries such as France, Germany, Japan, South Korea and the U.K. have introduced an average of five policies in the past five years.

While counting policies has limitations, this greater activity by high-income countries reflects the multi-pronged strategies that many are pursuing. Most policy instruments can be broadly categorized as restrictions and penalties, incentives or enablers (for more on the different categories of policies see here.) During the period under consideration, high-income countries and China predominantly used incentives

and enablers (though, as noted above, China introduced export restrictions for several minerals other than copper, lithium and nickel.)

Many of these high-income country policies involve the use of public funds to, among other things: provide direct financial support to value addition facilities in the form of grants, concessional loans, subsidies and sovereign guarantees; invest in energy and transport infrastructure; establish training programs to fill skills gaps; invest in research and development to encourage innovations that could provide a competitive advantage; and stockpile mineral supplies to ensure adequate supply for the country's mid- and downstream industries. For example, the U.S. has provided concessional loans to several domestic projects including USD 700 million to a planned lithium refinery, the EU Commission has committed funding of EUR 1.8 billion over the next two years to support European battery manufacturers and Canada has set up a Critical Minerals Infrastructure Fund of CAD 1.5 billion to support projects across the value chain. While we have not counted partnerships as policies, partnerships between high-income countries have also been used to channel public funds to processing projects.

Figure 1
Copper, Lithium and Nickel Value Chain Policies Introduced by Countries of Different Income Status



Note: For more on the categories of policies see NRGI, Six Keys to Unlocking Equitable Value Addition, 2024.

Source: Authors calculations based on IEA Policies and Measures Database, the OECD Inventory of Export Restrictions on Industrial Raw Materials, the New Industrial Policy Observatory and the authors' own research.

While low- and middle-income mineral producing countries benefit from access to minerals, their generally greater infrastructure constraints and weaker industrial base constitute a disadvantage in pursuing mineral value addition. A supportive policy environment is therefore particularly important for such countries. However, given their greater financial constraints, middle- and low-income countries tend to rely on restrictions and penalties, which may require less government spending to implement. Several governments, including Nigeria and Tanzania, have started issuing mining licenses only to companies that

commit to value addition. Other governments restrict the export of unprocessed minerals – such as Indonesia, Namibia and Zimbabwe – or charge higher taxes on them.

Some low- and middle-income countries also have incentives and enablers in their toolkit. However, these often come in the form of tax incentives or regulatory support rather than financial support. For example, Madagascar offers a lower royalty rate for processed exports, Indonesia applies lower taxes to value addition projects and the DRC, Zambia and Tanzania are establishing special economic zones. The DRC and Zambia are also attempting to cooperate on developing a battery value chain. Colombia and Mexico have established, or plan to establish, state-owned enterprises including to develop value chains.

The differences in the policies used by countries of different income status mirror a broader trend of high-income countries pursuing more active industrial policies that tend to use public funding, while other countries rely on trade restrictions. That said, high-income countries and China are increasingly also considering restrictions on technology exports. For example, the Chinese government is currently considering imposing export controls on lithium refining (and cathode) technologies.

The Policy Choice and Cost-Benefit Analysis

This competitive landscape of value addition policies underscores the need for mineral-producing countries to adopt clear strategies grounded in robust economic feasibility and cost-benefit analysis to develop domestic mid- or downstream activities. Such analysis is necessary to determine which projects are feasible, desirable and a priority, and how the policy approach used to advance them may change that calculus.

For countries without a clear comparative advantage, some policies are likely to be insufficient to encourage value addition and may come at significant cost. Export restrictions on raw commodities, for example, have rarely succeeded in increasing domestic processing—except in contexts where key success factors, such as market power, are already present. More often, such measures have led to a decline in mining activity, as illustrated by Indonesia's contrasting experience with nickel and bauxite export restrictions.

Incentives are likely to be more effective if sufficiently high to make projects commercially viable. However, particularly for countries with constrained public finances, some incentives may carry opportunity costs that outweigh the potential benefits of value addition. For example, NRGI analysis found that Ghana's pursuit of a lithium refinery could cost around $500 million in foregone government revenue from the corresponding lithium mining project.

Some enabling measures, such as infrastructure investment, also involve trade-offs—but design choices matter. For instance, shared use infrastructure may raise costs but still improve the cost-benefit calculus. That said, not all enablers carry significant costs. Implementing effective regulatory frameworks for mid- and downstream industries to manage environmental, social and corruption risks will be important for attracting investment. Regional cooperation, though not without challenges, can also improve the conditions for value addition.

Leading Economies' Industrial Policies Risk Reinforcing Inequities

As governments work to identify and take advantage of strategic opportunities to move along the value chain, they must account for the impact of the policy approach on the costs and benefits of value addition and recalibrate as necessary. In cases where the short-term costs are high and long-term benefits are likely limited, a government may better use its finite political capital, time or money on other ways that citizens can benefit from their mineral wealth (for example, taxation of mining projects or supporting local companies to supply goods and services to them.)

Beneficial Value Addition in Low- and Middle-Income Countries Should Receive External Support

Under current conditions, most low- and middle-income countries will struggle to meaningfully reduce the inequities in copper, lithium and nickel value chains. China's dominance of existing activity, along with the industrial base and infrastructure already in place in high-income countries, gives both a substantial head start in establishing new mid- and downstream activities.

This advantage is likely to be further reinforced by the limited effectiveness of penalties and export restrictions, especially when compared to the spending-based policies that wealthier countries are deploying.

However, accepting inequitable global mineral value chains would be unjust. It is also not even in the interests of high-income countries and China. Geographic concentration of value chains increases the risk of supply chain shocks (as emphasized recently by the IEA), particularly in an environment of increased geopolitical competition. It is also likely to exacerbate public frustration in low- and middle-income mineral producers, further increasing the risk of mineral supply disruptions and resulting in less global cooperation on supply chain management and other issues such as the climate crisis. Value addition in low- and middle-income countries can reduce costs and emissions from these industries under the right conditions, leading to more efficient and greener value chains. Collaboration can therefore help high-income countries compete as the world enters a new period of great power politics.

As a result, despite the recent turn inwards of some high-income countries and China, they should provide support to low- and middle-income country efforts to develop mid- and downstream mineral-based industries, where this aligns with mineral producer countries' priorities and economic circumstances. This could include financial or technical support, market access or carve-outs for any future technology export restrictions. The EU's recent designation of two processing projects in low- and middle-income countries—a Brazilian nickel and cobalt refinery and a Zambian cobalt refinery—as Strategic Projects (under the Critical Raw Minerals Act) is an encouraging development. However, with access to an advisory board on financing being the main benefit currently offered to third-country strategic projects, it remains uncertain how the EU will support their implementation and secure the necessary public and private funding.

High-income countries and China should also not distort global trade through high levels of financial support to their own domestic industries. Nor should they prevent the reasonable use of industrial policies of low- and middle-income countries. For example, some trade agreements have restricted trading partners' policy space to offer preferential prices to domestic facilities, while high-income country tariff escalation on finished goods adds further barriers.

As holders of a significant share of the world's mineral reserves, low- and middle-income countries can leverage this position to increase their chances of securing external support. That said, policymakers in these countries should recognize that development partners are likely to only support projects that are already nearly viable—for example, projects that would proceed with the help of a concessional loan to reduce the cost of capital or guaranteed offtake arrangements to increase bankability. Implementing a policy framework that supports viable mineral value addition projects that align with their national development plans therefore remains the critical first step for governments of low- and middle-income countries.

Endnote

This article draws on data from the IEA Policies and Measures Database, the OECD Inventory of Export Restrictions on Industrial Raw Materials, the New Industrial Policy Observatory and our own research. The survey covers 2019 to April 2025 for all countries, with a deeper focus on NRGI program countries and other large producers of copper, lithium and nickel from 2010 onwards. We have not accounted for policies that are not specific to mineral value chains: for example, we have not surveyed broader industrial policy that applies to several sectors. We have also only been able to account for different levels of policy detail and implementation to a limited extent.

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Thomas supports economic policy work across Africa, including on how countries can navigate the opportunities and challenges that the global energy transition provides for their mineral and petroleum sectors. This ranges from providing policy advice to governments to building the capacity of civil society actors. Before moving to London, he led NRGI's research, technical assistance and capacity building on economic policy issues in Tanzania. He is a member of both the sub-Saharan Africa and legal and economic teams.

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Benchmarking Opportunity in Transition-Critical Mineral Markets

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Introduction

Producer countries seeking to turn transition-critical mineral booms into lasting development outcomes must navigate market volatility, complexity, and uncertainty. The recent rise and crash of lithium prices underscore how quickly market realities can outpace expectations; in Brazil and Ghana, overoptimistic projections and plans have translated into deflated public revenues and challenged downstream ambitions. Given these challenges, the Jain Family Institute (JFI) is developing a suite of tools to reduce information asymmetries and support policymakers in assessing and managing market risks. JFI has begun with the *Mineral Market Dashboard*, which benchmarks varying projections for transition-critical mineral market growth and maps the distribution of historical production and current estimated resources and reserves to enable more grounded discussions on the scale and distribution of opportunity.

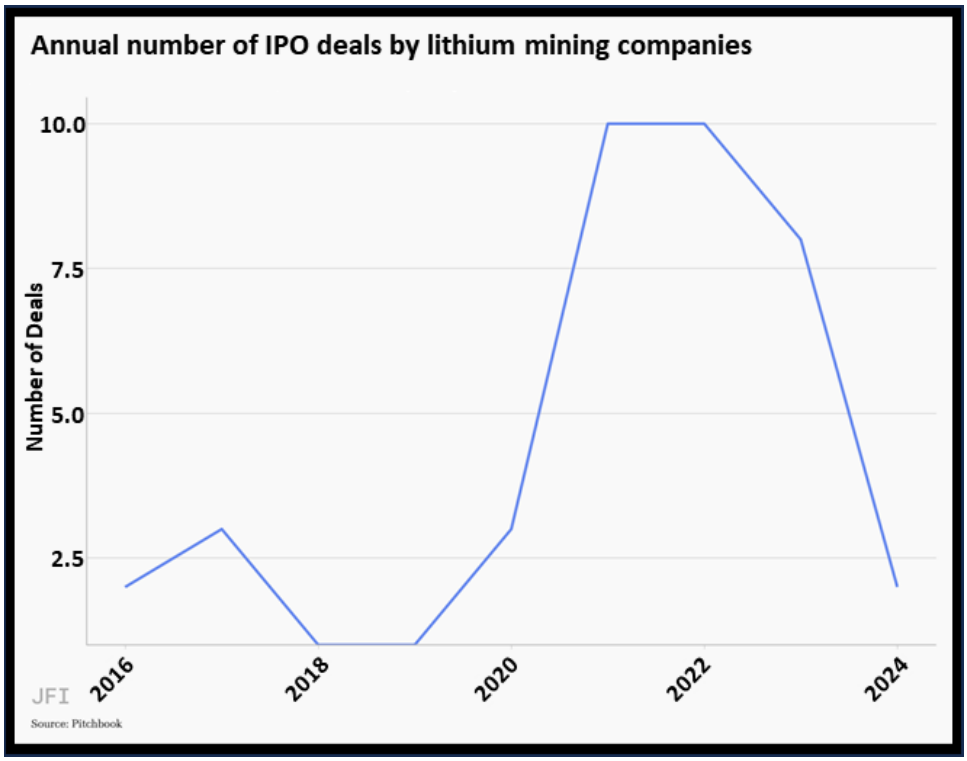
Context on Lithium Development in Brazil and Ghana

The lithium market in the summer of 2022 was burning hot. Market prices for lithium carbonate were skyrocketing, up 65% from the year prior and nearly 700% from 2020. The much-anticipated growth, driven by electric vehicles and their lithium-ion batteries, was materializing and taking off. Future growth forecasts were optimistic, too, buoyed by recent major climate policies, including the Inflation Reduction Act in the U.S. and Fit for 55 in the European Union. Prospective miners of all sizes were racing to cash in, and a flood of junior lithium companies worldwide sought new investments – among them Sigma Lithium of Brazil, Atlantic Lithium of Australia, and Piedmont Lithium of the U.S. Meanwhile, countries with rich lithium deposits saw the opportunity to capitalize and made strides to streamline permitting, shore up lithium-specific taxation regimes, and guide a slice of the investment toward their borders. The desire to turn the lithium boom into meaningful local development outcomes – and to avoid repeating the extractivist legacies of past commodity booms that left lasting environmental damage but few enduring benefits for surrounding communities – was strong, from Chile to Zimbabwe. For many resource-rich countries, the focus was not only on expanding into downstream industrial processes but also on ensuring that this new wave of investment redefined what it means to develop with minerals: delivering jobs, infrastructure, and long-term value for local populations rather than just export revenue.

In Brazil, Sigma Lithium spent much of the 2010s consolidating mineral rights around the Jequitinhonha Valley, a region tucked into the northeast corner of Minas Gerais state that contains 85% of Brazil's deposits. The valley was largely overlooked at the time – existing operations were small-scale and mostly supplied the domestic market. By 2021, Sigma had drilled to define known reserves, pitched investors on their planned production facilities, and raised sufficient capital for mine development. Around a wave of

new lithium market entries, Sigma stood out. Its flagship Grota Do Cirilo project was slated to be "quintuple zero" – including achieving goals for low carbon, low water use, and low toxicity. Their objective was to develop the valley's lithium resources efficiently and sustainably while creating opportunity and minimizing risks for the local community. Policymakers moved to support them – in 2022, the Bolsonaro Administration lifted export restrictions on lithium. In May 2023, a month after Grota Do Cirilo entered production, InvestMinas of the Investment and Trade Promotion Agency within the Minas Gerais State Economic Development Secretariat rebranded the region as Brazil's "Lithium Valley" to recognize its strategic importance for local industrial development. A day later, speaking at the Nasdaq's opening bell ceremony in New York alongside the Governor of Minas Gerais and the Deputy Minister of Mines and Energy in Brazil, Sigma's CEO Ana Cabral-Gardner highlighted the project's potential to attract downstream processing industries and develop a sustainable lithium supply chain in Brazil, calling on the Lithium Valley "to bring prosperity to the people of Vale do Jequitinhonha by growing the lithium industry while ensuring the social economic development of the entire region."

Figure 1
Lithium Mining Company IPOs



While Sigma targeted the opportunity to sell beneficiated spodumene to China for refining, state officials were focused on the potential to expand the region's presence further down the lithium value chain. A small domestic precedent already existed: Companhia Brasileira de Lítio (CBL) has operated in the Jequitinhonha Valley since 1991, processing around 2,000 tons of lithium chemicals annually (just 4% of its 45,000-ton spodumene output) to serve the domestic market. InvestMinas aimed to build on this foundation and support not only expanded extraction but also local processing, R&D, and industrial

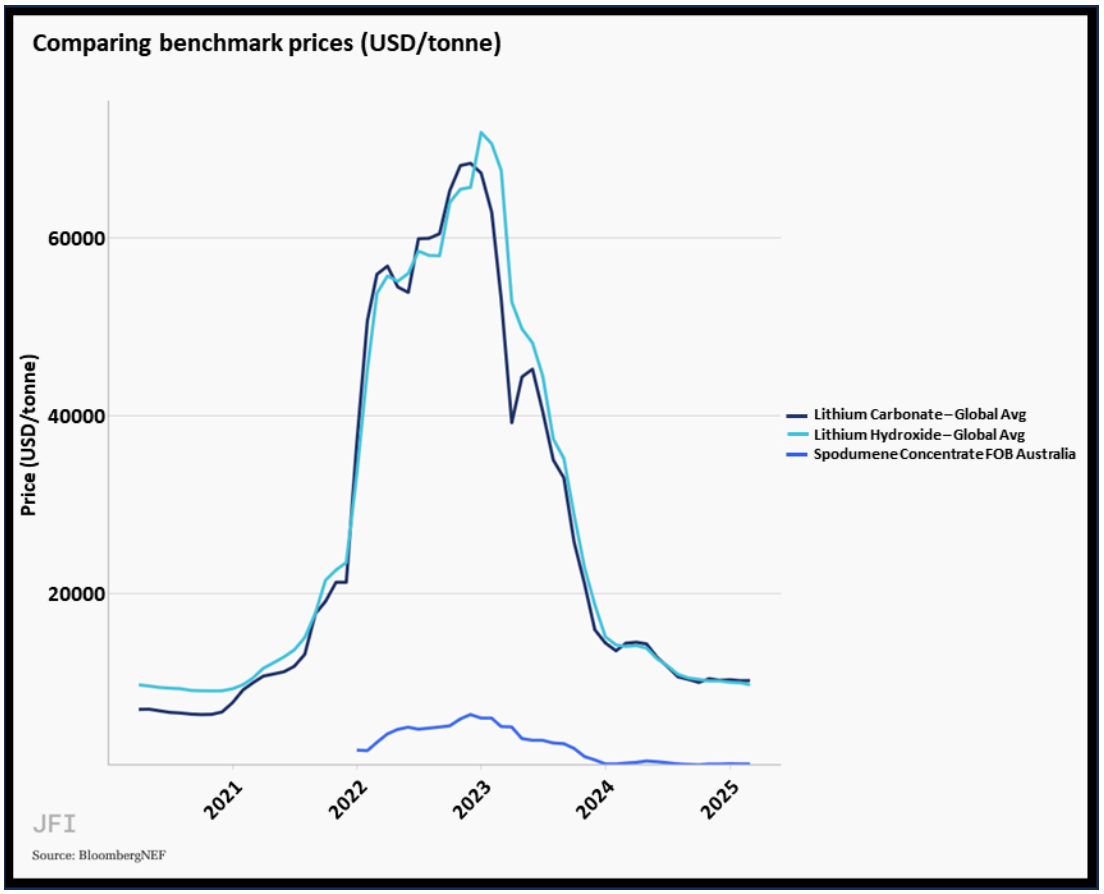
integration, positioning the Lithium Valley to eventually produce lithium carbonate for export and play a larger role in global supply chains.

Across the Atlantic, Piedmont Lithium and Atlantic Lithium were partnering to develop a greenfield deposit in Ewoyaa, Ghana, a rural region with strong infrastructure linkages. The development opportunity for Ghana was clear: its government had negotiated a uniquely favorable fiscal regime for the project, and the mine was key to the country's broader ambitions to build a value-added minerals sector. While 50% of Ewoyaa's output was committed to Piedmont's planned processing facilities in Tennessee, Atlantic Lithium announced intentions to establish a downstream processing capacity locally, creating the potential for Ghana to advance into the midstream. In support of this vision, Ghana's Minerals Income Investment Fund (MIIF) would eventually secure a 5% stake in the project, in line with the stated vision of "establish[ing] itself as a leading hub in Africa in the EV supply chain."

In January 2023, however, four months before Grota Do Cirilo entered production and one year before Ewoyaa was initially planned to break ground, lithium prices began to slip. Demand growth had been overestimated – greatly – and signs of a mismatch between ambitious supply buildouts and slower-than-expected uptake were emerging. EV sales growth was softening globally; subsidy rollbacks, inflation, and consumer hesitation over charging infrastructure and battery range were dampening enthusiasm. Battery manufacturers and automakers anticipated future price declines and began drawing down existing inventories rather than locking in new long-term contracts at elevated prices. Meanwhile, new supply from Australia and China was entering the market faster than anticipated, contributing to a growing surplus. BNEF was now projecting overcapacity in the lithium market lasting until 2030 at the earliest.[1,2] Prices are yet to recover; the ensuing months spelled disaster for lithium producers globally, which are still struggling to stay afloat. Of the nearly 400 lithium projects with known activity status in S&P's mining project database, only 12% are currently operating in advanced production stages.[3] The global average of benchmark prices for lithium carbonate fell from a high of $68,366 per ton to $10,238.00 today, about 15% of their value in December 2022; spodumene concentrate (what Grota Do Cirilo and Ewoyaa sell), fell from $6,400 per ton to only $840 per ton today, 13% of its value at peak.

Sigma and Atlantic are both weathering this storm, but it has put ambitions for local value capture and supply chain investment to the test. While Sigma has remained on track with production targets and is consistently producing at capacity, it has been selling its 5.5% lithium concentrate at a fraction of the prices forecasted in its January 2023 Technical Feasibility Study. The municipalities of Araçuaí and Itinga, where Grota Do Cirilo is located, had based their expectations of potential royalty payments on the figures quoted in Sigma's feasibility study; about USD$21 million in the first and second year of production, tied to Sigma's expectation of nearly $1.6 billion in gross revenues in both years, and Brazil's 2% royalty on gross revenue – 65% of which is then allocated to the municipality where extraction occurs. However, these projections relied on a sale price for their lithium concentrate averaging at $5,774 per ton in year one and $6,075 in year two, nearly 700% higher than SC6 benchmark prices today. The implication is that, according to data from the National Mining Agency, Araçuaí and Itinga received the equivalent of only about USD$1.8 million in 2023 and USD$2.5 million in 2024 in royalty payments from Sigma Lithium – only about a tenth of the value projected in the cashflow model of the technical feasibility study. Both mayors expressed this shortfall to JFI during our visit to the valley in February 2024.

Figure 2
Lithium Prices Over Time



This shortfall of about $20 million per year will be sorely missed. Jequitinhonha has another moniker: the Valley of Misery. It is one of the poorest regions in the country and faces acute food scarcity. Previous local commodity booms in lumber production, diamond, and gold mining in the previous two centuries translated not to lasting development outcomes but instead legacies of environmental degradation that continue to pose challenges to local agriculture and the livelihoods dependent on it. For its part, Sigma's aim to minimize the environmental footprint while bringing growth to the region seems to have been successful; it has become one of the largest employers in the valley, has consistently prioritized local hiring and skills training through partnerships with public and private institutions, and maintained strong community engagement and support for public services and local infrastructure.[4] Royalty payments, however, offer municipalities the chance to self-determine investment in social and public capital – resources that are flexible, locally directed, and essential for building the kind of structural change that outlasts any single project or boom.

Sigma has, impressively, been able to survive without acquisition (it considered several offers throughout 2024), meet its production targets, and even expand production. More broadly, however, the market volatility has put the State's aspirations for downstream processing to the test. Companhia Brasileira de Lítio has announced plans to "double mining capacity and triple lithium chemicals production," and

research partnerships have been formed with institutions such as SENAI (Serviço Nacional de Aprendizagem Industrial) to support local lithium processing and battery manufacturing capabilities. SENAI operates multiple research initiatives in Minas Gerais, including collaborations focused on mining innovation, permanent magnet production, and lithium-ion battery development. Whether these initiatives will materialize into expanded processing and meet the objectives to establish the Lithium Valley within the international value chain is yet to be seen.

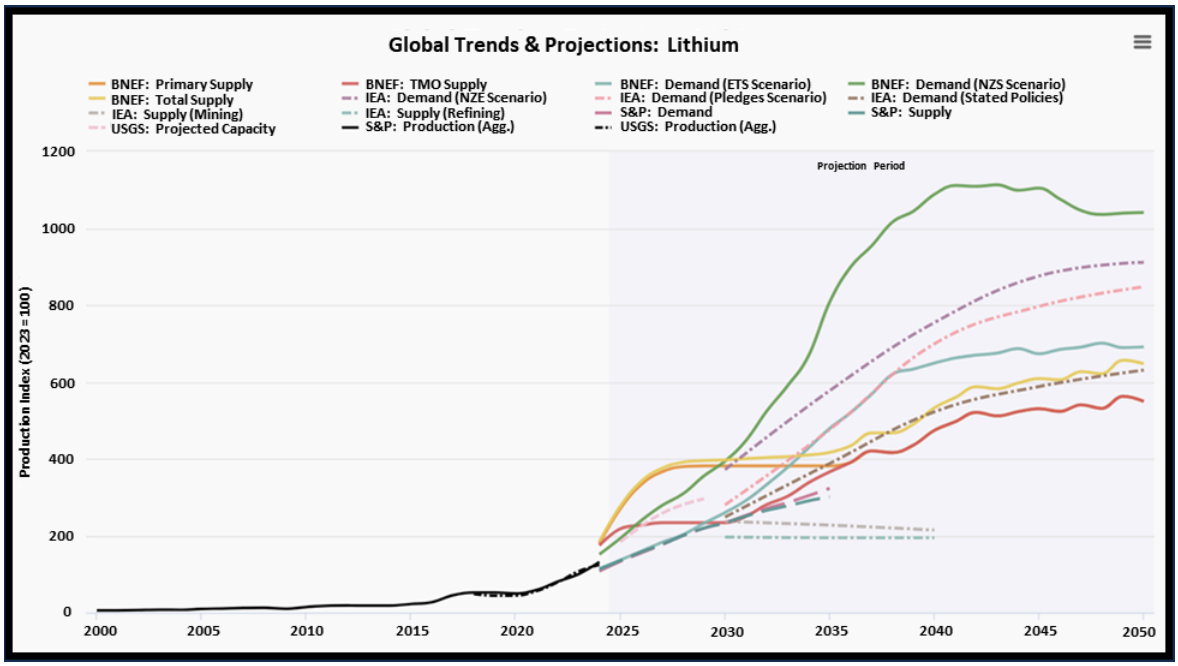
An even more challenging story unfolded for Atlantic Lithium's Ewoyaa project in Ghana. Like many other junior lithium miners over the past two years, Atlantic Lithium has repeatedly pushed back the mine's start date. It was originally planned to start production in mid-2024, but more recent targets reference the end of 2026 for initial operations and 2027 for full capacity; Atlantic Lithium recently announced that it is ready to break ground on construction. Eager to begin generating cashflow, the company has also downgraded on-site processing to a lower concentration spodumene product, which will of course sell for less, before adding more sophisticated processing once it has the revenues. Further, with pressure from shareholders including Piedmont, Atlantic Lithium has sought to sell forward the remaining 50% of Ewoyaa's output to raise funds, invariably at the expense of developing processing and refining capacity from the project within Ghana. The implication is that Ghana initially expected to receive royalties from the project last year, but now will not receive them until next year, at the earliest, and at a significantly reduced royalty base – both from suppressed market prices and the reduced sales price of lower quality product. In the long term, the ability of Ghana to move downstream based on Ewoyaa's production and establish Ghana within the global EV supply chain is in question.

These episodes highlight the complex challenges of transforming temporary booms in commodity sectors into durable solutions that drive long-term investment, growth, and prosperity, despite how often the potential to do so is touted. They also highlight a key misalignment between the role of investors and miners and state actors in resource-rich countries seeking to retain more local value from extraction. Across commodities, miners are incentivized to present the *best-case scenario* of project outcomes to effectively raise capital and support for project development; doing so is the industry norm, especially for junior miners without cashflows seeking to break into the industry with undeveloped and promising projects like Sigma and Atlantic. Companies can navigate headwinds as they arrive with the capital they have secured. However, local policymakers seeking to plan effective public programs utilizing revenues and long-term development from temporary commodity projects must be able to reference the *worst-case scenarios* and everything in between. Being able to reference independent and reliable forecasts, or at the minimum, compare producers' forecasts against benchmarks, is essential for local entities' ability to budget social projects effectively.

For these reasons, JFI is developing tools and research (including the *Mineral Market Dashboard*) to support policymakers in host countries, at all levels, to more accurately plan across future outcomes. We have begun by developing the *Mineral Market Dashboard*, which we will use to inform and orient interlocutors on the universe of transition-critical mineral market growth projections (which vary considerably), as well as producer country's past, current, and potential future positioning across these markets. The dashboard is intended to create products that can ground and benchmark development ambitions tied to these commodity markets, which are often overhyped at the expense of achieving

realistic and durable outcomes, and inform discourse on the scale of opportunity available to producer countries from transition-critical mineral market growth.

Figure 3
Global Lithium Projections Comparison (Indexed) within JFI's *Mineral Market Dashboard*



Sources of data: Bloomberg New Energy Finance (BNEF), International Energy Agency (IEA), S&P Global, and the U.S. Geological Survey (USGS).

Mineral Market Growth and Implications for Producer Countries

Understanding the volatility of transition-critical mineral markets requires grappling with the limitations of existing forecasting approaches. As detailed in the Technical Appendix (see *Forecasting Mineral Market Growth*), scenario models, mine-level forecasts, and equilibrium models each serve distinct purposes and reflect different assumptions, and thus all come with their unique set of strengths and weaknesses. Unfortunately, these models are frequently misunderstood or misapplied in public discourse and policy planning, and depending on the objectives of the user, can be manipulated. Most rely on deterministic frameworks that present single-outcome projections, offering limited insight into the range of possible futures or the uncertainty inherent in fast-evolving markets and the real world. The outputs of the Projections tab of the Dashboard addresses this challenge by offering a structured, side-by-side view of leading deterministic forecasts. While true stochastic modeling remains rare and resource-intensive, comparing a curated range of high- and low-bound projections allows users to benchmark assumptions and assess the plausible spread of outcomes. This approach doesn't eliminate uncertainty, but will provide a practical, accessible second-best for policymakers planning amid volatile and fast-moving market conditions.

In the long run, the extreme rise and fall in lithium prices over the past couple of years may ultimately be a symptom of an expanding market finding its footing. As new technologies emerge, demand expectations evolve, and as more capital flows into refining and production capacity, prices may settle into a more stable range. Market exchanges and public auctioning, which are essential for global price transparency, have only recently emerged for the lithium sector and are still maturing; widespread adoption will bring clarity. However, for producer countries seeking to build stable revenue streams or develop downstream industries, long-term optimism for market development is difficult to reconcile with near-term shortfalls and budgetary constraints. Subnational governments at the municipal and state level are responsible for managing infrastructure, services, and investment plans today, not in 2030. Their planning depends on royalty revenues that fluctuate with international prices and often reflect decisions made beyond their control.

As of now, prices have not recovered, the state of suppliers remains in question, and consistent and rapid advancements in battery technologies have important implications for material mixes and intensities. This leaves all actors – miners, investors, governments, and analysts – facing a future defined more by uncertainty than clarity. Further, commodity markets are inherently volatile – even the most established[5] – and are sensitive to a suite of risks and uncertainties ranging from the natural (geological variability, extreme weather), to project-level (spikes in water or energy costs, social resistance), to domestic and international policy (fiscal regime changes, trade policies, political instability), to name a few. Increasing (and inconsistent) tariff policies and trade tensions globally will only magnify these uncertainties. Producer countries must be equipped with robust strategies to navigate the volatility that defines commodity markets (see our previous report, Mineral Wealth and Electrification, for a detailed discussion).

Setting aside market uncertainty, royalty revenues are sensitive to policy decisions made at the federal level and beyond the control of subnational governments, which can have major implications in large countries such as Brazil. Contract terms, specific deductions allowed (such as on transportation or processing), and loose guidelines on transfer pricing (the price of goods and services sold between entities of the same multinational company, often across borders) are typically negotiated and governed at the national level but have key implications for local governments. Not to mention the seemingly innumerable design pathways for royalty regimes (also discussed in Mineral Wealth and Electrification), and decisions on how revenues are distributed. Understandably, national governments may favor foreign investment or downstream industrial objectives that reduce the effective royalty base for local governments. The implication is that even with high mineral endowments and active mining, many producing regions may see limited public revenues, undermining their ability to use extraction as a springboard for broader development goals.

The recent boom-and-bust cycle in the lithium market serves as a potent case study of initial projections colliding with the complex realities of market adoption and supply responses, leading to a dramatic price correction. This forecasting challenge is not unique to lithium; it plagues the entire transition-critical minerals sector and commodity markets more broadly. As the experiences in Minas Gerais and Ewoyaa demonstrate, the gap between the optimistic scenarios often required to secure investment and the inherent volatility of commodity markets can create significant obstacles for effective development planning. When local governments anchor budgets to peak projections, subsequent market downturns

can jeopardize essential public programs and undermine the goal of leveraging resource wealth for lasting community benefit.

To avoid these pitfalls, planners require insights that not only capture the full range of risks but can also reflect the complex policy designs that can help mitigate them. Yet most existing tools – whether academic equilibrium models or investor-oriented forecasting systems – are poorly suited to this task. Bridging this gap will require a new generation of tools: ones that help stakeholders understand the full range of potential outcomes and plan not only for best-case scenarios but also for the full distribution of risk, as well as accessible and public resources that democratize information essential to robust public planning capacity.

JFI has developed the *Mineral Market Dashboard* as a first step to addressing these needs. This platform synthesizes and visualizes data from leading global sources like S&P Global, Bloomberg New Energy Finance (BNEF), the International Energy Agency (IEA), and the U.S. Geological Survey (USGS). By analyzing numerous and diverse forecasts, historical production patterns, and resource data within a single interface, the dashboard will enable content that critically evaluates the often-conflicting narratives surrounding mineral market futures. Our upcoming publications will be a key resource for policymakers, analysts, investors, and other stakeholders who want to base their strategic decisions on a deeper, more comprehensive understanding of these fast-changing global markets. See the *Technical Appendix* for a detailed discussion of the dashboard's elements, which pull together different views on where markets might be heading, where they have been, where the minerals are, and who ranks where today, to foster a more informed basis for policy dialogue, strategic planning, and development initiatives aiming to build resilience amidst the volatility of global commodity markets.

Conclusion

Transition-critical mineral markets offer real promise for resource-rich countries and subnational governments seeking new development pathways. Yet these markets are complex, dynamic, and volatile. When fiscal frameworks are not explicitly designed to account for market complexity and uncertainty, budgets may be built on overly optimistic expectations, development plans can quickly unravel, and the promised economic and social gains for local communities may never materialize. Policymakers in resource-rich countries urgently need more robust, accessible tools and research that reduce information asymmetries and support better decision-making and policy design under conditions of volatility and complexity. The *Mineral Market Dashboard*, and the insights it will enable us to publish, is JFI's first step toward building tools and analysis that enable decision-makers to navigate uncertainty, test assumptions, and develop more robust development plans for long-term value creation from the boom and bust of commodity sectors.

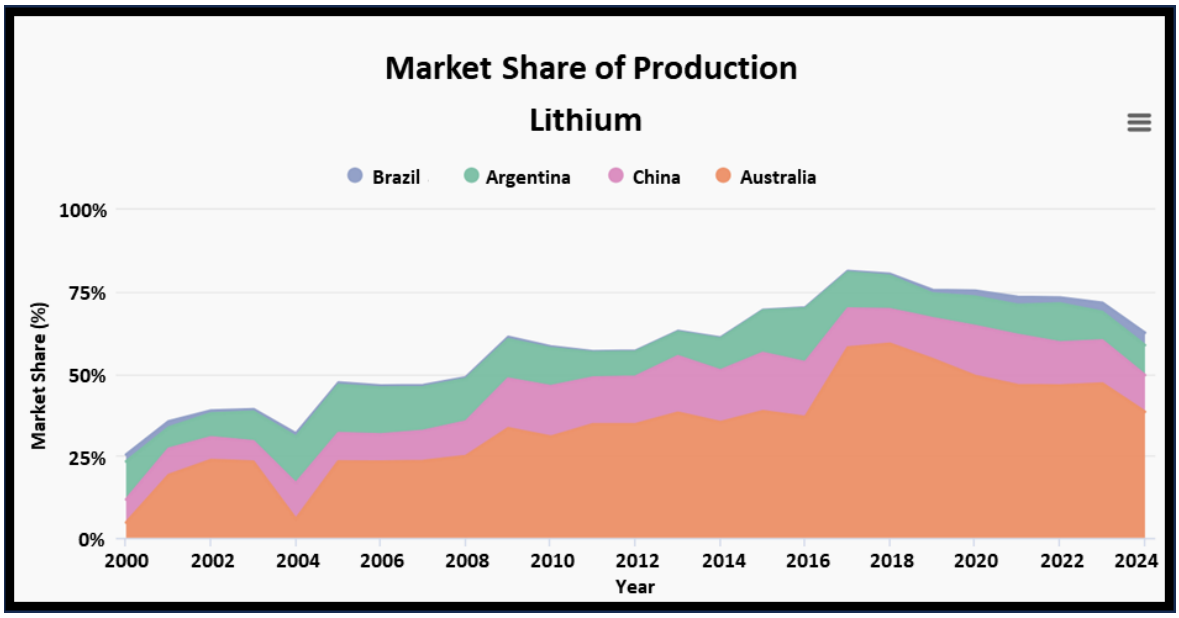
Technical Appendix

The following is how the *Mineral Market Dashboard* breaks down market dynamics:

1. **Global Projections:** This main panel confronts the forecasting challenge directly by visualizing long-term supply and demand projections (typically through 2050) from multiple authoritative sources. Users can compare distinct scenarios – such as the IEA's ambitious Net Zero Emissions pathway versus its more conservative Stated Policies outlook, or BNEF's different transition models – against the backdrop of historical production trends. All projections are displayed on a common, relative index scale, anchored to a slightly modified public baseline (derived from S&P 2023 production estimates.) This approach outlines the range of plausible market trajectories, highlights areas of consensus or significant divergence among forecasters, and provides a crucial benchmark against which specific project or policy assumptions can be assessed. The dashboard also highlights the difficulties and inconsistencies in even estimating *current* market size.

2. **Country Market Share:** The competitive landscape of mineral production is constantly evolving. This panel gives users a dynamic view of how global production patterns have changed over time. Ranging from 2000 to 2024, it depicts how the global market share for specific minerals has been distributed among countries, highlighting long-time leaders, emerging competitors, and potential evolving geopolitics of mineral supply chains.

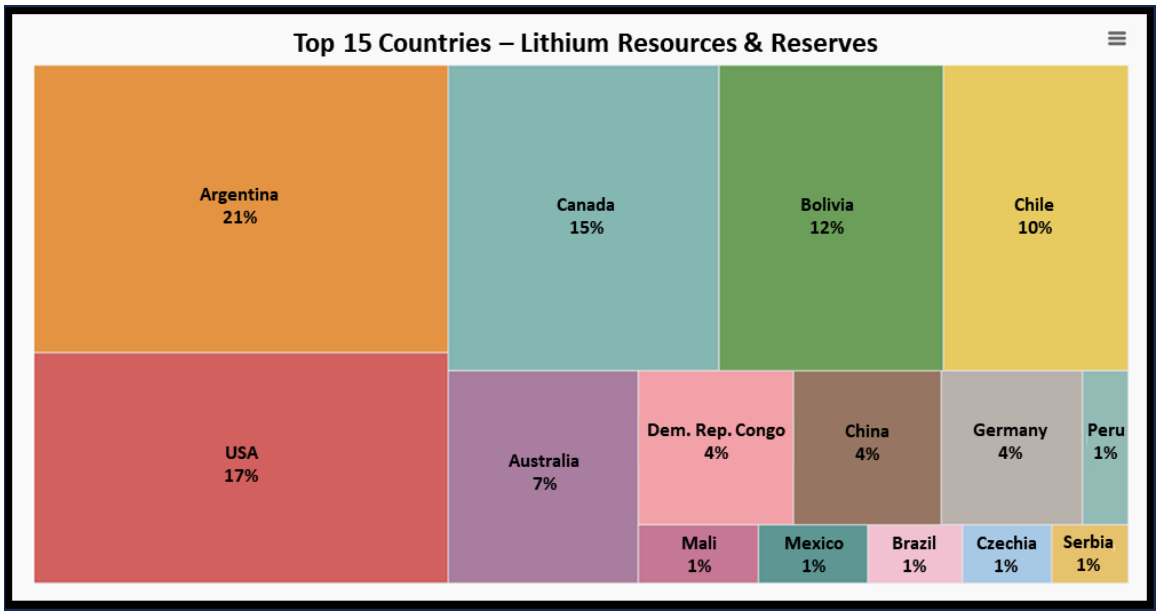
Figure A1
Historical Production Market Share for Lithium (Argentina, Australia, China, Zimbabwe)



Source: JFI *Mineral Market Dashboard* (Data: S&P Global).

3. **Resources and Reserves:** This panel maps the global concentration of known resources and reserves using S&P Global data. Interactive bar charts and treemaps allow users to visualize which nations possess the largest relative endowments of key minerals suitable for future extraction, offering critical insights into long-term supply potential and resource dependencies.

Figure A2
Global Distribution of Lithium Resources & Reserves (Top 15 Countries)



Source: JFI *Mineral Market Dashboard* (Data: S&P Global).

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4. **Country Profile & Rank:** For a consolidated view of a nation's standing, this panel provides detailed 2024 rankings for selected countries across multiple critical minerals. The tables present each country's global rank and percentage share for both production and resources/reserves, enabling rapid assessment and cross-commodity comparison of national significance in critical mineral markets. (See next page.)

Pulling together these different views (where markets might be heading, where they have been, where the minerals actually are, and who ranks where today) gives the *Mineral Market Dashboard* a depth that single forecasts lack. Instead of aiming to predict the future, it is meant to give users the information and tools they need to deal with inherent uncertainties. In doing so, we hope to foster a more informed basis for policy dialogue, strategic planning, and development initiatives aiming to build resilience amidst the volatility of global commodity markets.

Table A1
2024 Mineral Ranking Profile for Brazil and Ghana

Country Mineral Rankings (2024)

Brazil

Mineral	Production (% Share)	Production (Rank)	Resources & Reserves (% Share)	Resources & Reserves (Rank)
Aluminum	0.77%	9		
Bauxite	16.86%	2	6.53%	3
Graphite	3.16%	4	0.52%	12
Cobalt	0.13%	19	1.55%	12
Copper	2.14%	12	1.49%	18
Iron Ore	11.72%	2	14.09%	3
Lithium	3.76%	7	0.95%	13
Manganese	0.85%	12	2.62%	8
Nickel	5.63%	6	4.87%	7
Lead	0.76%	17	0.66%	23
Zinc	2.14%	13	1.09%	17
Phosphate			3.39%	7
Tin			5.39%	7

Ghana

Mineral	Production (% Share)	Production (Rank)	Resources & Reserves (% Share)	Resources & Reserves (Rank)
Manganese	5.31%	5	2.10%	10
Nickel	0.01%	46		
Graphite			0.28%	15
Iron Ore			0.16%	29
Lithium			0.14%	25

Source: JFI *Mineral Market Dashboard* (Data: S&P Global).

Forecasting Mineral Market Growth

Projecting mineral market growth – and its fiscal and industrial implications for producer countries – is an extremely difficult endeavor. Even the most sophisticated market analysts, financial institutions, and research centers struggle to produce accurate and consistent forecasts. There exists a range of strategies analysts use to forecast market growth, each with its strengths and limitations, which are closely guided by their intended use cases.

At the highest level, global mineral demand is most often projected through scenario-modeling frameworks, like those developed by the International Energy Agency (IEA), Bloomberg New Energy Finance (BNEF), S&P Global, and others. These scenario models represent how different policy choices, technological adoption rates, and climate ambitions might influence the future mix of end-use sectors such as transportation and electricity supply. Then, based on the mineral intensity of technologies meeting this demand, the models "solve" for mineral demand growth under each scenario model. Scenario models map well to policy and market dialogues, are easy to compare across predefined futures, and are generally more intuitive. However, scenario models are very sensitive to their assumptions. They may ignore price

feedbacks, may insufficiently constrain supply, or underrepresent the importance of substitution and innovation effects, like the declining role of cobalt in lithium-ion battery chemistries due to human rights concerns and expensive, geographically concentrated supply, or emerging alternative battery technologies altogether. The most aggressive growth/price scenarios, which miners tend to favor in their feasibility studies, often embed optimistic assumptions about the policy or market environments, and can overshoot reality substantially in practice, as seen with lithium.

On the supply side, some of these providers also offer detailed mine-level forecasts that aim to aggregate existing and prospective production capacity to estimate future output. Supply-side forecasts are often the backbone of investor analysis and short-to-medium-term supply outlooks and are essential for analysts' conclusions on whether markets will be over- or undersupplied. While they are granular and grounded in project-specific data, like permitting timelines, production costs, and technical feasibility, they are sensitive to assumptions around financing and construction and may inaccurately estimate actual delivery timelines, especially in volatile or high-risk markets like transition-critical minerals. It is also, of course, difficult to predict whether a specific project will be scrapped entirely, and likewise to keep abreast of every active mining concession and project globally.

Thus, these demand-side scenario models and supply-side mine forecasts often operate as separate analytical layers. Demand scenarios project theoretical requirements based on macro trends, while supply models quantify deliverable capacities rooted in physical realities. When the separate layers are not linked, it can create analytical blind spots: supply forecasts may not account for rapid demand accelerations from aggressive climate policies, while demand scenarios might overlook hard constraints in project lead times or geopolitical risks to mining infrastructure. Market analysts typically compare these parallel tracks to identify mismatches, but critical feedback loops, such as price volatility altering both mineral substitution trends and project financing viability, can be under-modeled. Ultimately, this bifurcated approach overlooks that these are interdependent systems shaped by unpredictable human and market behaviors – a nuance often unappreciated by the consumers of model outputs. Because these products are often proprietary, the models themselves can be a black box, making it difficult to validate or clarify the extent to which layers influence one another.

Academics and macroeconomic institutions, meanwhile, tend to favor partial and general equilibrium modeling, which link feedback loops more closely. These models attempt to simulate market dynamics by incorporating price feedback, trade flows, substitution and learning effects, policy interventions, and other elements. In theory, these models allow for richer treatment of endogenous variables, such as how producers and consumers respond to price signals and how technologies may evolve. In practice, they are limited by data availability, can make strong assumptions about elasticity and agent behavior, and can treat mining as a stylized input-output system, abstracted from the messiness of real-world politics, permitting, and supply chains.

Crucially, scenario modeling, mine forecasts, and equilibrium models are not competing modeling approaches but rather intended to meet distinct objectives and inform different types of decisions in separate contexts. Scenario models are intended for strategic planning and agenda-setting and allow users to consider the implications of varying future states of the world. Mine-level supply forecasts support

operational and financial decisions that depend on concrete project-level timelines and risk assessments, and can complement scenario models to identify and discuss potential market shortfalls statically. Equilibrium models, on the other hand, are intended to explore theoretical relationships and economic mechanisms, such as substitution, trade, and price formation, by simulating how interconnected markets adjust to shocks or policy changes. They are particularly valuable for testing the internal logic of economic systems and assessing how different assumptions influence outcomes across sectors.

Unsurprisingly, investors tend to favor mine-level forecasts and scenario models while academics require equilibrium models. (See next page.) The policy sphere may utilize any of these forecasts, depending on the use case, but a key concern arises when model use does not align with design. Academic models are sometimes called on to quantify future market size, despite being built to capture high-level relationships under idealized assumptions, rather than to make accurate predictions for real-world markets. And while production forecasts and scenario modeling can be valuable approaches, they are easily manipulated and often are opaque and proprietary; these vulnerabilities are especially acute when institutional or commercial incentives create pressure for more favorable assumptions. These mismatches — between what a model is built to do and how its outputs are interpreted — can lead to false confidence or poor decision-making, particularly in complex and fast-moving sectors like critical minerals.

Finally, all three of these modeling approaches are often deterministic but can also be stochastic. Deterministic models define a single outcome or pathway based on fixed assumptions, while stochastic models allow for randomness in key inputs or relationships and produce a distribution of possible outcomes rather than a single forecast. In principle, stochastic modeling should be the gold standard for planning under uncertainty, as it better captures the volatility and unpredictability of mineral markets, and more broadly, the real world. Stochastic models allow analysts and policymakers to test a range of inputs, such as prices, project delays, or technology uptake, and see how different combinations play out across time. However, in practice, stochastic models can be more resource-intensive and may be more difficult for audiences to interpret or compare across use cases. Still, being able to reference a curated set of deterministic projections – especially the highest and lowest bounds – is a powerful second-best approach. This is precisely the purpose of the Projections tab of the *Mineral Market Dashboard*, which enables us to assess how different institutions are modeling market growth and to benchmark the scale and timing of expectations across plausible scenarios.

Table A2
Model Types: Scenario Modeling, Mine-Level Supply Forecasts, and Equilibrium Models

Model Type	Description	Intended Use Cases	Strengths	Key Limitations
Scenario Modeling	Demand projections under defined futures, short- to long-term.	Policy analysis, strategic planning, public narratives, goal-setting, etc.	Aligns well with policy and market dialogues; easy to compare across scenarios, and is more intuitive.	May assume unconstrained supply, omit price feedback, or underestimate substitution and innovation effects. Projections from proprietary services lack transparency and are difficult to validate. Can be used to support preferred narratives, making aggressive scenarios manipulable.
Mine-Level Supply Forecasts	Short- to medium-term supply projections.	Strategic planning, project finance, investor due diligence, etc.	Granular, project-level detail; essential for market balance analysis; widely used by investors.	Sensitive to assumptions about financing, permitting, and construction; may overestimate delivery timelines. Methods are often proprietary and not standardized; difficult to validate.
Equilibrium Models	Simulating market interactions and trade flows for medium- to long-term projections.	Academic research, system exploration, stress-testing under complex dynamics, etc.	Incorporates price feedback, substitution, trade, and policy response; models endogenous behavior.	Built primarily for theoretical exploration, not forecasting; may oversimplify sectors like mining. Use in policy or finance contexts can be misleading. Even when methods are transparent, abstraction makes validation challenging.

Endnotes

1 Yiyi Zhou, "Lithium Prices, Oversupply Squeeze China's Battery Margins," *BloombergNEF*, April 24, 2023.

2 Jiayan Shi, "EV Battery Glut Set to Endure as China Meets World's Needs," *BloombergNEF*, August 7, 2023.

3 Statistic includes lithium projects globally that were last updated in January 2022 or later and have a known activity status and development stage in S&P's database. Projects classified as "advanced production stages" include those marked as Operating, Construction Started, Construction Planned, or Commissioning. Only projects with both non-missing activity status and development stage fields were included in the denominator (n = [actual count]). Projects labeled as Inactive, On Hold, Care and Maintenance, or in early-stage exploration were not considered "advanced."

4 Recent research from three universities in Brazil and the London South Bank University calls into question the sustainability of Sigma's processes and accuses the firm of greenwashing.

5 For example, see copper futures prices recently, which have been traded on the London Metals Exchange since 1877.

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Jonah Allen is the Lead Researcher for the Energy Transition Value Chains portfolio at the Jain Family Institute. In collaboration with partners at the subnational and international levels, he leads research origination and dissemination, and advises on projects across the portfolio to develop quantitative tools and insights that support more equitable benefit-sharing in the extraction, trade, and use of resources critical to the energy transition.

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Analysis on ASM Role in Indonesian Nickel Production

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Indonesia now dominates the global supply of nickel, an essential raw material for lithium-ion batteries and stainless steel. Nickel production in the country has more than doubled in the last four years, fueled by the government's "value chain" strategy that drove domestic development of smelting/refining capacity.

The supply chain of raw nickel ore is characterized by a blend of large- and small-scale mining. The contribution of artisanal and small-scale mining (ASM) to Indonesian nickel production is unclear, however, largely because reporting practices are inconsistent and much of ASM activity is subsumed within large-scale mining (LSM) operations. Nevertheless, we believe it might be as much as 25% of recent production.

This sizeable impact raises the imperative for Indonesia to understand ASM's contribution to and the nature of domestic nickel production. That understanding can inform crafting constructive ASM management practices, including formalizing ASM rights and setting operating and reporting standards, which can set the basis for optimizing the economic benefit for local communities and the country as a whole.

Current Status of ASM in Indonesia

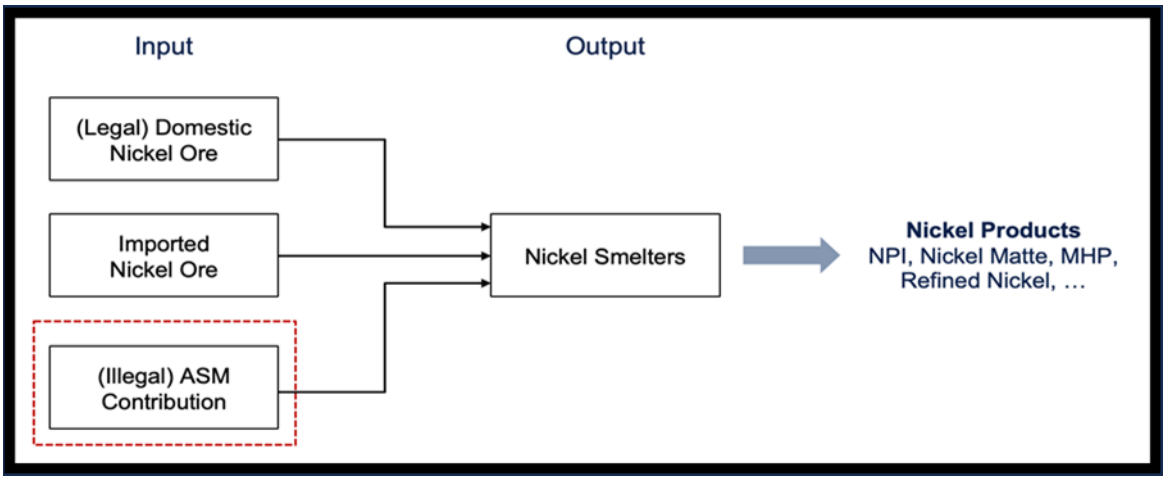
Indonesia's (national) mining law is mute with regards to ASM, focusing instead on LSM. Further, while ASM can be licensed as community mining permits, few such permits are issued [1]. However, despite the lack of formal recognition, it is readily acknowledged that ASM activity is widespread, including by nickel LSM companies that have complained of losing profits to these much smaller actors [2].

It has been reported that smelting companies, most of them Chinese majority owned, take advantage of unapproved local miners, primarily by exercising their market power [3] as the only buyer. The smelters' market power is (a likely unintended) result of the government's strict policy banning the export of nickel ore. (It should be noted that smelter owners exert this market power not only on ASM but also on LSM operators, by offering ore-buying prices well below government-gazetted prices for most of the period,[1] although as smaller sellers, ASM has even less negotiating leverage.)

Indonesia ASM Nickel Production Estimation

Because recording of nickel production in Indonesia is not required of all participants, ASM's contribution to nickel ore production is difficult to ascertain. Yet the nickel ore export prohibition policy allows estimating the ASM production through an Input-Output model (Figure 1). Theoretically, by subtracting the nickel content of (legal) domestic nickel ore inputs and imported inputs from nickel intermediate outputs, the difference comprises the (illegal) ASM contribution. The logic can be expressed as a formula as follows:

Figure 1
Input-Output Model for the Nickel Value Chain in Indonesia
ASM Share = Nickel Output - (Domestic "Legal" Ore + Imported Ore)



It is worth acknowledging that this approach has limitations, including:

1. The definition of ASM in nickel mining is limited to unsanctioned activities that are therefore not recorded in the government database. Yet as noted above, LSM engages with small-scale miners and thus "commandeers" production of what might in other circumstances be considered ASM.

2. Gaps in publicly available data remain, as described below. This includes time lags in production reports from mines and administrative inefficiency.

3. Inventories are ignored, thus annual ore production is assumed equal to annual consumption.

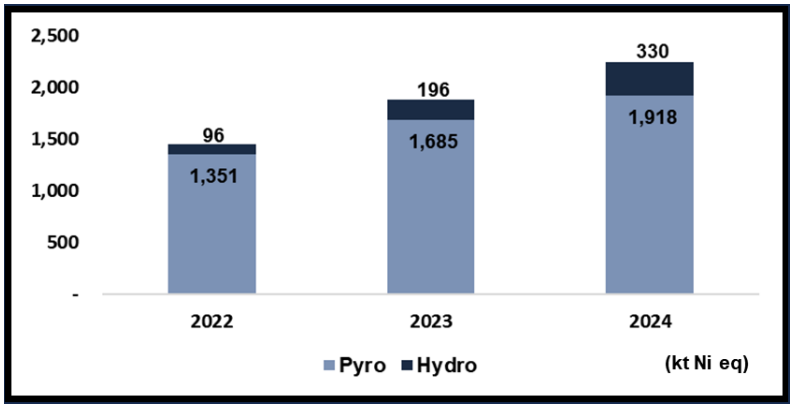
Despite these limitations, we see value in the estimation process as it offers some insight to ASM's contribution.

Nickel Smelting Products (The Output)

Most production data from mining and processing in the country's legitimate system is unavailable, especially for nickel outputs (many smelting entities are not required to publish detailed reports). The Ministry of Energy and Mineral Resources of Indonesia (ESDM) publishes annual industry reports, but they have limitations, including that only pyrometallurgically processed products are tracked, missing 10-20% of total production (hydromet products), and that ore processed in stand-alone smelters, *i.e.*, those without integrated mining rights, are not included.

Due to these limitations, we believe estimates from private providers more accurately reflect reality. These estimates vary due to the lack of data from small-scale operations; we elect to use Wood Mackenzie's estimate because of its in-depth coverage of the global nickel industry. Per WoodMac's estimate, in 2024, Indonesian nickel smelted products totaled 2.2 million tonnes, up 20% from 2023. Pyrometallurgical processes using higher grade nickel ore (saprolite) rose 14% to 1.9 million tonnes, while hydrometallurgical processes, which produce mixed hydro precipitates (MHP) from high pressure acid leaching (HPAL) smelters using lower grade ore (limonite), rose 68% to 330 kilo tonnes (Figure 2).

Figure 2
Indonesian Smelter Outputs (Wood Mackenzie)



Domestic Nickel Ore (Input 1)

Government data on legal domestic nickel ore production also lacks fidelity. ESDM's reported annual production is 20-30% less than figures from ESDM officials [4] [5] [6] (Figure 3 on the next page), mainly due to time lags in mining companies reporting their production. For modelling purposes, we elect to use production figures from public comments made by relevant government officials.

To compare the input with the output, nickel ore tonnes are converted to metal-equivalent tonnes. This conversion yields raw ore production on a metal equivalent basis of 1,939 kilo tonnes in 2024 (Table 1, also on the next page).

Figure 3
Raw Nickel Ore Production Comparison (ESDM Performance Reports, Officials)

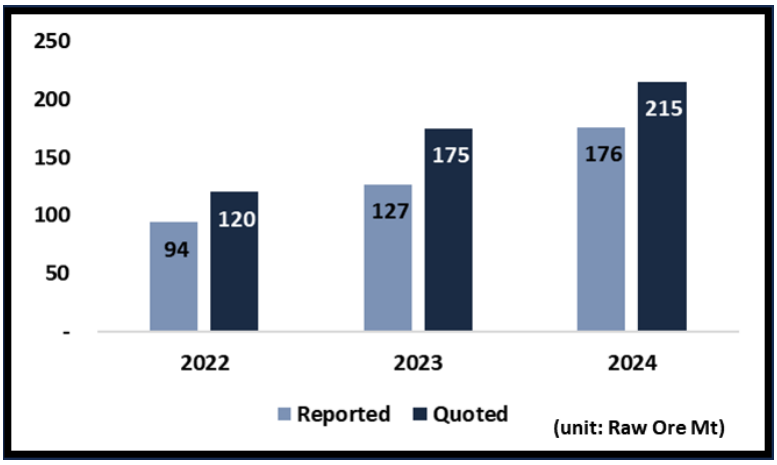


Table 1
Domestic Nickel Ore Production[2]

(unit: Raw Ore Mt, Metal Equivalent kt)	2022	2023	2024
Raw Ore	120	175	215
Average Ni Content	1.6%	1.6%	1.5%
Average Moisture Content	35%	35%	35%
Metal Equivalent	**1,105**	**1,595**	**1,939**

Imported Nickel Ore (Input 2)

Indonesia has been importing nickel ore for the last two years, mainly from Philippines [7] (Figure 4 on the next page). This is primarily due to internal and external factors, including ESDM delays in approving additional permits, production disruption in Sulawesi region (where most of the nickel is produced) due to high precipitation levels in 2024, and additional smelting capacity outstripping domestic ore production.

Production Estimation

Netting the two Inputs against the Output allows derivation of an estimate of ASM production in the Indonesian nickel mining industry (Table 2, also on the next page). The derivations suggest that ASM production has decreased over the last three years in absolute terms. Possible reasons for this include the government's strict policy on illegal mining (*i.e.*, the government has actively curtailed such activity), larger

firms focusing on lower quality deposits due to high nickel demand, and large companies integrating ASM into their operations.

Figure 4
Indonesia Nickel Ore Imports (Statistics Indonesia)

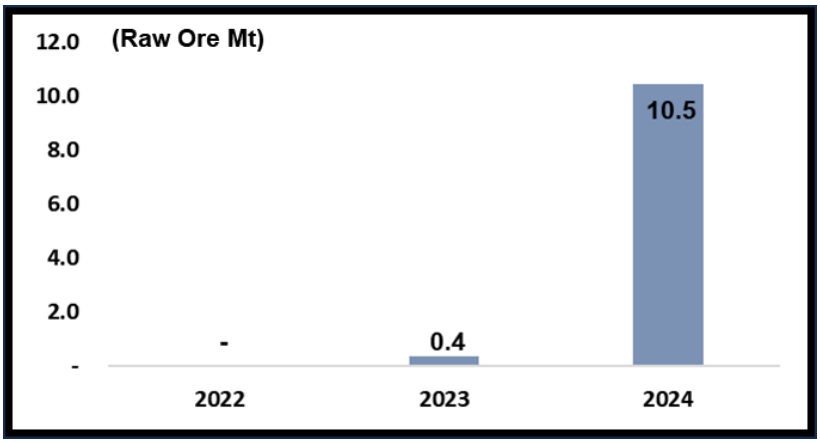


Table 2
Production Estimation for ASM in the Nickel Industry

(unit: Ni eq kt)	2022	2023	2024
(+) Output	1,448	1,881	2,248
(-) Input – Domestic	1,105	1,595	1,939
(-) Input - Imported[3]	-	3	86
ASM Production	343	283	224
Ore equivalent (Mt)[4]	**37**	**31**	**25**
Input Share	**24%**	**15%**	**10%**

It is worth noting that our channel checks with regional analysts [11] support the view that ASM's contribution is likely higher (across all years). That bias appears to also be based on some version of the same "derivation" as is described above. Similarly, there is recognition that the issue is clouded by the use of small miners as contract hires, and thus that the effective contribution of ASM is therefore much greater.

ASM's contribution to nickel production in Indonesia is significant and it has the potential to be even more so. Effective integration of small mining activities, protection for the rights of ASM workers, and creating more open marketplaces for large and small miners to sell their nickel can set the stage for meaningful growth in mined volumes and economic value creation. In other words, small-scale nickel mining, if

managed well, can significantly contribute to Indonesia's economic development, at local and national levels.

Endnotes

1 Smelters have offered premiums on occasions due to supply deficits since mid-2023.

2 Conversion factor: nickel grade, moisture content from the Shanghai Metals Market (SMM) index [8], saprolite/limonite ratio inferred from the output data, and smelter recovery rate assumed to be 90% [9] [10].

3 Conversion factor: nickel grade, moisture content from SMM index.

4 Same conversion factor used as domestic nickel ore (Input 1).

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