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Artisanal and Small-Scale Mining of Critical Minerals

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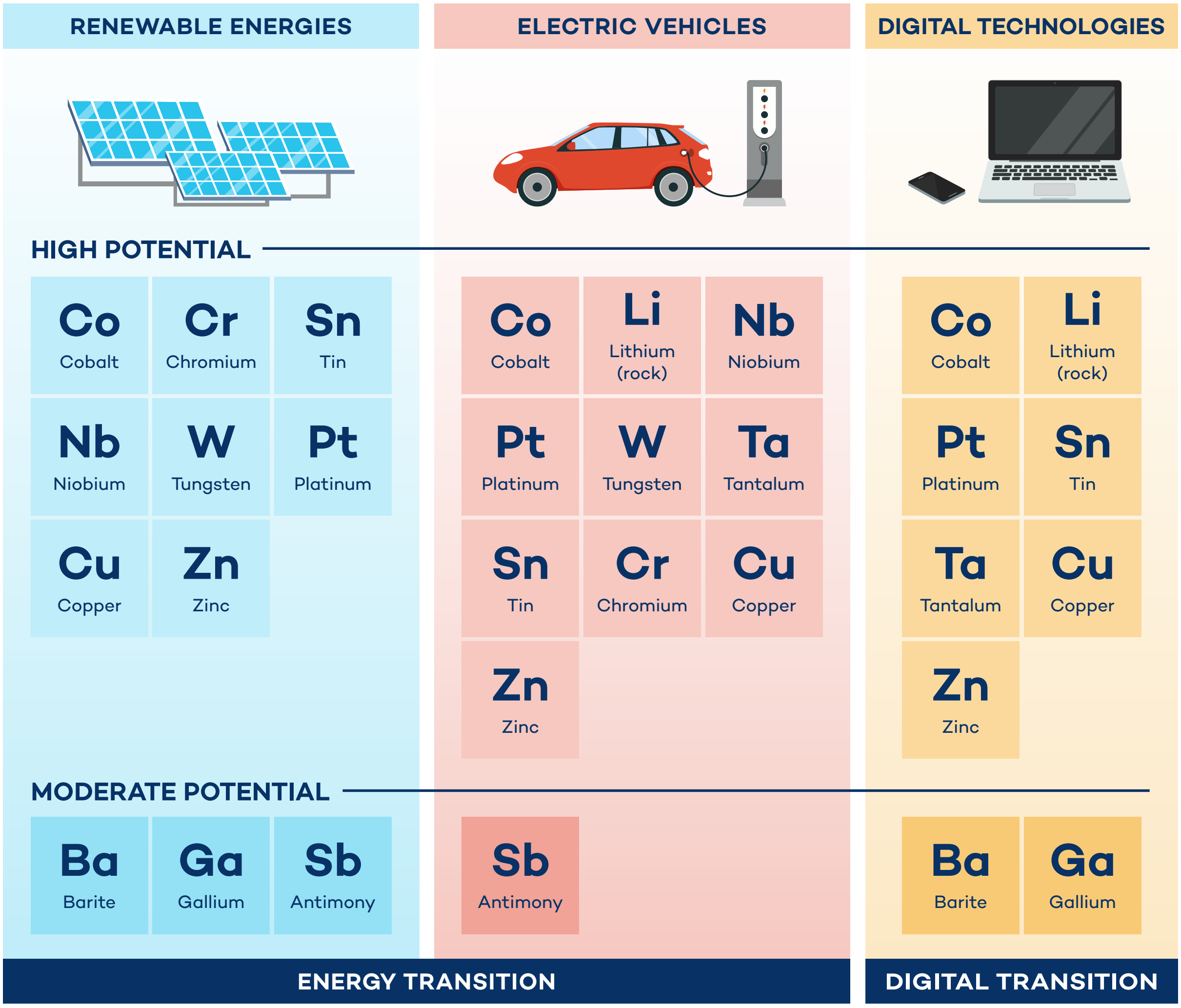
Executive Summary

This report examines the potential for artisanal and small-scale mining (ASM) to take an expanded role in the global supply of critical minerals as governments and industries scramble to meet demand driven by the adoption of low-carbon energy and digital technology.

The ASM sector involves labour-intensive mineral extraction. It is an overlooked source of many critical minerals, despite being a significant contributor to the global supply of critical minerals and several other minerals. Although not all critical minerals can be easily sourced through ASM, there is a potential for a greater role for ASM in sourcing them (Figure 1).

FIGURE ES1. Critical minerals, their associated technologies, and the potential for sourcing through ASM



Source: Authors.

The expanded role of ASM would support much-needed livelihoods and economic development in local communities. However, considering that ASM activities can be environmentally destructive and executed by subsistence operators, major shifts in policy and regulatory stances are required to formalize and support the sector in realizing its full potential.

The report begins by analyzing key developments in critical minerals, including revisiting why industries and governments are rushing to secure access to these commodities and where key reserves are located. It then turns to ASM itself. Because it is difficult to gather ASM data due to the deeply informal nature of many critical mineral supply chains, this report includes case studies of key locations that are making important contributions to supply and where information is available. The report also identifies new ASM frontiers that could become significant if developed with the right support.

The report provides important next steps that must be taken if ASM is to become a more significant part of the critical minerals equation moving forward. Each step would go a long way toward providing the sector with the platform it needs to be viewed as a reliable contributor to the global critical minerals supply. Each step relates to strengthening ASM formalization, which would provide the sector with much-needed visibility in debates on critical minerals supply. The report, overall, seeks to advance discussions on the importance of ASM in the critical minerals space.

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Acronyms

3Ts	tin, tungsten, and tantalum
ASM	artisanal and small-scale mining
DDP	due diligence programs
DRC	Democratic Republic of the Congo
ENAMI	Empresa Nacional de Minería
EU	European Union
EV	electric vehicle
GHG	greenhouse gas
IEA	International Energy Agency
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
iTSCi	International Tin Supply Chain Initiative
IUP	Izin Usaha Pertambangan Khusus (Special Mining Business Licence)
OECD	Organisation for Economic Co-operation and Development

1.0 Introduction

1.1 Context

Critical minerals are minerals and metals that play an actual or potentially important role in countries' economies. They are indispensable for industrial processes and essential to manufacturing sectors but are vulnerable to supply chain disruptions due to factors such as geographic concentration, political instability, or market volatility (Ramdoo et al., 2024). In this report, the term "critical minerals" implies minerals and metals that are deemed essential from the perspective of either producing or consuming countries.

Two largely interrelated movements are fuelling the rush for critical minerals worldwide. The first is the transition toward low-carbon and decarbonized energy systems, which has ignited a surge in exploration for and production of the "battery minerals" (graphite, cobalt, nickel, and lithium, among others) needed to power low greenhouse gas (GHG) emissions technologies. In its *Sixth Assessment Report* (AR6), the Intergovernmental Panel on Climate Change (IPCC) warns that under high GHG emissions scenarios, global temperatures could surpass 2°C above pre-industrial levels by mid-century (IPCC, 2023). Achieving net-zero emissions will require transformative technological changes, which offer the most viable pathway to mitigating warming and limiting severe climate impacts.

The second movement is the transition to the digital economy. Technologies that fall into the category of "digital industry" include big data analysis, machine learning, industrial Internet of Things, augmented reality, 3D printing, and robotics (Hushko et al., 2021). The tangible impact of digital technologies—the metals and resources essential to their production—becomes clear when one considers, for example, the demand for wireless technology and computing alone. The digital economy even extends to the extraction of the very minerals being coveted, as a number of large-scale mines are becoming increasingly automated (Ramdoo et al., 2024).

These two major drivers occur while the demand for societal needs, industrialization, and development stays high. The most conservative forecasts indicate that enormous supplies of critical minerals will be required to satisfy the projected demand over the next 3 decades (International Energy Agency [IEA], 2022b). Significant attention has been paid to battery minerals because of their use in energy storage and electric vehicle (EV) technologies. The Sustainable Development Scenario developed by the IEA in line with the Paris Agreement (climate stabilization below 2°C global temperature rise, aiming to reach net-zero globally by 2050) suggests that global demand in 2040 compared to 2021 could grow 40 times for lithium and between 20 and 25 times for nickel, cobalt, and graphite (Fu et al., 2020; Hailes, 2022; IEA, 2022ba; Ritoe et al., 2022). In Europe alone, to meet the escalating demand for EV batteries and energy storage, the supply chain will require securing 18 times more lithium by 2030 and up to 60 times more cobalt by 2050 compared to 2020 (Bobba et al., 2020).

The development of critical mineral lists by an increasing number of countries has driven the demand upward, putting significant pressure on traditional producers of certain commodities: the Democratic Republic of the Congo (DRC) for cobalt; Madagascar, Mozambique, and China for graphite; Chile, Bolivia, and Argentina for lithium; Indonesia and the Philippines for nickel; China and Indonesia for tin; and Chile, the DRC, Peru, and Zambia for copper (U.S. Geological Survey, 2023). To meet this demand, governments and industries have led efforts to identify and explore new sources of critical minerals.

This report focuses on the supply of critical minerals from the artisanal and small-scale mining (ASM) sector. While ASM is generally associated with simple, minimal use of machinery operations and is largely labour intensive, its activities can also be slightly more capital intensive and carried out by small groups of individuals or communities. The sector's potential, however, is largely unknown, given that so many of its operations are found in the informal economy. If formalized and/or supported, ASM could become a prominent player in the supply of critical minerals moving forward.

This report is based on two interrelated arguments: (i) that ASM is an underestimated source of critical minerals and (ii) that it is already making contributions to the global supplies of several commodities. After highlighting additional trends linked to demand for critical minerals, the report proceeds as follows. Section 1.2 of the report provides an overview of critical minerals, including outlining where key resources are located and profiling the digital and low-GHG emissions technologies that they support. Section 2 analyzes the potential for increasing ASM operations' share of the global supply of battery minerals. Section 3 identifies some of the key challenges that must be overcome if ASM were to take on a more recognized and legitimate role in the global supply of critical minerals. Section 4 seeks to further legitimize the expanding role of the ASM sector in supplying critical minerals, sharing case studies of lesser-known yet emerging ASM critical minerals regions. Section 5 identifies important challenges that must be addressed to legitimize the role of the ASM sector. Section 6 concludes and provides pathways for the next steps to be taken if the expanding role of the ASM sector in supplying critical minerals is to become a reality.

1.2 Locating Critical Minerals and Matching Technological Needs

Many countries and regional groups have developed their own methodologies and formulas for developing their lists of critical minerals (e.g., European Commission et al., 2017). If one examines forecasts for both the low-carbon transition and digitalization, the outlook appears bleak, given the gap between the current levels of extraction and what is needed. For example, the production of copper, which is used (among other metals) in the manufacture of power lines and wiring, needs to double by 2040. Copper demand for electrification is expected to increase annual copper production to 36.6 million tonnes[1] by 2031; the current 30.1 million tonnes projection falls short of this demand (Crooks et al., 2023).

[1] Note that "tonnes" refers to metric tonnes (1,000 kg) throughout.

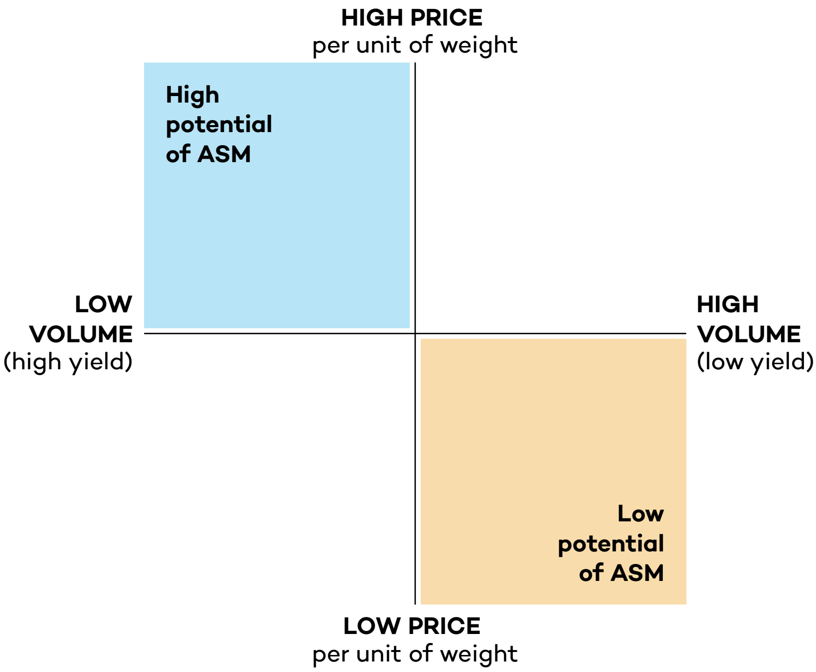
Table 1 provides a list of minerals now broadly identified as "critical" and deemed essential for both securing a low-carbon future and supporting the growth of the digital economy. In the table, an attempt is made to identify which of these minerals has the potential to be sourced via ASM operations.

The potential for ASM mineral extraction is categorized into three levels: high, moderate, and low (Figure 1).

- **Low potential:** Minerals that are characterized by high volume/low yield and low value per unit of weight, which requires economies of scale for economically viable production. These attributes typically confine their extraction to large-scale and mechanized operations, leaving negligible opportunities to nurture ASM operations for these minerals.
- **High potential:** Minerals that have low volume/high yield and high value per unit of weight, providing opportunities for profitable ASM operations.
- **Moderate potential:** Minerals that fall in the spectrum between the two categories above.

The categorization of ASM potential, as presented in Table 1, is based on these characteristics and is also informed by minerals that currently already contribute substantially to global output and are extracted through ASM. The categorization also considers whether a mineral is produced as a primary or as a by-product. The price per weight unit is a crucial factor in assessing the potential for ASM extraction. Price fluctuations can cause a mineral to shift between categories (high to low potential and vice versa), depending on whether the price enables or hinders economically viable ASM operations.

FIGURE 1. Potential categorization of ASM based on volume/yield and price per unit of weight



Source: Authors.

TABLE 1. Major critical minerals and the locations of main reserves

Mineral	Main production countries	Leading global producer, country (2022)	Leading global producer, production (2022)[2]	Location of largest reserves	Reserves	Additional strategic reserve locations	ASM potential
Alumina	Guinea, China, Vietnam, Australia, Brazil, Canada, Jamaica	China	76,000	Guinea	7,400,000 (bauxite)	Indonesia, India	Low
Antimony	China, Russia, Bolivia, Kyrgyzstan, Australia	China	60	China	350	Canada, United States, Tajikistan, Pakistan	Moderate
Barite	Iran, Kazakhstan, India, China, Türkiye	China	1.9	Iran	100,000	Russia, Morocco	Moderate
Bismuth	China, Vietnam, Mexico, Bolivia	China	16	N/A	N/A	China (produced as a by-product from lead ores),[3] Japan, Peru, Mexico, Canada	Low
Chromium	Kazakhstan, South Africa, India, Türkiye	South Africa	18	Kazakhstan	230,000 (shipping grade)	Finland, United States	High
Cobalt	DRC, Indonesia, Russia, Australia	DRC	130	DRC	4,000	Morocco, Australia, Indonesia	High
Copper	Chile, China, Australia, Peru, Russia, Mexico	Chile	5,200	Chile	190,000	United States, Peru, DRC, Indonesia, Zambia, Kazakhstan, Canada	High

2 In thousand tonnes, unless otherwise noted.
3 Deady, Moon et al., 2023.

Mineral	Main production countries	Leading global producer, country (2022)	Leading global producer, production (2022)[2]	Location of largest reserves	Reserves	Additional strategic reserve locations	ASM potential
Fluorspar	Mexico, China, South Africa, Mongolia, Spain	China	5,700	Mexico	68,000	Vietnam, United States, Iran	Low
Lithium	Australia, Chile, China, Argentina, Bolivia	Australia	61	Chile	9,300	Brazil, Zimbabwe, DRC	High[4]
Gallium	United States, China, Japan, South Korea, Russia	China	540,000 kg	N/A	N/A	Germany, Kazakhstan	Low
Graphite	China, Mozambique, Madagascar, Brazil	China	850	Türkiye	90,000,000	Tanzania, India, Uzbekistan, Mexico, North Korea	Low
Magnesium (compound)	Russia, China, Slovakia, Australia, Greece	China	17,000	Russia	2,300,000	Türkiye, India, Austria	Low
Manganese	South Africa, Gabon, Australia, China	South Africa	7,200	South Africa	640,000	Ghana, India, Brazil, Ukraine (concentrate)	Low
Nickel	Indonesia, Australia, Brazil, Russia, New Caledonia	Indonesia	160	Indonesia, Australia	21,000 (each)	Philippines, Canada, China, United States	High

[4] ASM potential for lithium is limited to lithium deposits in pegmatite. Salar deposits typically require large investments and infrastructure that cannot be sustained by ASM operations.

Mineral	Main production countries	Leading global producer, country (2022)	Leading global producer, production (2022)[2]	Location of largest reserves	Reserves	Additional strategic reserve locations	ASM potential
Niobium	Brazil, Canada, United States	Brazil	71.1	Brazil	16,000	N/A	High
Platinum	South Africa, Russia, Zimbabwe, United States, Canada	South Africa	140,000 kg	South Africa	63	N/A	High
Tantalum	Brazil, China, Australia, DRC, Nigeria, Rwanda	DRC	860 tonnes	China	180	N/A	High
Tellurium	China, Russia, Canada, South Africa	China	340 tonnes (refinery production)	Russia	4.5	United States, Sweden	Low
Tin	China, Indonesia, Myanmar, Peru, DRC, Brazil, Bolivia	China	95	Indonesia	800	Australia, Russia	High
Tungsten	China, Russia, Vietnam, Bolivia	China	71	China	1,800	Austria, Portugal, Spain	High
Vanadium	China, Russia, Brazil, South Africa	China	70	China	9,500	United States, Australia	Low
Zinc	Australia, China, India, Mexico, Peru	China	4,200	Australia	66,000	Kazakhstan, Canada, United States, Sweden	High

Source: U.S. Geological Survey, 2023.

Although not all critical minerals are easily minable through ASM, as illustrated in Table 1, some of them have the potential to be extracted by ASM operations. New and reliable supplies of critical minerals are needed if growing (current and anticipated) demand in all three areas of energy transition technologies, digital transition technologies, and society are to be met. ASM can be an important contributor to the future global needs of critical minerals.

Critical minerals have diverse uses, including, among others, their roles in everyday products, industrial applications, and modern technologies. For example, tin is used to improve the corrosion resistance of copper and nickel and in a range of alloys, including with copper in bronze, and in various electronics, where it is utilized in lead-free solders and in thin films that conduct electricity used in touch screens. The chromium extracted from chromite is found in the paint used throughout the household and on cutlery and toasters. Critical minerals are also found in a variety of products relied upon for personal use. For example, bismuth is found in both cosmetics and electronics and is an ingredient of Pepto-Bismol, a medicine used to treat heartburn. Zinc similarly features in a range of medical implements, foremost x-ray devices.

Table 2 maps those minerals that have high and moderate potential to be sourced by ASM, matching them with energy transition technologies, digital technologies, and societal needs. The intention is to illustrate how ASM can contribute to future global needs.

ASM could assume an expanded role, moving forward, in providing crucial supplies of critical minerals. It is already playing this role to some extent, albeit vastly understatedly. Intensifying support for small-scale miners engaged in the extraction of various critical minerals could go a long way toward shoring up concerns around supply.

TABLE 2. Mapping selected critical minerals against energy transition technologies, digital technologies, and societal needs and their potential to be sourced through ASM

Potential to be sourced through ASM	Critical minerals	Energy transition			Digital		Society		
		Solar photovoltaics	Wind turbines	EV technologies	Smartphones, tablets, and laptops	Data transmission networks	Electronics, appliances	Household products[5]	Medicine[6]
High	Chromium	✓	✓	✓	✓		✓		✓
	Cobalt		✓	✓	✓		✓	✓	✓
	Copper	✓	✓	✓	✓	✓	✓	✓	✓
	Lithium (pegmatite)	✓[a]	✓[a]	✓	✓	✓	✓	✓	✓
	Niobium		✓	✓	✓		✓		✓
	Platinum			✓[b]	✓	✓	✓	✓	✓
	Tin	✓	✓	✓		✓	✓		✓
	Tungsten		✓	✓	✓	✓	✓		✓
	Zinc	✓	✓	✓	✓	✓	✓	✓	✓
Moderate	Antimony	✓		✓	✓	✓	✓	✓	✓
	Barite							✓	✓

[5] Food, kitchen utensils, cleaners, paints, etc.
[6] Including dental implants, surgical tools, and machines.

Potential to be sourced through ASM	Critical minerals	Energy transition			Digital		Society		
		Solar photovoltaics	Wind turbines	EV technologies	Smartphones, tablets, and laptops	Data transmission networks	Electronics, appliances	Household products[5]	Medicine[6]
Low	Bismuth			✓		✓	✓	✓	✓
	Gallium	✓		✓	✓	✓	✓		✓
	Tellurium	✓		✓	✓	✓	✓	✓	
	Vanadium	✓[a]	✓[a]	✓	✓	✓	✓		

Source: IGF compilation.

Notes: [a] Essential in energy storage infrastructure rather than energy production infrastructure.
[b] Fuel cell EVs, where energy stored as hydrogen is converted to electricity by fuel cells, hybrid EVs, and plug-in hybrid EVs.

2.0 Critical Minerals: Is there a space for ASM?

The report now turns to the ASM sector specifically, weighing in on how it can expand its role in providing crucial supplies of critical minerals moving forward. A number of "critical" minerals are being extracted and/or can potentially be processed on artisanal and small scales. For three of the battery minerals (lithium, graphite, and cobalt), however, the outlook is mixed. While there are obvious locations to target, only a few are likely to be economically viable via small-scale extraction, at least in the short term.

2.1 Lithium

Large lithium deposits are narrowly distributed in some very specific regions. Lithium is a highly soluble and mobile chemical element, which leads to its widespread distribution across various soils, rocks, and bodies of water—sea, groundwater, and surface water—rather than forming large accumulations or deposits (Gramling, 2019; Mends & Chu, 2023). Lithium deposits occur in (i) pegmatite deposits, many of which are rich in tantalum, fluorine, tin, and caesium; (ii) volcanic clay deposits; and (iii) brine deposits, where it occurs in a solution that becomes enriched via evaporation or through geothermal processes (Bowell et al., 2020).

TABLE 3. Locations of the largest reserves of lithium and corresponding mine production

No.	Country	Reserves (tonnes)	Mine production 2021 (tonnes)	Mine production 2022 (tonnes)
1	Chile	9,300,000	28,300	39,000
2	Australia	6,200,000	55,300	61,000
3	Argentina	2,700,000	5,970	6,200
4	China	2,000,000	14,000	19,000
5	Brazil	250,000	1,700	2,200

Source: U.S. Geological Survey, 2023.

Note: The largest known resources are by far estimated to be in Bolivia (21 million tonnes), Argentina (20 million tonnes), and Chile (11 million tonnes).

Extracting lithium from brine beneath salt flats (salars) is simpler than from other deposits. It involves pumping the brine into large evaporation ponds, where natural evaporation concentrates the lithium, followed by chemical processing. This method does not require extensive rock excavation.

In contrast, extracting lithium from pegmatite and volcanic clay requires traditional mining: heavy machinery removes topsoil to access deposits, then the ore is excavated or mined and then crushed and ground before chemical processing.

Salars require significant infrastructure, investment, and technology. Ore processing time is also significantly long (the natural evaporation process in ponds takes several months), large areas of land (1 to 10 km^2) are required to build ponds, and weather conditions may affect ore processing time. Lithium concentration in salars is generally low. Pegmatite and clay deposits, in contrast, have higher lithium concentrations and involve high operational costs due to energy-intensive processes like excavating, crushing, and grinding. However, once mined, this type of ore processing takes a shorter time than ore processing from salar deposits.

Nevertheless, for ASM operators, lithium extraction from pegmatite is the most feasible because it follows traditional mining and extraction processes, which, if supported with investment and technical assistance, could become profitable. The Zimbabwe and Brazil cases are examined more closely in Section 4.2 of this report.

Upcoming developments include activities in the Nigerian Lithium Belt, which stretches 725 km from the southwest corner of the country to Kano State in the north. Continental Lithium, founded in 2017, has acquired 15 exploration leases covering about 450 km^2 and has partnered with artisanal miners since 2018, producing over 15,000 tonnes of lithium concentrate. Artisanal mining of lithium minerals has occurred there for years (Continental Lithium Limited, 2023a, 2023b). Similarly, Thor Explorations Ltd., through Newstar Minerals Ltd., has acquired exploration leases over 600 km^2 in several states, including Oyo, Kwara, Osun, Ogun, and Ekiti (The West Oyo Project), targeting areas with a history of artisanal lithium mining (Thor Explorations Ltd, 2023a, 2023b).

In Ghana, officials are working to allocate sections of the Saltpond Enclave in the Central Region to licensed small-scale miners, though the full plan has not yet been revealed. This initiative coincides with the upcoming opening of Atlantic Lithium's Ewoyaa Mine, which includes spodumene-rich pegmatite deposits in Ewoyaa, Abonko, and Kaampakrom. Lithium is set to be extracted starting in 2024 (Atlantic Lithium Limited, 2023). There are discussions about small-scale miners selling their ore to larger companies, a strategy previously tried by the government with gold and diamonds, with limited success.

Additional examples of lithium pegmatite deposits currently under exploration include the Kamativi pegmatite in northwestern Zimbabwe; the Karibib project in Namibia; and pegmatite exploration projects in the DRC, the most advanced of which is Manono-Kitotolo (AVZ Minerals Limited, n.d.; Galileo Resources Plc, n.d.; The Extractor Magazine, 2024).

Australia is currently the largest lithium producer, with deposits largely hosted in pegmatites (U.S. Geological Survey, 2023). What the Australia case reveals—albeit indirectly—is how lithium mineralization hosted in pegmatite can support a small-scale lithium mining sector. The Greenbushes project in Western Australia, now the world's largest hard rock lithium mine, commenced in 1980 when lithium was first discovered in the area. In 1983, a small-scale mine began operation here, supplying lithium to specialized businesses engaged in glassmaking, steel production, castings, alloying, and the manufacturing of lubricants (Kurmelovs, 2022). Greenbushes has since become one of the world's most important lithium production centres, currently accounting for one fifth of global output (Talison Lithium Australia Pty Ltd, n.d.).

Australia's experience shows that the path from artisanal to large-scale lithium mining is possible with pegmatite deposits. In other countries, with the support of governments, companies appear to be following the Australian blueprint and using artisanal and small-scale lithium miners as pathfinders. As previously indicated, this is already happening in Nigeria and could be what the Ghanaian government is planning with the Saltpond Enclave. In areas of Zimbabwe and potentially Brazil, where lithium pegmatite occurrences are abundant, the plan to use small-scale miners as pathfinders for large-scale companies is far more overt (Section 4.2).

The evidence from these cases suggests that ASM could play an expanded role in supplying some critical minerals—at least in the case of lithium—if governments in countries where there is a potential for profitable ASM operations are prepared to consider this option.

2.2 Graphite

Compared to lithium, there is lower potential for small-scale projects in graphite mining—due to the low value per unit of weight of ore extracted, nearly all actors are large-scale operators. China dominates graphite production, accounting for approximately 60% of the global market share, although Brazil, India, and North Korea have sizable outputs (see Table 4). Most of the largest deposits consist essentially of graphite, described as "flake graphite" and "amorphous graphite," which would have carbon grades ranging from 5% to 40% and 25% to 80% carbon, respectively. Africa has the potential to become a leading producer of graphite; its current production comes largely from Madagascar, Mozambique, Namibia, and Tanzania and accounted for 15% of global output in 2021 (Mitchell & Deady, 2021).

In the context of ASM, one exception is Sri Lanka. Even though it accounts for less than 1% of the world's production, graphite ore known as "crystalline graphite" is mined by ASM operations in veins that forms "infill fissures" in igneous and metamorphic rocks (Graphano Energy, n.d.). Crystalline graphite is typically high grade (>90% carbon), making ASM mining a possibility. In 2017, Lanka Graphite Limited was granted its first artisanal mining licence, targeting an initial monthly production of 20 tonnes of ultra-high grade (97% to 99% total graphitic carbon) and then increasing the production exponentially to ~5,000 tonnes within the 2 years after entering production (Lanka Graphite Limited, 2017). Other operators, like Ceylon Graphite, have also ramped up production from their small-scale operations (Ceylon GraphiteCurie, 2021).

TABLE 4. Locations of largest reserves of graphite and corresponding mine production

No.	Country	Reserves (tonnes)	Mine production 2021 (tonnes)	Mine production 2022 (tonnes)
1	Türkiye	90,000,000	2,700	2,900
2	Brazil	74,000,000	82,000	87,000
3	China	52,000,000	820,000	850,000

No.	Country	Reserves (tonnes)	Mine production 2021 (tonnes)	Mine production 2022 (tonnes)
4	Madagascar	26,000,000	70,000	110,000
5	Mozambique	25,000,000	72,000	170,000
6	Tanzania	18,000,000	N/A	8,000
7	India	8,000,000	7,000	8,300
8	Uzbekistan	7,600,000	110	N/A
9	Mexico	3,100,000	2,100	1,900
10	North Korea	2,000,000	8,100	8,100

Source: U.S. Geological Survey, 2023.

2.3 Cobalt

Cobalt has been and is still heavily mined on a small scale in the DRC. The country accounts for over 70% of the global production of the mineral. Between 15% and 30% of this output originates from ASM sites (Gulley, 2022; Soguel, 2023; Wischer, 2022). The low level of initial capital investment is one main factor attracting miners into cobalt ASM in the DRC. However, challenges related to regulatory compliance, safety, environment management, and workers' rights hinder the full development of this significant part of the global cobalt chain supply.

2.4 Other Minerals

When the critical minerals portfolio is broadened beyond these three battery minerals, more opportunities for ASM extraction emerge. Nearly all of the world's primary refined tin (~97%) is produced in emerging and developing countries, of which ~40% is sourced from ASM operations (International Tin Association, n.d.). Indonesia is a major producer, contributing to a quarter of the world's tin supply (74,000 of 310,000 tonnes), with ASM operations accounting for 60% of Indonesia's output (U.S. Geological Survey, 2023). Similarly, ~60% of the world's tantalum is mined in ASM operations, primarily in Africa's Great Lakes Region (Schütte & Näher, 2020).

3.0 ASM Prospects in Critical Minerals

3.1 An Overview

Although one needs to acknowledge the limited data available, it still appears clear that ASM accounts for a significant share of global output for a number of commodities that fall into many countries' "critical minerals" lists (Appendix A).

As will be described in detail, the global ASM sector currently makes notable contributions to global outputs of cobalt, tin, and tantalum. However, ASM production is also significant in the global production of tungsten, accounting for 6% of the total (Schmidt, 2012a). Many of the examples cited in this section of the report will be expanded upon, as well as additional case studies. What remains unclear at this point, however, is the role—if any—that governments envision ASM to play in countries where ASM has a high potential in at least partially addressing the critical minerals supply gap moving forward. Specifically, how prepared are policy-makers for ASM to take on an expanded role in the critical mineral supply that extends beyond its current contributions to the global production of these minerals?

In recent years, several countries have initiated formalization processes in the ASM sector by providing a legal framework for ASM miners to operate. However, more efforts have yet to be deployed to obtain the results initially expected with the ASM formalization process. These efforts will involve, among other steps, mobilizing essential technological and financial support, simplifying regulations, and releasing mining permits in areas where, for instance, ore deposits are too small to attract and justify large-scale mining investment—all to support a formalized ASM sector. Several examples illustrate the challenges that ASM operators face to operate legally and secure the necessary mining permits, including the gold sector, alluvial diamonds, and other precious and semi-precious gemstones. Laborious and potentially lengthy steps must be taken to lay the institutional and policy bedrock for a formalized critical minerals sector that provides opportunities for—and a voice to—ASM.

3.2 Overcoming Obstacles to Unlock ASM Potential

There is a case for prioritizing ASM as a source of critical minerals, especially its potential for short-term access to minerals and as a path to explore new areas. However, several challenges would need to be overcome for key players and their critical inputs to come together to enhance ASM contributions on this front.

This section of the report offers an analysis of the challenges ASM faces in becoming a reliable and trusted source of critical minerals. Understanding these challenges is crucial to developing and proposing the necessary policy changes.

3.2.1 Informality

The sector's informality could be viewed as both an obstacle and an opportunity. Many ASM activities worldwide, regardless of the commodity being extracted, are carried out by individuals who do not possess a licence. Reasons could include inappropriate legal frameworks (such as costly permitting fees or bureaucratic licensing application procedures), a lack of geological data on which to base decisions, a shortage of capital, and minimal access to equipment (Fritz et al., 2018; Hilson et al., 2018a; IGF, 2018). Regulatory and policy frameworks in place for the sector may exacerbate ASM's informality due to their inadequacy to meet ASM needs.

A big push will therefore be needed to usher in the changes required to facilitate the sector's formalization. Greater recognition of ASM's undervalued contributions to the critical minerals space could, however, be the push needed to make the sector a bigger part of this equation moving forward. Putting this vision into practice will require making key changes in strategic locations where ASM is heavily anchored in the production of key critical minerals. The following are but a few examples:

- **Indonesia:** According to the Directorate-General of Mineral and Coal at the Ministry of Energy and Mineral Resources, as of 2021, "illegal ASM" was taking place at 2,645 sites scattered across 30 provinces (Meutia et al., 2022).
- **DRC:** Most artisanal cobalt mining is informal and conducted outside of the legal code, often on sections of concessions demarcated to large-scale operators (Bridle et al., 2021). Major concerns, including conflicts and limited access to formal markets, hinder the stable and increased production of tantalum, accounting for ~40% of the world's output (Hoex et al., 2023).
- **Peru:** Artisanal copper mining is on the rise across the country's Apurimac region, in particular, and must be examined closely by the government if it is to make notable contributions to formal supply chains moving forward (Pachas, 2022).

To explore the potential for dedicated ASM licensing for critical minerals, it is essential to study and understand the informal dynamics within the ASM sector in key locations. The IGF ASM guidance document for governments (Fritz et al., 2018) examines broader sector-specific issues and lays out strategies to implement ASM formalization; however, there are currently no established or specifically designed legal frameworks for "ASM in critical minerals." Developing such frameworks could position these areas as leaders in implementing complementary changes elsewhere. This process requires a thorough assessment of existing practices and potentially designing tailored legal and regulatory structures to support sustainable development in the sector.

3.2.2 Specificity of ASM Operations

A second barrier is a poor understanding of ASM demographics. It is imperative to develop deeper knowledge of who is involved in ASM if sustainable structures that are capable of facilitating the acquisition of critical minerals from ASM sites are to be installed. Understanding who is involved and how they are organized is fundamental if the ASM sector is to become a legitimized player in the global supply of critical minerals.

The organizational structures and units found at ASM sites have been studied mostly on a case-by-case basis; the analysis available is not particularly broadly applicable, as the dynamics of these locations, the commodities being mined, and the markets they supply are very different. Very little can be drawn from a country such as the DRC to explain related phenomena in the likes of Indonesia or Peru.

3.2.3 Unknown Motivations for Mining Critical Minerals

A substantial amount of work carried out on mineral extraction by ASM has focused on ASM groups engaged in the extraction of gold, diamonds, and other precious and semi-precious gemstones. There are few complementary storylines, outside of cobalt in the DRC and the 3Ts (tin, tantalum, and tungsten) in the wider Great Lakes Region, concerning those engaged in the small-scale extraction of critical minerals (Cuvelier et al., 2014; Diemel & Cuvelier, 2015; Diemel & Hilhorst, 2019). Developing various classifications of miner types has helped clarify the broader dynamics of the ASM sector. These typologies, described in the next paragraph, are designed to contextualize specific circumstances and factors that drive participation in ASM.

As so little research about ASM livelihoods linked to the extraction of critical minerals has been carried out, generalizing about individual motivations for pursuing work in this subsector is challenging. Are the motivations poverty-driven or mostly opportunity-based? Moreover, where are people moving into the ASM sector from another mining subsector or other industries altogether? The literature organizes miners into four groups: 1) gold-rush miners (or rush miners, in this case), 2) permanent miners, 3) seasonal miners, and 4) poverty-driven miners (United Nations. Economic Commission for Africa, 2003; Weber-Fahr et al., 2001).

Livelihood studies provide information about the dynamics of communities linked to cobalt extraction in the DRC and tin mining in Indonesia (see Bikubanya & Radley, 2022; Cuvelier et al., 2014; Iguma Wakenge et al., 2021; Maia et al., 2019), but overall, there is insufficient detail available to articulate why people are moving into the critical minerals space, where they are coming from, if they come with mining experience, and where the activities they undertake feature in their income portfolios. Without sufficient data, it is difficult for policy-makers to further motivate miners to move into the critical minerals space or deter them from bad practices.

3.3 The Limitations of ASM Categories

The categorization of ASM in laws and policies may become a barrier by either "oversimplifying" its diversity by grouping varied kinds of operations under a single category or by "overspecifying" categories. ASM operations fall into one large subcategory of mining activities; however, its characteristics greatly differ from large- and medium-scale mining, given the size of operations, the level of mechanization, production volumes, the number of workers, or the environmental impacts. The consequence of developing ASM categories that do not adapt to the reality of the ASM mining sector is having policies that fail to address the specific needs of different ASM types.

There has been a push in a number of African countries, such as Ghana and Sierra Leone (Conteh & Maconachie, 2021; Johnson, 2020), to recategorize ASM on the basis of the level of mechanization. The logic here is that a group of artisans should not be receiving the same policy treatment as a cooperative comprising hundreds who are mining on a small scale and using excavators. However, the level of mechanization alone does not reflect the diversity of ASM operations. Additional factors, such as the size of operations, the expected production volumes, the number of workers, and environmental impacts, should also inform ASM categorization policies. The cases of Sierra Leone, Mozambique, and Liberia, where there are currently separate categories for small-scale and medium-scale mining or their equivalents (Hilson & Maconachie, 2020), have shown that those found in the lowest category are typically prohibited from using heavy machinery, which stifles their production and development. These limitations highlight the need for more suitable ASM categorization that accounts for the full range of ASM practices, rather than focusing solely on a single factor like the level of mechanization or permit size.

For ASM to realistically develop into a reliable supplier of critical minerals—through direct partnerships with manufacturers or any other models—operations need scaling up and financial backing. The purpose of ASM categorization should be to enable the ASM sector to be more compliant with regulations and drive ASM operations, thus facilitating their transition toward larger-scale mining if, and when, possible.

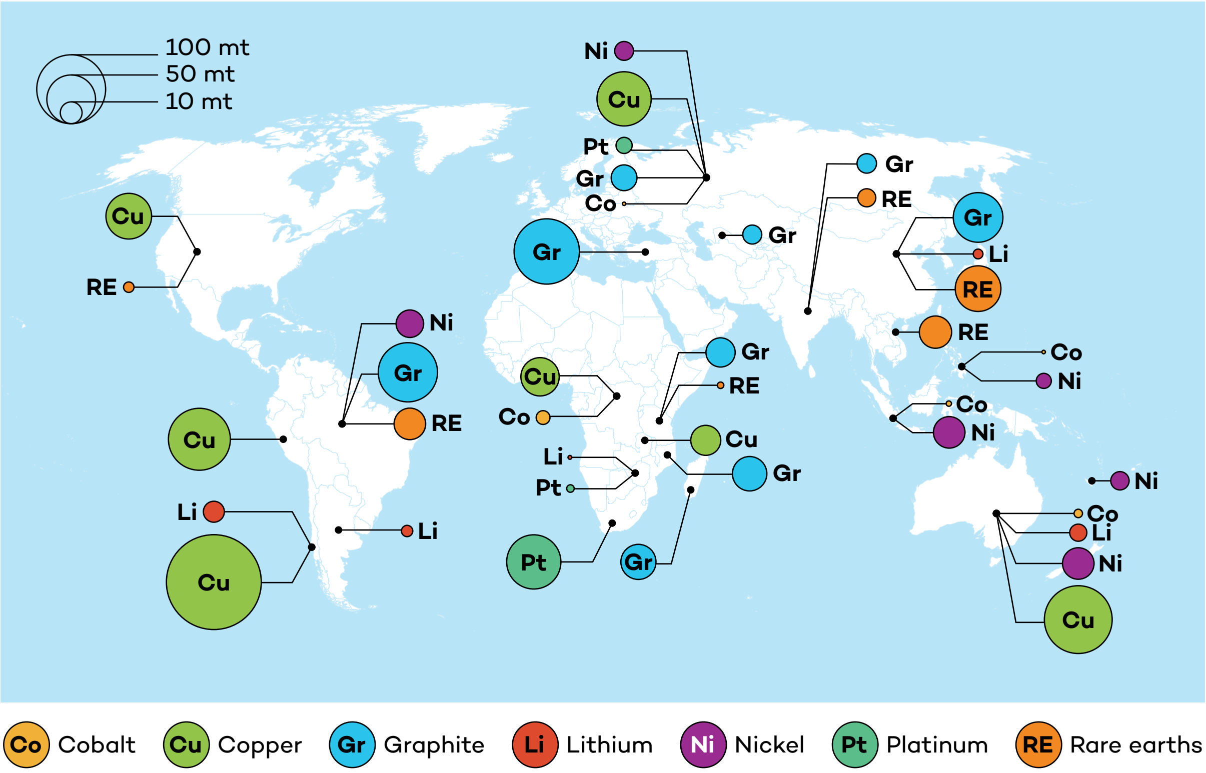
Balancing essential support for ASM operators with effective ASM categorization is crucial. ASM categorization should not result in additional bureaucracy or overcomplicated licensing procedures, alienating those who struggle to meet more advanced sets of rules (i.e., requirements to undertake more comprehensive audits, complete costly environmental impact assessments, and pay even higher licensing fees). To pursue an approach targeting advanced ASM operations in critical minerals, it is crucial that the countries involved have suitable regulatory frameworks to support licensing. A review of global practices shows that, in countries where critical minerals are a significant part of the ASM sector, such as in the DRC and Indonesia, there is often a tendency to apply generic regulatory and policy treatment in this unique subsector. Adopting a more tailored approach that addresses the unique aspects of critical minerals in ASM could, however, be a significant driver of growth.

Based on the discussion presented in this section, key policy changes and commitments from host governments, the international community, industry, and non-governmental organizations are needed to overcome barriers to ASM becoming a reliable and trusted source of critical minerals. These minerals will be used to manufacture the technology needed to meet renewable energy deployment targets and support an expanding digital economy.

4.0 Case Studies

Currently, ASM contributes significantly to the global supply of these commodities, accounting for approximately 8% of cobalt, 40% of tin, and 60% of tantalum production worldwide (Cobalt Institute, 2022; International Tin Association, n.d.; Schütte & Näher, 2020). This section of the report uses case studies of a combination of established settings and new frontiers (Figure 2) as a solid foundation upon which to operationalize a vision of a critical minerals sector supplied by ASM.

FIGURE 2. Graphical representation of the location of selected critical minerals production hubs worldwide



Source: Authors.

4.1 Established ASM Locations With the Potential for Growth

The DRC: Cobalt

- The DRC produces at least 74% of the world's cobalt (Cobalt Institute, 2022), mostly as a by-product of copper (Gulley, 2022).
- 20% to 25% of DRC´s cobalt is sourced from ASM operations (Le Petit, 2019).
- The majority of ASM is informal.
- ASM directly employs an estimated 200,000–255,000 people (Le Petit, 2019).

In this sector, intricate systems of diggers, industrial and artisanal "investors," traders, crushers and sorters, and even association leaders extract copper and cobalt-rich ore that is transported in sacks and, in turn, sold to mine licensees or *entités de traitement* (typically, Chinese or Indian), who then process and/or export it (DeCarlo & Matthews, 2019; Rachidi et al., 2021; Sovacool, 2019). Officials at the Cobalt Institute concede that the unlicensed nature of most ASM operations in the DRC makes it challenging to ascertain precise production figures and articulate trends (Cobalt Institute, 2022). In other words, tracking the origins of cobalt ore extracted by Congolese ASM operators is challenging.

Depots set up specifically to buy ore are established by those in possession of a buying licence and export licence. These people commonly own *entités de traitement* (ore treatment centres) (Vetter & Schüutte, 2019). Usually, Indian and Chinese merchants forge agreements with artisanal miners linked to cooperatives by helping them open their pits—by removing overburdened soil to access ore buried at depth—and buy equipment; in return, they receive the production of cooperatives. In some cases, the situation can become complex, like in the town of Kolwezi, where all lands are under concession to large-scale mining companies and pinpointing the sources of cobalt becomes nearly impossible because of the complex artisanal networks sustained by operators who collect ore to sell from virtually anywhere. There is currently no mandatory requirement for owners of *entités de traitement* to disclose the sources from whom they purchase ore.

But herein lies the dilemma: companies in need of cobalt are contractually trying to exclude ASM groups because of the sector's burgeoning informality—yet at the same time, they are desperate to secure access to cobalt (Baumann-Pauly, 2023). Informal operators have been condemned for being associated with exploitative practices, child labour, and environmental destruction. The presence of informal operators, however, means that product is likely to find its way into supply chains despite companies' best efforts to avoid this, which is why many have formed alliances and launched development interventions. For example, in 2019, a number of hi-tech companies, including the BMW Group, BASF, Samsung SDI, and Samsung Electronics, launched Cobalt for Development, an intervention aimed at making ASM more responsible by supporting operators (Cobalt for Development, n.d.; Lawson, 2021). Another similar initiative is the Fair Cobalt Alliance, a multistakeholder action platform that was established to "strengthen and professionalise DRC's artisanal cobalt mining sector" through safeguarding children's rights and facilitating economic diversification in ASM communities (Fair Cobalt Alliance, n.d.).

In the DRC, the artisanal mining sector is governed by the 2018 Mining Code. It states that activities can only take place in designated Zones d'Exploitation Artisanale, which can be up to a maximum of 1.7 km^2. Operators must be registered and obtain an official card, be part of a cooperative, and pay taxes to the government. To promote formalization and marketing of ASM, the government established the Entreprise Générale du Cobalt as the state buyer for cobalt ore (Articles 3 and 4 of the new Ministerial Decree 19/15 (2019)) and created the Autorité de Régulation et de Contrôle des Marchés des Substances Minérales Stratégiques (ARECOMS) (Ministerial Decree 19/16 (2019)), which governs the Entreprise Générale du Cobalt's purchasing. In addition, the Permis d'Exploitation de Petite Mine, established under Article 97 of the 2018 Mining Code, allows a large-scale mining company to cede a section of its concession to a group of artisanal miners (Deberdt, 2021; Umpula et al., 2021).

In addition to these regulatory foundations, the government recently decided to raise royalties on minerals designated as "strategic." As stated in Article 241 of the country's revised mineral code[7] (Mines Ministry, 2018), the royalty on "strategic minerals" *(les substances stratégiques)*, defined as "any mineral substance which, depending on the international economic situation of the moment, at the discretion of the government, is of particular interest for consideration of criticality and geostrategic context,"[8] is now 10%, up from 2%.

The Great Lakes Region: 3Ts

- 60% of the world's tantalum is mined on a small scale, primarily in Africa's Great Lakes Region (Schütte & Näher, 2020).

A case in point is the International Tin Supply Chain Initiative (iTSCi) scheme, designed specifically to address conflict mineral concerns in Africa's Great Lakes Region by establishing traceability in the upstream segment of the mineral chain for 3Ts minerals—tin, tungsten, and tantalum (International Tin Supply Chain Initiative, 2016b). The scheme is intended to support the *OECD Due Diligence Guidance* and the Dodd-Frank Act (Cuvelier et al., 2014; Organisation for Economic Co-operation and Development [OECD], 2016). Data collected between the years 2016 and 2018 from the eastern provinces of the DRC shows that half of the 623 mine sites employing an estimated 115,500 artisanal miners were covered by due diligence programs (DDPs). Nearly 52% of these mine sites produced 3Ts minerals (cassiterite -Sn, coltan – Nb and Ta, and wolframite – W); the rest produced mainly gold. Armed groups were present on 35% of mine sites and interfered in 26% of the mining sites, with a big difference between DDP mining sites (10%) and non-DDP sites (40%) (IPIS/ULULA, 2019).

In Rwanda and Burundi, known 3Ts ore deposits currently being mined are not often suitable for capital-intensive mineral extraction, and as a result, the culture of ASM is more persistent than that of other countries. As of the end of 2023 in Rwanda, there were 31 active small-scale mining licences and 76 medium-scale mining licences linked to 3Ts mineral extraction in the country (Rwanda Mines Petroleum and Gas Board, n.d.). Due to its comparatively smaller size, Rwanda presents a more monitorable and auditable setup than the neighbouring DRC. The mining sector in Burundi consists mostly of ASM actors, including 10,000 people who

7 Loi n°18/001 du 09 mars 2018 modifiant et complétant la Loi n° 007/2002 du 11 juillet 2002 portant Code minier, www.leganet.cd/Legislation/Droit%20economique/Code%20Minier/Loi.18.001.09.03.2018.html.

8 Author's translation: "Substance stratégique : toute substance minérale qui, suivant la conjoncture économique internationale du moment, à l'appréciation du Gouvernement, présente un intérêt particulier au regard du caractère critique et du contexte géostratégique." See Titre 1ier: Des generalites chapitre 1ier: des definitions des termes, du champ d'application et des principes fondamentaux, Loi n°18/001.

engage in the extraction of 3Ts minerals (International Peace Information Service, 2015). Similarly, Burundi's Mining Code indicates that only registered cooperatives can apply for licences, which should provide some assurance to foreign governments and companies across the world looking to forge partnerships.

The case of the 3Ts in the Great Lakes Region is a reminder of how scarce these minerals are and how little flexibility governments seeking to secure them have as a result. ASM partnerships coming to fruition will require some skillful manoeuvring on the part of governments of importing countries, industry actors, and end-users. Working closely with multistakeholder or non-governmental organizations (e.g., the European Partnership for Responsible Minerals,[9] IMPACT, PACT, or the Alliance for Responsible Mining) that have extensive experience working in ASM communities could facilitate the design and implementation of acceptable partnerships. Establishing buying depots for critical minerals extracted on ASM operations will require recognizing the challenges of gathering pre-purchase details on products mined. As will be explained, the case for partnering within the framework of ASM on the critical minerals front is as much about it being straightforward, given the circumstances, as it is about convincing importing countries and private sector partners that large-scale mining is not necessarily in the best position to unlock ASM's potential to increase its contribution to the global output of critical minerals.

The Great Lakes Region, Indonesia, Myanmar, and Beyond: More on tin

- Approximately 97% of the world's refined tin is produced in emerging and developing countries, with around 40% sourced from ASM operations (International Tin Association, n.d.).
- Indonesia is a major producer, contributing to a quarter of the world's tin supply (74,000 of 310,000 tonnes), with ASM operations producing 60% of Indonesia's output (U.S. Geological Survey, 2023).

China dominates in tin production (95,000 tonnes in 2022), although there are a number of other significant producers scattered across the globe, such as Peru (29,000 tonnes in 2022), Bolivia (18,000 tonnes in 2022), Vietnam (5,200 tonnes in 2022), and Brazil (18,000 tonnes in 2022) (U.S. Geological Survey, 2023).

In Africa's Great Lakes Region, the main tin ore mined is cassiterite, which occurs either as alluvial deposits or hosted in pegmatite and stockwork veins (Hosking, 1988). Mining is conducted mostly as ASM operations, though one project by Alphamin Resources—Mpana North & South—carries out mining on a larger scale (Alphamin Resources, n.d.; Macháček et al., 2022). Data collected by the Federal Institute for Geosciences and Natural Resources indicate that there are 40,000, 35,000, and 3,300 artisanal miners engaged in the 3Ts sector in eastern DRC, Rwanda, and Burundi, respectively, although far more are likely unrecorded (Federal Institute for Geosciences and Natural Resources, n.d.). These miners are part of a dynamic microeconomy system that, aside from the miners themselves, involves traders, including women trader groups, buyers, and financiers (Byemba, 2020).

[9] EPRM is a multistakeholder partnership conceived "to increase the proportion of responsibly produced minerals from conflict-affected and high-risk areas" and "to support socially responsible extraction of minerals that contributes to local development." It is aligned and works in conjunction with the EU Conflict Minerals Regulation (European Partnership for Responsible Minerals, n.d.).

The spotlight on the 3Ts sector in the Great Lakes Region has garnered attention because of ongoing conflicts in the region, which has had implications for local mining activities, especially in relation to human rights abuses. It has spawned a series of traceability schemes designed in the spirit of the *OECD Due Diligence Guidance*, including the aforementioned iTSCi, the Federal Institute for Geosciences and Natural Resources' Certified Trading Chain, and the Responsible Minerals Initiative's Conflict-free Smelter Program (Barume et al., 2016). In the Great Lakes Region, 3Ts minerals appear to be less associated with armed interference than other commodities being mined on a small scale, an observation recently affirmed in a study of 1,615 mines visited in eastern DRC during the period 2013–2015 (Weyns et al., 2016). When disaggregating the data between 3Ts minerals and gold, it emerged that approximately 21% of the 3Ts minerals extraction was conducted in areas where armed groups are involved compared to 64% for gold. This is likely due to gold's comparatively higher unit price and the ease with which gold ore can be refined, concealed, and transported.

Although it has attracted criticism for failing to have much of a reach in the DRC, the iTSCi scheme provides a foundation for destination countries to establish working relationships with ASM (Gouby, 2022). The scheme currently covers over 1,300 mine sites and more than 80,000 individuals in Burundi, the DRC, and Rwanda (International Tin Supply Chain Initiative, 2016b). Of the three, Burundi seems to be the most overlooked as it recovers from the country's 2015 political crisis, which led to the suspension of the country's iTSCi program. However, investors have since returned, which has led to the reopening of flagship mines such as Kidunduri (International Tin Supply Chain Initiative, 2016a). Other potential opportunities exist in Uganda, where companies buy directly from artisanal and small-scale mines. A case in point is APRU, a Ugandan company that processes and exports cassiterite mined by artisanal miners at Nyarubungo and Katanga sites (Nénot & Daigle, n.d.).

Indonesia—the world's second-leading tin producer, contributing 27% of global output with 60% of production coming from ASM—also offers opportunities to foster partnerships. Most tin mining activities in the country are found on Banka Island and Belitung Island. There is a specific regulatory framework that governs ASM activities. The Ministry of Energy and Minerals makes specific locations, called People's Mining Areas, available. Access is obtained through requests to the respective provincial authorities. However, many people who work in People's Mining Areas are doing so illegally, unlike those who are found in territories covered by the Special Mining Business Licence (called Izin Usaha Pertambangan Khusus [IUPs]). All IUPs must be secured from the national government, but the key difference is that they are held by private and public companies. Artisanal miners working lands covered by IUPs, therefore, have partnerships with the respective companies, which the law permits (Maia et al., 2019).

By comparison, in Myanmar, it is more challenging to develop short-term partnerships with small-scale miners, mainly because foreign investors have been discouraged by the lack of minority shareholder protection, the inability to access credit, concerns with insolvency protection, and general difficulties in starting a business (Sykes & Gardiner, 2016). The country's tin-producing areas are located in the Dawei District along the southern coast and the Shan States in the northeastern region along the border with China (Gardiner et al., 2015). Tin mining in Myanmar has a 1,000-year history, and after a long decline, it experienced a sudden increase in the 2000s. Myanmar became the world's third-largest producer in 2010, with tin output that surged by over 4,000% between 2009 and 2014. Production reached 10,000 tonnes in 2011 and continued to rise, peaking at 60,000 tonnes in 2016 (Gardiner et al., 2015; McFarlane & Villalobos, 2019).

A remarkable case of ASM operations in Myanmar includes the Man Maw site in the Shan States, which produces ~30,000 tonnes yearly. It is described as a single large mining area, where an undefined number of ASM operators are mining and processing ore by gravity separation methods (Gardiner et al., 2015; McFarlane & Villalobos, 2019). Myanmar is certainly a case worth monitoring, given the plethora of trade sanctions imposed by the likes of the European Union (EU)—seventh round at the time of writing—the United States, and the United Kingdom (European Commission, 2023; HM Treasury and Office of Financial Sanctions Implementation, 2018; U.S. Department of State, n.d.-a).

Building partnerships in Cameroon could also provide potential opportunities. Cassiterite ore from alluvial deposits has been mined in ASM operations in the Bambol and Mayo Sen regions since the early 1930s and has continued to date (Njiganga et al., 2023). In the Mayo Darlé commune, the South Korean company Posco International (formerly Daewoo International of the Daewoo Group) secured full exploration rights (Permit 259) to explore for tin in Mayo Darlé, initially for a 3-year period from 2011 to 2014 (Republic of Cameroon EITI committee, 2013). Consultations with local experts reveal that despite never securing a mining lease, Daewoo was purchasing cassiterite from local artisanal miners but had stopped following the onset of the pandemic. Posco International and South Korea's approach extends beyond Cameroon—in 2011, Posco signed a Memorandum of Understanding with the DRC's state-owned Sodimico and Taejoo Synthesis Steel (Chung & Chung, 2011).

Chile: Copper

The Government of Chile established Empresa Nacional de Minería (ENAMI) in 1960. Since then, it has successfully formalized ASM operators, particularly those extracting copper. As per ENAMI records between 2011 and 2021, there were 1,360 small-scale mining businesses registered (95% of which extract copper). Altogether, they produce up to 10,000 tonnes monthly (Atienza et al., 2023).

The ENAMI platform began as an entity through which the Government of Chile provided mostly technical assistance to ASM. This assistance included facilitating access to ore processing facilities that produce concentrates, blisters, and copper cathodes of the same grades as large-scale miners. In 2003, however, ENAMI's objectives expanded following the implementation of Decree 76, which established a national policy for small- and medium-scale copper mining in Chile. Through Decree 76, USD 8 million is made available annually to support ASM. It is used to promote small- and medium-scale operators' access to (1) development and finance, (2) ore processing units, and (3) commercialization services. Decree 76 has facilitated these changes through the establishment of a venture capital fund, credits for equipment purchase, access to markets through buying agencies and ore processing units, and fixed prices. Miners must first register with ENAMI to access this support and formalize their activities. The 1,360 miners registered with ENAMI, who are scattered mostly throughout northern Chile, are entitled to this assistance (Atienza et al., 2023; Castro & Sánchez, 2003; Noetstaller, 1987; Poveda-Bautista et al., 2022).

The key takeaway in this case study is that ENAMI is a tested model for ASM formalization and support. It provides a much-needed platform for parties interested in investing in copper and operators seeking to access markets. Recently, the ENAMI model was advanced by World Bank officials in Tanzania as an ASM formalization model in the country under its USD 45 million Sustainable Management of Mineral Resources Project (2009–2015) as part of its key Lessons for Tanzania (World Bank, 2015).

4.2 New Frontiers for ASM

Outside of the established ASM critical minerals zones, such as the Great Lakes Region, Indonesia, and Chile, there are currently very few emerging hotspots. In areas where there is potential, such as lithium, host governments appear to be using the ASM sector's operators as pathfinders.

Zimbabwe: Lithium

- Zimbabwe is the world's sixth-largest lithium producer (U.S. Geological Survey, 2023).
- The Lithium Association of Zimbabwe, a quasi-governmental entity established in 2022, represents the interests of the country's artisanal and small-scale lithium miners.
- There are currently six registered (licensed) small-scale lithium miners (now all joint ventures with Chinese investors).

Zimbabwe hosts one of Africa's largest lithium deposits in the Bikita Mine, and its government aspires to ensure that the lithium being extracted is processed in the country so it can add value locally. The government recently issued a ban on exports of unprocessed lithium, passing the Base Minerals Export Control (Unbeneficiated Base Mineral Ores) Order, 2023 (BMEC Order 2023) (Government of Zimbabwe, 2023). As a result, ASM operators that do not process ore prior to export are impacted, but companies producing spodumene concentrate are unaffected because the ban does not consider concentrates as unbeneficiated ore (Mpofu, 2023). Examples of producers not affected by the ban include the following:

- The Sinomine Resource Group's Bikita Mine, currently the only site producing lithium in the country, which contains an estimated mineral resource of 13 million tonnes of ore at 1.6% Li_2O as of 2020 (Goodenough et al., 2021);
- The Australian-based company Prospect Resources' planned Arcadia Mine, which had estimated mineral resources of 43.2 million tonnes at 1.41% Li_2O as of 2019 (Goodenough et al., 2021); and
- Chinese-based companies Zhejiang Huayou Cobalt and Chengxin Lithium Group, which have, over the past year, acquired lithium projects at various stages of developing mines and processing plants, exempting them from the ban (Mitchell, 2023).

Ultimately, the impetus behind the ban is to prevent artisanal miners from exporting unprocessed ore and implement government plans to build domestic processing capacity and take advantage of the soaring lithium price on the market (Mitchell, 2023).

Prior to the ban, individuals interested in extracting lithium (or any other mineral, for that matter) on a small scale would apply for a Prospecting License (in line with Section 20(1) of the Mines and Minerals Act) at the relevant provincial Ministry of Mines and Mining Development Office, which entails registering a syndicate and making a USD 75 payment. A Prospecting License is tenable for 5 years and can be renewed for another 5 years (Government of Zimbabwe, 2021). It authorizes the holder to conduct exploration in the country's provinces to identify places to "peg," with the goal of identifying a "block" for mining. After selecting a "block," approval must be obtained from the Ministry of Mines and Mining Development Office. If granted, a Certificate of Registration is issued, allowing mining to begin.[10]

According to the law, no individual or entity can buy lithium-bearing ores from a miner or any other person (Government of Zimbabwe, 2023). The exceptions are instances where the individual/entity (i) has a lithium ore purchase licence or (ii) obtains a lithium ore purchase licence themselves, unless they own or control an approved processing plant. Mineral export controls are set under BMEC Order 2023, including no permits granted for the export of beneficiated lithium at a selling price for export that is less than the amount set by the government-owned Minerals Marketing Corporation and no permit issued for unbeneficiated lithium unless the exporter has an approved processing plant or has concurrently obtained a permit to do so.

The Lithium Association of Zimbabwe, a quasi-government entity established in 2022 to represent the interests of the country's artisanal and small-scale lithium miners, should provide a link between operators and senior officials in Harare. It has already provided a much-needed forum for miners to share information and to identify potential sources of equipment. The association is also used to lobby the government to ensure that Zimbabwe nationals who are artisanal and small-scale lithium miners are afforded similar economic opportunities to companies. There are currently only six registered (licensed) small-scale lithium miners in Zimbabwe (now all joint ventures with Chinese investors).

Many consumer countries have imposed sanctions on the country—many of which go as far back as the 1990s (EU, n.d.; Foreign Commonwealth & Development Office, 2020; Government of Canada, n.d.; U.S. Department of State, n.d.-b; U.S. Department of the Treasury, 2022). It is unclear if they will consider buying lithium from Zimbabwe, even from licensed miners. Chinese mining companies, on the contrary, have already invested more than USD 1 billion to date to develop lithium projects in the country, which includes a move made by Prospect Lithium Zimbabwe, part of China's Zhejiang Huayou Cobalt, to establish a USD 300 million (lithium) processing plant in Goromonzi, some 80 km southeast of Harare (Chingono, 2023; Gbadamosi, 2023; Sanchez, 2023).

Brazil: Lithium

- Small-scale lithium mining occurs in lithium pegmatites sometimes associated with gemstones (Proctor, 1984).
- A number of large-scale mining companies are conducting lithium exploration in an area historically mined by artisanal miners (Sigma Lithium Corporation, 2023).

Small-scale lithium mining is quietly gaining traction in Brazil. This comes at a time when lithium is also being explored by large-scale miners such as Companhia Brasileira de Lítio's, which has reported a 4-million-tonne mineral reserve in its operating Cachoeira Mine in the Middle Jequitinhonha region (Minas Gerais state) with the capacity to produce 36,000 tonnes/year of spodumene concentrate at 5.5% Li_2O. Similarly, another operator, Sigma Lithium, has in the same region conducted exploration and reported estimated mineral

[10] According to Section 5(1) of the Mines and Minerals Act, "pegging" is the placement of a post or rod, excluding metal, with a minimum height of 1.2 metres and a diameter of at least 100 mm (Government of Zimbabwe, 2021). Under a Prospecting License, up to 10 claims (each no larger than 1 hectare) can be pegged. Once a deposit is found, a pegger places the pegs, marking the area with a Discovery Peg (Mining Zimbabwe, 2018; Tsabora & Parawira, 2023).

resources of 77 million tonnes from five deposits (Nezinho do Chicão, Xuxa, Barreiro, Murial, and Lavra do Meio) on its Grota do Cirilo licence (see Table 5) (Silva et al., 2023).

TABLE 5. Lithium mining interests in Brazil

Deposit	Owner	Resource estimates (million tonnes)	Average grade Li O (%)	Status
Cachoeira	CBL	4	1.6	Operating
Nezinho de Chicão	Sigma lithium	26.7	1.49	Feasibility
Xuxa	Sigma lithium	17.41	1.55	Feasibility
Barreiro	Sigma lithium	25.08	1.38	Feasibility
Murial	Sigma lithium	5.56	1.14	Feasibility
Lavra do Meio	Sigma lithium	2.27	1.09	Feasibility
Volta Grande	AMG	-	-	Operating

Source: Silva et al., 2023.

Jequitinhonha is today referred to as the country's "Lithium Valley." It hosts two major lithium pegmatite districts: Cel. Murta/Virgem da Lapa and Itinga. In addition to Minas Gerais State, there are significant exploration works elsewhere, including in the southern Tocantins, northern Goiás, and southern Bahia regions (Silva et al., 2023). There are many other lithium exploration projects in Brazil, including those being carried out by publicly listed companies, such as Atlas Lithium, Latin Resources, Lithium Ionic, and AMG. Applications for lithium exploration permits in Brazil increased from 35 applications in 2017 to 417 applications in 2022. In April 2023, 165 companies and cooperatives submitted 1,079 applications related to lithium, including exploration and mining permit applications (Agência Nacional de Mineração, n.d.).

Artisanal mining in Jequitinhonha dates to the 17th century, when people mined gemstones like chrysoberyl, tourmalines, and topaz (Puppim de Oliveira & Ali, 2011). Since lithium is found in the pegmatite associated with gemstones (Proctor, 1984), gemstones miners are, in effect, selling their "waste rock" that contains lithium (in spodumene and lepidolite) to buyers, mostly Chinese merchants, as they are legally allowed to do so. There are currently 76 artisanal mining permits in Jequitinhonha, most issued for the extraction of quartz and gemstones. Only one of these permits is specifically authorized for lithium. As most small-scale lithium production associated with the production of gemstones originates from "waste," production and quantities traded are challenging to track.

But as these interconnected mining activities are a relatively new phenomenon, they lack the cohesion and underpinning structures as those galvanizing rapidly in Zimbabwe. As a result, they are not particularly well organized and are often sporadic. There is now an abundance of opportunistic traders who visit gemstone sites in their vehicles, making offers to purchase mine wastes from operators. Producers are aware of the demand for their wastes—knowing that they contain trace quantities of spodumene and lepidolite—and therefore wait for competitive spot prices. There are rumours that traders have been carrying handheld x-ray analyzers since 2022, which are deployed to ascertain lithium contents to arrive at their price (G. de Tomi, personal communication, June 19, 2023). Once a deal is struck, the corresponding trader organizes transport, logistics, and loading of the ore and transports it to a port, where it is blended and then exported, often to China.

Since 2020, the local government has been working to implement policies to promote best practices and stimulate dialogue among stakeholders embedded within the lithium value chain in the region. Major moves made by the local government include implementing tax incentives and other mechanisms to encourage the establishment of new local businesses that are capable of supporting the lithium value chain. They have also invited representatives from local communities, artisanal miners' associations, industrial mining, entrepreneurs, and other actors in the lithium value chain to discuss and develop a plan of action for the region (see state law PL 1992/2020,[11] which is currently under review).

There are indications, however, that moving forward, ASM will not be a part of the government's plan to unlock lithium potential in Brazil. Officials appear to have decided to auction lithium-bearing regions to large-scale mineral exploration and mining companies. In addition, similar to what is unfolding in Nigeria and Zimbabwe, they plan to use historical artisanal exploration work as a guide to identifying prospects. For example, at its Solonópole Lithium Project, Perth-headquartered Oceania Lithium identified 20 historical small-scale mines during field exploration. It is using the information gathered from an analysis of these mines to guide its lithium exploration strategy across its concession, which comprises 10 permits covering an area of 124 km^2 (Oceana Lithium Limited, n.d.). Toronto-based Sigma Lithium appears to be taking the same approach at its Grota Do Cirilo Lithium Project in Northeastern Minas Gerais State. The project's feasibility report indicates that the area where the Lavra do Meio pegmatites are located "was historically mined using artisanal methods for spodumene and feldspar," which it is now studying closely (Sigma Lithium Corporation, 2021). Company officials also concede that, generally, in the locations where it is conducting exploration, it studies the "former artisanal mines within Sigma Lithium's mineral concessions to define the volumes and grades" (Sigma Lithium Corporation, 2023). The key takeaway from lithium developments in Brazil, therefore, is that large-scale companies are attracted by the same lithium deposits as ASM groups and that, increasingly, they are using historical ASM vestiges as pathfinders to locate economic reserves.

Brazil's lithium mining sector is clearly in a state of transition. It is an evolving, albeit fluid, situation, but opportunities remain for end-users and countries to broker purchasing agreements with ASM parties mining lithium ore. These opportunities are shrinking but will likely remain open as long as large-scale exploration for lithium and lithium mine development in the country has reached full maturity. As a guide, the structures in the gemstone mines found in Minas Gerais—specifically, the cooperatives organized there, which have responded to external pressures and environmental/social demands quite well—can serve as the foundation for designing lithium purchasing strategies moving forward.

[11] https://www.almg.gov.br/projetos-de-lei/PL/1992/2020

5.0 Key Challenges Moving Forward

5.1 Sourcing Strategies

Moving forward, legitimizing the ASM sector as a major supplier of critical minerals will require navigating complex geopolitics. Major importers' critical minerals policies and strategies suggest that they are committed to identifying fresh supplies of critical minerals of all types (see Appendix B). For this reason, if they can be convinced of the merits, many may be willing to consider ASM as a potential vehicle for sustaining the global supply chain.

The first step toward bringing such a strategy to fruition is rewriting policy to emphasize its importance. For some countries, an ASM critical mineral sourcing strategy would be a welcome addition to existing policy. The United States has set targets around renewable energy, with substantial funding under the Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law, for programs supporting a transition to 100% clean electricity by 2035 (U.S. Department of Energy, 2023). It has also committed to ensuring that half of all vehicles sold in the country are electric powered by 2030 and rallying autoworkers and companies around this idea (The White House, 2022). Yet, the government has made these pledges despite being almost 100% dependent on imports and scraps for its cobalt consumption (Wischer, 2022) and 100% dependent on imports of graphite (Karl et al., 2022) and rare earth elements (Ben-Achour, 2021) while producing only 1% of global lithium (a single brine operation: Albemarle's Silver peak site in Nevada) (Anderson, 2022). Moreover, despite the country importing 88% of its batteries from China in Q1 2023, in order to lock the full EV consumer credit under the IRA, a sizable proportion of the minerals contained within batteries used have to have been recycled in North America or been extracted or processed in a country that has a free trade agreement with the United States. The battery must have also been manufactured or assembled in North America (Carbon Publisher, 2023; McKinsey & Company, 2022).

The EU would also benefit from an ASM critical minerals sourcing strategy. The block initially laid out plans in the Green Deal (2020)[12] on how it intends to become carbon neutral by 2050. Revised goals and objectives are enshrined in the Critical Minerals Act, 2023, following which a revised list (the fifth iteration) of *Critical Raw Materials* was published (European Commission, n.d.). The bloc's ambitious plan to reduce emissions by at least 55% from 1990

[12] European Commission. The European Green Deal. COM(2019) 640 final, European Commission, Brussels.

levels by 2030 is also included in the Green Deal. This is despite the EU being in a similar position as the United States, importing 93% of its magnesium from China (Zimmermann & Aarup, 2023), sourcing 87% of its lithium from Australia and the balance from its single operating mine in Portugal (Tidey, 2022), and importing 98% of its natural graphite, including 47% from China (Hebestreit, 2022). In short, both the United States and the EU, along with a number of other countries, have committed to achieving net-zero by 2050, despite being almost entirely reliant on imports of the critical minerals needed to manufacture the technologies required to achieve this.

The point about China requires further elaboration. China has near-monopolistic control over the midstream and downstream segments of the critical minerals space (Figures 4 and 5). Highlights include the following:

- China refines 59% of the world's lithium and 73% of its cobalt.
- It controls most of the global production of components for battery cells, including 70% of cathodes, 85% of anodes, 66% of separators, 62% of electrolytes, and 78% of the world's cell manufacturing capacity for EV batteries (Castillo & Purdy, 2022).
- Chinese-backed companies own or have financial interests in 15 of 19 cobalt mines in the DRC, which, again, account for over 70% of global production of the mineral (Gulley, 2022; Wischer, 2022).

The United States, by comparison, did not refine cobalt and was selling stockpiles of rare earth elements when China was increasing its stranglehold over critical minerals supply chains and low-carbon technologies. Much of the same applies to the EU, which sources, among others, more than 70% of its lithium-ion batteries and 93% of magnesium from China. The bloc does not even have the capacity to produce the latter, having closed its last smelters in 2001 (Tidey, 2022; Zimmermann & Aarup, 2023). Moreover, only China has the facilities and workforce qualified to process heavy rare earth elements, which are the most suited for advanced applications in the energy transition (e.g., in permanent magnets for wind turbines), compared to light rare earth elements, for which processing capability is geographically more diverse; as a result, China effectively controls the entire global supply chain for rare earth elements (Pulina, 2019).

FIGURE 3. A depiction of the global critical minerals market

UPSTREAM SECTOR

Chile & Australia: 70% of the world's lithium

DRC: 70% of the world's cobalt

Indonesia: 30% of the world's nickel

Chile & Peru: 40% of world's copper

MIDSTREAM SECTOR

China refines:

59% of the world's lithium

73% of the world's cobalt

68% of the world's nickel

40% of the world's copper

DOWNSTREAM SECTOR

China manufactures:

70% of the world's EV batteries

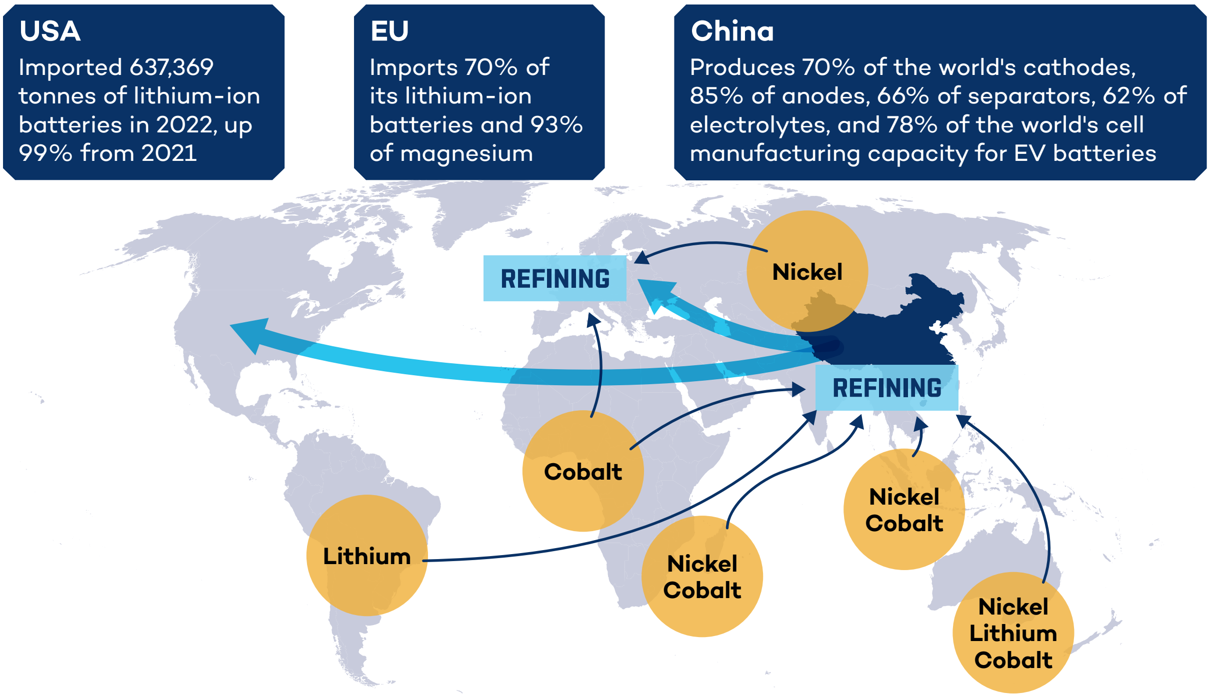
the bulk of the world's solar panels

3/4 of the world's lithium-ion battery factories

LOW-CARBON TECHNOLOGY MANUFACTURING

Source: Authors, based on facts and figures presented in this report.

FIGURE 4. Conceptualizing China's role in the upstream, midstream, and downstream segments of the critical minerals sector



Source: Authors, based on facts and figures presented in this report.

For the EU, the United States, and many other countries that are seeking to identify and source fresh supplies of critical minerals, implementing an ASM (critical mineral sourcing) strategy would be worthwhile, but given the current policy orientation, it might not be straightforward.

While ASM represents a promising pipeline of critical minerals supply, which in the years to come promises to expand markedly, for several countries, sourcing from the sector would require a comprehensive change in approach. It must start with rewriting the narrative on ASM and reviewing the standards applied to it.

5.2 Coproducts and By-Products

Moving forward, putting ASM more on the critical minerals agenda will also depend on how the global mining sector responds to surging demand. Critical minerals rarely form economically viable deposits on their own. They are, indeed, mostly extracted as coproducts or by-products during the mining of major metals, such as copper or nickel. Of the metals considered critical for the energy transition and for digital technologies, more than 60% are produced as coproducts or by-products (Bellois & Ramdoo, 2023).

Various countries' critical mineral lists differ slightly, depending on their priorities, sourcing strategies, and extraction capabilities. At the time of writing, in the United States, six critical minerals are extracted as by-products: indium, tellurium, gallium, germanium, rhenium, and cobalt (Humphreys, 2019); the United Kingdom's list is nearly double this, at 11. As a result, those mining these commodities (e.g., antimony from gold or bismuth from copper) are unlikely to increase by-product production, despite high demand (Deady et al., 2022). Generally, the supply of a by-product is dictated by the output of the main product (Humphries, 2019), but also the higher prices of the by-product on the market. The factors above will ultimately determine what major companies prioritize moving forward and how much manoeuvrability ASM will have in responding to shifts in global demand and sourcing strategies.

For example, cobalt, which, with the exceptions of Morocco (Bou Azzer mine) and the DRC (Mutanda Mine and, in the past, Mukondo Mine), is mined as a by-product of nickel (38% in 2022) and copper (60% in 2022) throughout the world (Cobalt Institute, n.d.). The economics, in this instance, are dictated heavily by firms engaged in the extraction of these commodities, but they are managed by companies that do not necessarily wish to restructure operations in response to the growing demand for cobalt.[13] This includes the DRC, where an economy of cobalt extraction in the large-scale mining sector has evolved on the back of the copper extracted in the Copperbelt in the southeastern part of the country.

Crucially, in the DRC's ASM sector, cobalt is not viewed as a by-product but is rather their primary focus of extraction. This raises the question of why governments and industries are relying on their multinationals to supply it. Perhaps the reluctance of governments to engage small-scale cobalt miners in the DRC is due to their activities exhibiting the hallmarks of informality. Most ASM sites do appear chaotic to the naked eye, and governments would be wise to commit to studying the dynamics of operations at selected sites before attempting to forge partnerships with mining cooperatives. Much of the same applies to the two mini-case studies examined here. In both instances, informal miners have used their ingenuity to navigate bureaucratic hurdles and put themselves in a position to extract ore and access markets. In doing so, they have managed to sufficiently insulate themselves under a regulatory apparatus and policy framework that is not designed specifically for the type of mining they engage in. End-users, including governments, may also be forced to be as creative if they become convinced that partnerships with ASM could alleviate shortages in the critical minerals supply.

5.3 A Reliance on Large-Scale Mining

At this point, governments and companies looking to source critical minerals can sometimes be unwilling to overlook the biases they may have toward ASM. More specifically, they may simply be unable to view sourcing from the sector as anything other than a risky proposition.

Dismissing ASM as a key contributor to critical minerals supply would be a major flaw, given the time and investment required to bring the industrial operations online. In a recent survey of 127 large-scale mines carried out by S&P Global, it was revealed that from the discovery of a mineral to mining, production takes, on average, 15.7 years (Manolo, 2023). The following examples highlight why:

- In Canada, there are provincial and federal permitting processes linked to processing, construction, operations, closure, and reclamation.
- In the EU, it can take up to 15 years to get a mine to the production phase. Brussels, however, is attempting to amend this through the Critical Minerals Act. It allows critical mineral projects to be designated as "strategic," which gives them hard permitting deadlines of 2 years (for extraction projects) (Poliscanova, 2023).

[13] For a comprehensive review of the implications of critical minerals as by-products, see McNulty & Jowitt, 2021 and Bellois & Ramdoo, 2023.

- In the United States, it takes, on average, 7–10 years to secure the permits needed for mining, compared to Canada and Australia, where, despite having equally stringent environmental legislation, it takes approximately 2 years (Minerals Make Life, n.d.).
- Commodity price cycles affect project development, particularly when they are in the early stages of exploration.

One added complication is that the discovery of a mineral deposit does not immediately yield a mining project. The most visible evidence of this among critical minerals hotspots is Bolivia, which, despite having the world's largest resources of lithium, struggles to attract the investment needed to extract it because of regulatory and technical reasons, including infrastructure and a high content of magnesium and potassium that hinders lithium recovery during processing. Overall, less than 1% of mineral exploration projects become producing mines (Goss, 2023). Given the challenges faced by large-scale miners described above, the ASM sector could provide a quicker source of supply if formalized and supported.

6.0 Conclusion and Next Steps

On the balance of the limited evidence available, ASM is already making important contributions to global critical minerals supply—albeit subtle. It could have an even greater impact with the required level of support from industry and governments, which have tended to underestimate its importance in global supply chains. Given the geological nature of certain minerals and their tendency to coexist with major metals and be commercially extracted as by-products, there are limitations to what contributions ASM can make in this space. At present, however, these contributions are nowhere close to being realized, largely because of the perceptions private sector actors and many governments around the world have of the sector: as an informal, disorganized collection of activities populated by individuals who are unwilling to comply with international environmental, social, and economic standards.

These very actors are scrambling to identify new sources of the critical minerals needed for the manufacture and development of components essential for low-carbon and digital technologies, the demand for which has reached unprecedented levels and continues to escalate. ASM could provide answers to pressing supply problems. It seems especially logical to do so given countries' ever-expanding lists of critical minerals, ASM's ability to enhance its contributions to delivering the global supply of many of these, and the achievable actions governments and industry would have to make to ensure that the sector could impact this space in a more formalized capacity. The latter point is especially important because it would go a long way toward changing the narrative on ASM, forcing decision-makers to seriously consider its potential economic importance as an international supplier of critical minerals.

As a point of departure and taking stock of the material presented here, the report identifies important next steps that must be taken if ASM is to become a more significant part of the critical minerals' equation moving forward. Each step would go a long way toward providing the sector with the platform it needs to make more tangible contributions to the critical mineral supply and be viewed internationally as a reliable contributor on this front. Each step relates to strengthening the formalization of the sector, which would provide it with much-needed visibility in debates on critical minerals supply.

1. Greater attention should be paid to the formalization of the sector

The first step is a move that applies to most ASM worldwide: greater attention should be paid to the formalization of the sector. Globally, there has long been a push to formalize the ASM sector. However, experience has shown—most visibly in gold mining—that a combination of costly permit fees, bureaucratic licensing application procedures, and a lack of access to economically viable deposits (the result of most areas with known prospects being parcelled out as concessions to larger mining and mineral exploration companies) have impeded the legalization and provision of coordinated support to ASM across Asia, Latin America, and sub-Saharan Africa (Echavarría & Reynolds, 2015; Hilson et al., 2018b; International Labour Organization, 1999; Venugopal, 2014). Debates have raged about the need for governments to streamline licensing for ASM, but with limited effect. A focus on critical minerals provides a fresh storyline that could generate the momentum needed to facilitate a comprehensive overhaul of ASM licensing worldwide.

2. Provide the geological foundation and exclusivity in mineral-rich areas needed to support a formalized ASM sector

The second step is to provide the geological foundation and exclusivity in mineral-rich areas needed to support a formalized ASM sector. As has been observed with gold, the terrain must be adequately prospected and blocked out for prospective licensees. The DRC and Indonesia, where cobalt and tin extraction have long been staples of the ASM economy, provide valuable lessons in this area. Both have ring-fenced plots to support (licensed) operators engaged in the extraction of these commodities on a small scale: the former uses corridors, and the latter, People's Mining Areas (Geenen, 2012; Maia et al., 2019). While concerns about the security of the tenure of both loom large, the formula is very clear: identify viable areas, block them out, and issue licences to those who wish to engage in mining activities as ASM operators. There are two takeaways here. The first is that such a move would go a long way in building confidence among industries and governments that remain skeptical about engaging with ASM, let alone for a reason as important as sourcing critical minerals. The formula described legitimizes ASM as a legal entity, which is a necessary move if it is to feature more prominently as a source of critical minerals supply moving forward. The second is that, given how both the DRC and Indonesia have managed to achieve this with cobalt and cassiterite, there is a precedent for promoting this formula as a strategy in other regions where ASM is linked to critical minerals production.

3. Rethink the entire regulation and policy treatment of the ASM critical minerals branch

The final step is more of an observation and cannot be considered unless the previous two are taken. It concerns rethinking the entire regulation and policy treatment of the ASM critical minerals branch. Specifically, there is a need for separate licences and regulations for this subsector, as the architecture in place in most countries, which was designed for gold and, in some instances, diamonds and gemstones, is largely inappropriate. Of course, more information must be gathered about the characteristics of operations, the geological environment where they are found, and the individuals who undertake them, as this is likely a change that should be pursued in the medium-to-long term. At this point, it is sufficient to simply acknowledge the need to do so.

ASM operators are actively engaging in dialogues at various levels, including the international stage, with global institutions like the United Nations. A recent dialogue organized by the

United Nations Secretary-General's Panel on Critical Energy Transition Minerals, co-chaired with ASM operators from different countries, highlighted key issues within the ASM sector that require urgent attention. ASM miners highlighted critical issues, including the following: (1) the impacts of restrictive legislation, a lack of formal markets, and limited knowledge in valuing minerals like lithium in Zimbabwe, for example, which disproportionately affects small-scale miners; (2) training and education were emphasized as key to advancing ASM operations, with examples from Burkina Faso and Indonesia showcasing the benefits of geological knowledge and business skills for miners; (3) ASM copper miners from the Andes expressed concerns over land concessions favouring large-scale mining, which limits their opportunities to formalize operations and improve livelihoods; (4) health risks, such as silicosis in India, and the need for better technology and protections; (5) more investment in local processing, access to financing, and the inclusion of women in the sector, as called for by ASM associations from Namibia and Tanzania (United Nations Secretary-General, 2024). These perspectives underline the need for supportive policies, better access to resources, and collaboration to empower ASM communities globally.

This report has attempted to build a case for the better integration of ASM into the critical minerals supply. As ASM already supplies a large share of certain critical minerals, the foundations of workable and formalized sourcing strategies are already in place, and there are new frontiers that could be brought into the fold. While sweeping policy and legislative changes will be needed to bring such strategies to fruition, the gains from doing so promise to be significant. Worldwide, governments and industries are rushing to find fresh supplies of critical minerals; the ASM sector should be on all their radars.

ASM then could assume an expanded role, moving forward, in providing crucial supplies of critical minerals. This is a role it is already playing to some extent, albeit vastly understatedly. Intensifying support for artisanal and small-scale miners engaged in the extraction of various critical minerals with high and moderate potential could help in shoring up concerns around supply.

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Appendix A. Commodities Identified as Critical in Selected Organisation for Economic Co-operation and Development Countries

Commodity	Uses	USA (Yes/ No)	EU (Yes/ No)	Canada (Yes/ No)
Aluminum	Almost all sectors of the economy	Yes	No	Yes
Antimony	Lead-acid batteries and flame retardants	Yes	Yes	Yes
Arsenic	Semi-conductors	Yes	Yes	No
Barite	Hydrocarbon production	Yes	Yes	No
Bauxite	Raw material used in road aggregate and used to make aluminum	No	Yes	No
Beryllium	An alloying agent in the aerospace and defence industries	Yes	Yes	No
Bismuth	Medical and atomic research	Yes	Yes	yes
Boron	Rocket fuel ignitor, bleach, and food preservative	No	Yes	No
Cerium	Medical and atomic research	Yes	No	No
Caesium	Research and development	Yes	No	Yes
Chromium	Primarily in stainless steel and other alloys	Yes	No	Yes
Cobalt	Rechargeable batteries and superalloys	Yes	Yes	Yes
Coking coal	To produce coke, the primary source of carbon used in steelmaking	No	Yes	No
Copper	Tools, wiring, coins, and hardware	No	Yes	Yes
Dysprosium	Permanent magnets, data storage devices, and lasers	Yes	No	No

Commodity	Uses	USA (Yes/ No)	EU (Yes/ No)	Canada (Yes/ No)
Erbium	Fibre optics, optical amplifiers, lasers, and glass colourants	Yes	No	No
Europium	Phosphors and nuclear control rods	Yes	No	No
Fluorspar	The manufacture of aluminum, cement, steel, gasoline, and fluorine chemicals	Yes	Yes	Yes
Gadolinium	Medical imaging, permanent magnets, and steelmaking	Yes	No	No
Gallium	Integrated circuits and optical devices like LEDs	Yes	Yes	Yes
Germanium	Fibre optics and night vision applications	Yes	Yes	Yes
Graphite	Lubricants, batteries, and fuel cells	Yes	No	Yes
Hafnium	Nuclear control rods, alloys, and high-temperature ceramics	Yes	Yes	No
Helium	Scientific research, medical technology, and high-tech manufacturing	No	Yes	Yes
Heavy rare earth elements	Glass, lights, magnets, batteries, and catalytic converters	No	Yes	No
Holmium	Permanent magnets, nuclear control rods, and lasers	Yes	No	No
Indium	Liquid crystal display (LCD) screens	Yes	No	Yes
Iridium	Coating for anodes in electrochemical processes and as a chemical catalyst	Yes	No	No
Lanthanum	Produces catalysts, ceramics, glass, polishing compounds, metallurgy, and batteries	Yes	No	No
Light rare earth elements	Mobile phones, electric cars, and medical equipment	No	Yes	No
Lithium	Rechargeable batteries	Yes	Yes	Yes
Lutetium	Scintillators for medical imaging, electronics, and some cancer therapies	Yes	No	No

Commodity	Uses	USA (Yes/ No)	EU (Yes/ No)	Canada (Yes/ No)
Magnesium	An alloy and for reducing metals	Yes	Yes	Yes
Manganese	Steelmaking and batteries	Yes	Yes	Yes
Molybdenum	Alloys, catalysts, lubricants, and pigments	No	No	Yes
Natural graphite	Electrodes, lubricants, and batteries	No	Yes	No
Neodymium	Permanent magnets, rubber catalysts, and in medical and industrial lasers	Yes	No	No
Nickel	To make stainless steel, superalloys, and rechargeable batteries	Yes	Yes	Yes
Niobium	Mostly in steel and superalloys	Yes	Yes	Yes
Palladium	Catalytic converters and a catalyst agent	Yes	No	No
Phosphate rock	Fertilizers, soaps, and detergents	No	Yes	No
Phosphorus	Fertilizers, animal feeds, rust removers, and corrosion preventers	No	Yes	No
Platinum	Catalytic converters	Yes	Yes	No
Praseodymium	Permanent magnets, batteries, aerospace alloys, ceramics, and colourants	Yes	No	No
Potash	Soap making, explosives, glassmaking, and pharmaceuticals	No	No	Yes
Rare earth elements	Computer drives, computer/phone screens, and light bulbs	No	No	Yes
Rhodium	Catalytic converters, electrical components, and as a catalyst	Yes	No	No
Rubidium	Research and development in electronics	Yes	No	No
Ruthenium	Catalysts, as well as electrical contacts and chip resistors in computers	Yes	No	No
Samarium	Permanent magnets, as an absorber in nuclear reactors, and in cancer treatments	Yes	No	No

Commodity	Uses	USA (Yes/ No)	EU (Yes/ No)	Canada (Yes/ No)
Scandium	Alloys, ceramics, and fuel cells	Yes	Yes	Yes
Silicon metal	Solar cells and semi-conductors	No	Yes	No
Strontium	Paints and plastics	No	Yes	No
Tantalum	Electronic components, mostly capacitors and superalloys	Yes	Yes	Yes
Tellurium	Solar cells, thermoelectric devices, and an alloying additive	Yes	No	Yes
Terbium	Permanent magnets, fibre optics, lasers, and solid-state devices	Yes	No	No
Thulium	Various metal alloys and lasers	Yes	No	No
Tin	Protective coatings and alloys for steel	Yes	No	Yes
Titanium metal	Aerospace, automotive, defence, chemical processing, jewellery and watches, electronics, architecture and art, medical and dental	No	Yes	Yes
Titanium	A white pigment or metal alloy	Yes	No	Yes
Tungsten	Primarily to make wear-resistant metals	Yes	Yes	Yes
Uranium	Pipes, aircraft, and spacecraft	No	No	Yes
Vanadium	Primarily as an alloying agent for iron and steel	Yes	Yes	Yes
Ytterbium	Catalysts, scintillometers, lasers, and metallurgy	Yes	No	No
Yttrium	Ceramic, catalysts, lasers, metallurgy, and phosphors	Yes	No	No
Zinc	Primarily in metallurgy to produce galvanized steel	Yes	No	Yes
Zirconium	High-temperature ceramics and corrosion-resistant alloys	Yes	No	No

Source: Authors.

Appendix B. Critical Minerals Policies in Selected Organisation for Economic Co-operation and Development Countries

Country/region	Key policies/legislation	Goals/objectives	Significant developments
Australia	The Critical Minerals Strategy 2023–2030	The strategy has four core objectives: • establishing diverse, resilient, and sustainable supply chains by strengthening and securing international partnerships; • augmenting sovereign capability in critical minerals processing; • using Australia's critical minerals to help the country attain the status of a renewable energy superpower; and • extracting more value from Australia's resources onshore and creating jobs and economic opportunities for all, including regional and Indigenous communities.	• Australia produces lithium for consumption. • Australia is home to 24 commodities, including cobalt, lithium, manganese, tungsten, and vanadium, which are ranked in the top five for world economic resources. • The 2022 prospectus highlights 55 investment-ready projects across the country. These projects, according to the Australian Government, have significant potential to mitigate the anticipated production shortages, strengthen supply chain security, and contribute impactfully to a net-zero future.

Country/region	Key policies/legislation	Goals/objectives	Significant developments
Canada	The Canadian Critical Minerals Strategy	The Canadian Critical Minerals Strategy has five key objectives: • promoting economic growth and competitiveness and generating employment; • fostering climate action and environmental protection; • encouraging reconciliation with Indigenous Peoples; • cultivating diverse and inclusive workforces and communities; and • strengthening global security and partnerships with allies.	• Canada provides a 30% tax rebate for companies exploring critical minerals. • There are plans to develop lithium mines in Quebec and other parts of the country.
European Union (EU)	The Critical Raw Materials Act (applied nationally)	The act outlines how the EU can • establish secure and resilient EU critical raw materials supply chains; • ensure that the EU can mitigate supply risks; • invest in research, innovation, and skills; • protect the environment by developing circular and sustainable critical raw materials; and • secure international engagements by diversifying imports of critical minerals, as well as the formation of the Critical Raw Materials Clubs and strategic partnerships.	• At present, the EU is dependent on imports of critical minerals. It is seeking critical mineral deals with Africa, given its lack of reserves of such strategic minerals. • The EU currently sources 64% of bauxite from Guinea, 68% of cobalt and 36% of tantalum from the Democratic Republic of the Congo. • The EU faces an uphill battle in its quest to diversify its critical mineral imports because of its lack of control over the environmental, social, and governance requirements that must be met across the supply chain.

Country/region	Key policies/legislation	Goals/objectives	Significant developments
United Kingdom	The Critical Minerals Strategy	Among the strategy's goals is to • develop the United Kingdom's domestic critical mineral resources in a socially and environmentally responsible way; • collaborate with its international partners to secure additional flows of critical minerals; and • achieve its goals/objectives by using its new A-C-E approach, which entails **Accelerating** the United Kingdom's domestic capabilities, **Collaborating** with international partners, and **Enhancing** international markets.	• The British Government launched the Task & Finish Group on Critical Minerals Resilience, which enables British industry to investigate issues pertaining to critical mineral dependencies, vulnerabilities, and opportunities across sectors. • The government is accelerating collaboration with its international partners (such as the agreements made recently with Canada and South Africa and its participation through the Minerals Security Partnership, the International Energy Agency, and the G7).

Country/region	Key policies/legislation	Goals/objectives	Significant developments
United States (International Energy Agency, 2022a)	The U.S. Department of Energy's Critical Mineral and Material Strategy	The strategy has four goals: • fostering scientific innovation and developing technologies to ensure resilience and safeguarding critical mineral and material supply chains detached from the country's foreign adversaries; • catalyzing and promoting private sector adoption and capacity for sustainable domestic critical mineral and material supply chains; • developing a sustained mineral and material innovation ecosystem that fosters new capabilities to mitigate future challenges in the supply chain; and • coordinating with strategic international partners, allies, and other U.S. federal agencies to diversify global supply chains and ensure that best practices for sustainable mining and processing are accepted.	• It has been friend-shoring the production of critical minerals from its allies through agreements such as the Critical Minerals Agreement with Japan and the Minerals Security Partnership – MSP spearheaded by the United States (Vivoda, 2023; Woods, 2023).

Source: Adapted from Australian Trade and Investment Commission, 2024; European Commission et al., 2023; Department for Business Energy & Industrial Strategy, 2023ab, 2023ba; Economist Intelligence, 2023; Hiyate, 2023; International Energy Agency, 2022a, 2022b; Naimul, 2022; Natural Resources Canada, 2022; Usman et al., 2021; Vivoda, 2023; Woods, 2023.

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