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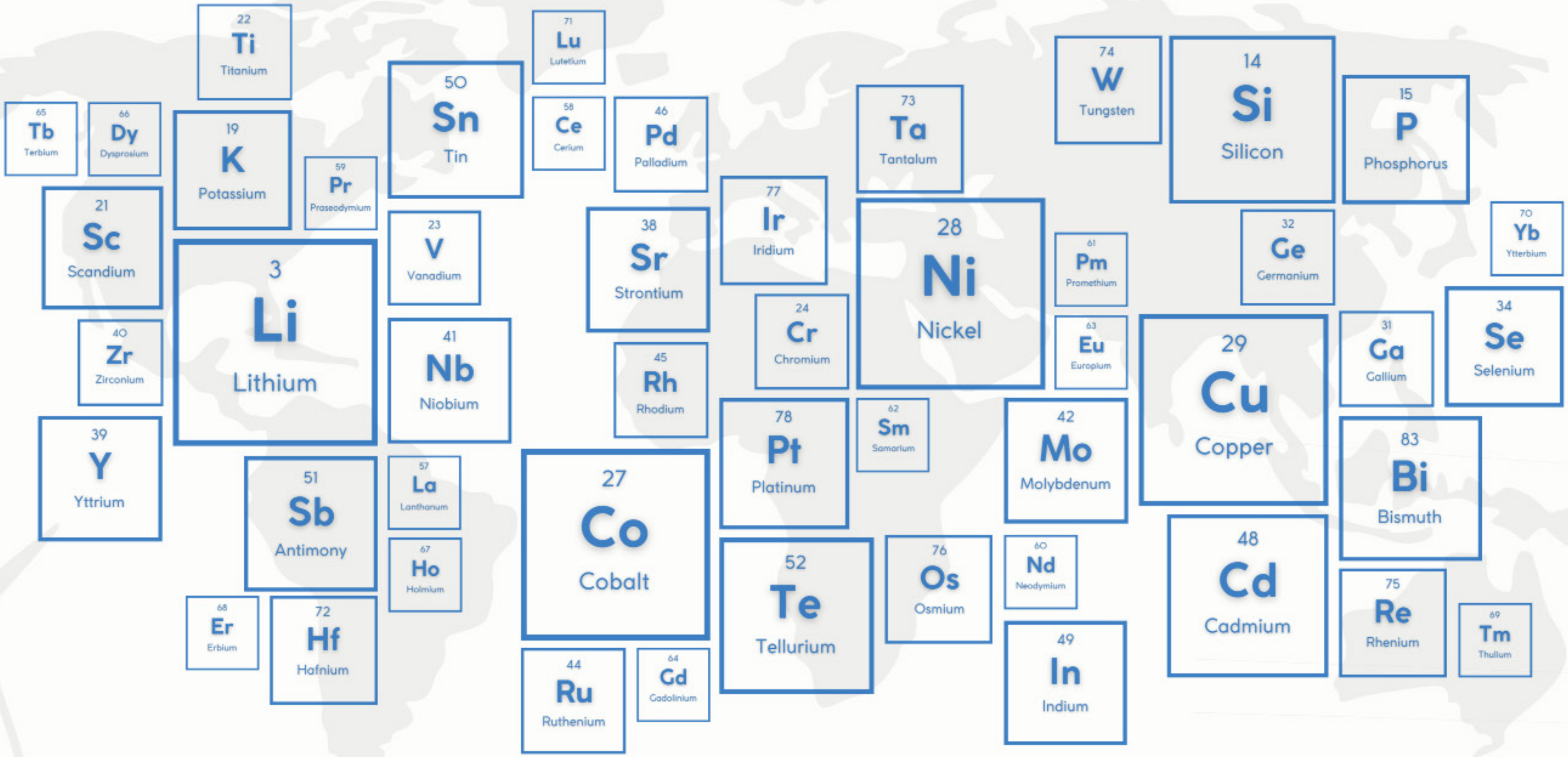
STATE OF THE SECTOR
CRITICAL ENERGY TRANSITION MINERALS FOR INDIA



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Organisations

Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources.

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FOREWORD

As the world shifts towards sustainable development, securing a reliable supply of Critical Energy Transition Materials (CETMs) has never been more vital. These minerals are essential for renewable energy technologies, such as electric vehicle batteries, solar panels, and wind turbines, which are central to achieving global climate and clean energy goals.

The transition to a clean energy system is expected to significantly increase the demand for these CETMs. In a scenario that aligns with the Paris Agreement, the share of total demand for clean energy technologies is projected to rise sharply over the next two decades: over 1.5x for copper, 1.9x for rare earth elements, 2.1x and 2.2x for nickel and cobalt, and nearly 8.7x for lithium (International Energy Agency 2021). Electric vehicles and battery storage have already surpassed consumer electronics as the largest consumers of lithium and are projected to overtake stainless steel as the largest end-user of nickel by 2040. The strategic importance of CETMs therefore cannot be overstated.

Like most progressive nations, India has embarked on several low-carbon technology initiatives and has committed to achieving net-zero emission by 2070. To meet this target, India must secure a responsible and reliable supply chain for CETMs, especially given the thrust for Atmanirbharta (self-reliance) in manufacturing these technologies. Moreover, concentrated supply chains and limited investments in these resources can lead to potential supply disruptions and high price volatility, which could hinder the deployment of low-carbon technologies, affecting India's sustainability goals.

This report underscores the need for a comprehensive strategy to ensure a reliable supply of CETMs crucial for India's clean energy and low-carbon technology initiatives. It aims to develop a detailed understanding of CETMs, fostering a richer dialogue around this crucial agenda.

The report explores various strategies for securing these essential materials, offering valuable insights into the CETM value chain – from exploration and extraction to processing and recycling. The report also addresses the geopolitical, environmental, and social dimensions associated with CETM security. Its recommendations aim to inform policy stakeholders and accelerate the creation of a resilient and sustainable supply chains for these minerals.

We urge all stakeholders to engage with the findings and recommendations, which are crucial to securing the raw materials necessary for India's clean energy transition. Together, we can build a clean, resilient and low-carbon future, ensuring India's continued progress and prosperity.

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ACRONYMS AND ABBREVIATIONS

AEL	Alkaline Electrolysers
AEM	Anion Exchange Membranes
AMD	Acid Mine Drainage
APEP	Americas Partnership for Economic Prosperity
APS	Announced Pledges Scenario
ARCI	International Advanced Research Centre for Powder Metallurgy & New Materials
BESS	Battery Energy Storage System
BRICS	Brazil, Russia, India, China and South Africa
CCS/CCUS	Carbon Capture, (Utilisation), and Storage
CECA	Comprehensive Economic Cooperation Agreement
CETM	Critical Energy Transition Minerals
CIF	Cost, Insurance, and Freight
CIS	Commonwealth of Independent States
CL	Composite License
CME	Chicago Mercantile Exchange
CPCB	Central Pollution Control Board
CSIR	Council of Scientific & Industrial Research
DLE	Direct Lithium Extraction
DMF	District Mineral Foundation
DRC	Democratic Republic of the Congo
EC	Environmental Clearance
ECTA	Economic Cooperation and Trade Agreement
EIA	Environmental Impact Assessment
EITI	Extractive Industries Transparency Initiative
EL	Exploration Licence
EMD	Electrolytic Manganese Dioxide
EPI	Environmental Performance Index
EPR	Extended Producer Responsibility
ERGI	Energy Resource Governance Initiative
ERMA	European Raw Materials Alliance
ESG	Environment, Social and Governance
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FPIC	Free, Prior, and Informed Consent
GCAM	Global Change Assessment Model
GHG	Greenhouse Gases
GSI	Geological Survey of India
HCL	Hindustan Copper Limited
HPAL	High Pressure Acid Leach
HS	Harmonised System
IBM	Indian Bureau of Mines
ICMM	International Council on Mining and Metals
IGF	Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IPEF	Indo-Pacific Economic Framework for Prosperity
IRA	Inflation Reduction Act
IREL	Indian Rare Earths Limited
IRMA	Initiative for Responsible Mining Assurance
ISDS	Investor-State Dispute Settlement
KABIL	Khanij Bidesh India Limited
LARR	Land Acquisition, Rehabilitation, and Resettlement Act, 2013
LCT	Low-carbon Technology
LFP	Lithium iron phosphate
LiB	Lithium-ion Battery
LME	London Metal Exchange
MECL	Mineral Exploration Corporation Limited
ML	Mining License
MMDR	The Mines and Minerals (Development and Regulation) Act, 1957
MOIL	Manganese Ore India Limited
MSP	Mineral Security Partnerships
NALCO	National Aluminium Company Limited
NEA	Notified Exploration Agency
NGDR	National Geoscience Data Repository
NMC	Nickel Manganese and Cobalt
NMET	National Mineral Exploration Trust
NZE	Net-Zero Emissions
OVL	ONGC Videsh Limited
PEM	Proton-exchange membrane
PGM/E	Platinum Group Metals/Elements
PLI	Production Linked Incentives
Quad	Quadrilateral Security Dialogue
REE/REO	Rare Earth Elements/Oxide
RMI	Responsible Minerals Initiative
SDF	Sustainable Development Framework
SEBI	Securities and Exchange Board of India
SHFE	Shanghai Futures Exchange
SOEC	Solid Oxide Electrolysis Cell
UNCTAD	United Nations Conference on Trade and Development
UNFC	United Nations Framework Classification
WGI	World Governance Indicators

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EXECUTIVE SUMMARY

Critical Energy Transition Minerals (CETMs) are essential for clean energy technologies such as solar panels, electric vehicle batteries, and the grid, playing a crucial role in India's clean energy transition. The resilience and sustainability of supply chains are key considerations in today's global economy, especially as industries and governments strive to meet ambitious climate targets.

However, concentrated value chains and under-investment in CETM development have led to high price volatility and potential supply disruptions, posing significant manufacturing challenges for low-carbon technologies. Instances such as Indonesia's unprocessed nickel ore export ban, China's Covid-19 lockdown, and the Russia-Ukraine war have all adversely impacted the supply chains of specific critical minerals.

India has set ambitious targets for renewable capacity additions and electric vehicle deployment, along with the intent to become self-reliant (Atmanirbhar) in the manufacture of these clean energy technologies. However, it does not have enough reserves of these minerals to meet the projected demand for clean technologies.

Besides, the global production of many CETMs is concentrated in a few countries with significant geological endowments. For example, the majority of the world's lithium is produced in Australia, Chile, and China; cobalt is dominated by the Democratic Republic of Congo; and REEs are primarily mined in China. The lack of domestic resources and processing capacity for these minerals necessitates the formulation of policies aimed at securing reliable and diversified supply chains through international collaborations and strategic partnerships.

Exploration, mining and capital investments in CETMs are on the rise. However, challenges in increasing global capacities persist. A report by S&P Global predicts that the demand for CETMs will outstrip supply by 2024. The geographical concentration of mining operations elevates the risk of supply shortages in the event of disruptions affecting the producing countries. Various other challenges in ramping up production include diversifying mining and processing locations to more countries and ensuring sustainable mining practices.

The demand for CETMs is likely to remain strong with lithium demand being among the highest due to its lack of substitutability for conventional EV batteries. Demand for other minerals also remains high to enable manufacture of green technologies. Their supply constraints are expected to further intensify. Consequently, identifying the major producers of critical minerals becomes pivotal in establishing more resilient CETM supply chains, particularly for minerals with no known resources in India.

This report provides a national roadmap for India to secure CETMs needed for its clean energy transition by addressing immediate and long-term challenges through strategic policy interventions and international cooperation.

The primary objective of this report is to improve awareness across stakeholders involved in the climate and minerals sectors of government, civil society organisations, and industries about the importance of CETMs. While stakeholders have developed a basic understanding of the issue, there is a need for greater knowledge about market dynamics, finance, contracting, environmental and social issues, and institutional frameworks related to CETMs.

The report covers a broad range of topics, including the concept and framework of criticality, the economic importance and supply risks associated with these minerals, and their role in India's Net Zero transition. The report examines the growing demand for CETMs up to 2050, assesses global and Indian mining capacities, explores the entire value chain from extraction to manufacturing, and highlights the technological and financial aspects of securing CETMs. It talks about existing legislative framework, both in India and in other countries and regions. It also addresses the environmental and social concerns related to mining and offers strategic recommendations for demand signals, international diplomacy, long-term investments, substitution technologies, and material efficiency to improve India's mineral security and support its sustainable development goals.

The study connects the concentration of CETMs with the needs of low-carbon technology manufacturing, evaluating existing frameworks and proposing one tailored to India's needs. Six specific minerals—Copper, Lithium, Manganese, Neodymium, Nickel, and Silicon—have been identified for detailed analysis. The study forecasts future demand for low-carbon technologies up to 2050, identifying supply chain vulnerabilities and proposing policy levers for transforming India's mineral policy landscape.

An in-depth analysis of existing value chains for selected minerals focuses on exploration, extraction, refining, and circularity, identifying geographic concentrations and factors impacting the value chain, such as policy, technology, markets, investments, and ESG considerations. Lastly, the report assesses uncertainties, including global demand, technology choices, geopolitics, security, environmental and labour concerns, and domestic policies.

Here are the recommendations to enhance India's mineral security for technological and energy advancements up to 2050, through a comprehensive policy framework and strategic initiatives:

Key Recommendations:

Promoting domestic mineral exploration is crucial for India's mineral security. Utilising cutting-edge technologies such as remote sensing and automated drilling can significantly improve exploration and extraction efficiency. To attract private investment, it is essential to broaden the scope of Exploration Licenses (EL) and Composite Licenses (CL) and expedite clearance processes while mitigating environmental and social impacts. Additionally, increasing funding for private exploration agencies through the National Mineral Exploration Trust (NMET) and incentivising EL holders will further boost exploration activities.

Improving domestic processing capabilities is another vital aspect. Supporting the development of processing infrastructure through incentives and streamlined regulations can reduce India's reliance on external processors and diversify global supply chains. Establishing accredited mineral processing labs in each state will provide technical assistance and ensure adherence to environmental, health, and safety standards, thereby promoting responsible resource management and attracting investment in critical mineral processing projects.

Promoting international cooperation is essential for securing a stable supply of CETMs. Encouraging exploration and investment in countries with untapped reserves, particularly in Africa, can diversify supply sources. Maintaining strategic stockpiles will help India withstand supply chain disruptions and stabilise prices. Simplifying negotiations and promoting long-term contracts through standardised contracting frameworks will attract investment. Strengthening relations with key countries and participating in multilateral frameworks like the Mineral Security

Partnership (MSP) will enhance India's geopolitical influence and access to global resources.

Incentivising recycling and circularity are crucial for sustainable CETM management. Developing a graded incentive system for recycling efficiency and quality, integrating informal recyclers into the formal ecosystem, and establishing Resource Recovery Parks (RRPs) will facilitate waste exchange and support recycling activities. These initiatives will improve material efficiency, create a viable market for recycled materials, and promote the circular economy.

Adopting high Environmental, Social, and Governance (ESG) standards is imperative for resilient and reliable mineral supply. Integrating international ESG standards into mining operations will enhance sustainability, transparency, and ease of export. Engaging local communities in decision-making and benefit-sharing will help gain the social license to operate. Implementing digital battery passports will ensure quality and environmental responsibility from production to recycling. Repurposing mining-generated wastelands for productive use will promote sustainable land management and support local communities.

Promoting innovation through collaboration between academia and industry is essential for advancing CETM technologies. Establishing dedicated platforms for knowledge exchange and incentivising joint research projects will drive innovation and efficiency in mineral exploration, extraction, and processing. Expanding government initiatives like SATYABHAMA (Science and Technology Yojana for Aatmanirbhar Bharat in Mining Advancement) to promote technology transfer and innovation will enhance India's self-reliance and competitiveness in the critical mineral sector.

Conclusion:

India's path to achieving self-reliance in the manufacture of low-carbon technologies depends on securing a stable and responsible supply chain of CETMs. While global competition for these resources intensifies, India's strategic actions can help mitigate risks and position the country as a leader in clean energy technology. Through concerted efforts in domestic exploration, international cooperation, and the promotion of sustainable mining practices, India can secure its mineral future and support its broader energy transition goals, while promoting environmental stewardship and economic growth.

1

INTRODUCTION

1 INTRODUCTION

Critical minerals, also called critical raw materials (CRMs), refer to minerals, both primary and processed, that are essential inputs in a wide array of industrial and technological processes. Their supplies could be disrupted due to non-availability or price volatility, posing significant risks to the economy. While some are used in traditional industries, others are vital for high-tech products (semi-conductors and digital technologies), clean energy technologies, defence, aviation, and space applications. Many of these minerals lack viable substitutes and have limited recycling processes. Critical minerals or critical raw materials is often the terminology used by nations to shortlist minerals they deem important enough from an economic standpoint to require specific policy support.

In the context of the global shift towards decarbonisation and renewable energy, a specific subset of these critical minerals—Critical Energy Transition Minerals (CETMs)—has taken centre stage. CETMs, such as lithium, cobalt, nickel, rare earth elements, and copper, are indispensable for the clean energy technologies driving the energy transition. These minerals are integral to the production of key technologies, including batteries and motors for electric vehicles (EVs), wind turbines, solar panels, hydrogen electrolysers and energy storage systems. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies. As countries ramp up efforts to meet climate targets, the demand for CETMs is soaring, highlighting their strategic importance. For instance, between 2017 and 2022, the demand for lithium surged by 300%, while nickel and cobalt saw increases of 40% and 70%, respectively (IEA 2023b).

Supply constraints and vulnerabilities

The International Energy Agency has identified vulnerabilities in supply chains for CETMs. Major vulnerabilities include high geographical concentration not only in production but also processing, long project development lead times, declining resource quality, increased environmental and social scrutiny, and heightened exposure to climate risks (International Energy Agency 2021).

A significant share of CETMs is mined in politically unstable regions, such as the Democratic Republic of Congo (DRC), where artisanal mining practices and child labour pose social and ethical challenges. Moreover, natural disasters, political conflicts, and export restrictions, such as Indonesia's unprocessed nickel ore export ban, have demonstrated the fragility of global supply chains, leading to price fluctuations and supply shortages. Environmental concerns, like those surrounding lithium mining in Chile and Bolivia, further complicate the picture, as local protests over water resource depletion have highlighted the environmental trade-offs of extracting CETMs.

The COVID-19 pandemic and geopolitical conflicts, including the Russia-Ukraine war, have reinforced the need for supply chain resilience, particularly in securing access to CETMs. The prices for CETMs increased by 93% between 2020 and 2023. Although prices have moderated since then, the price volatility of CETMs have a direct bearing on the manufacturing and competitiveness of LCTs. Between 2020 and 2022, the increased cost of raw materials led to a 38% rise in the cost of installing one megawatt of wind energy capacity (Global Wind Energy Council 2023). Likewise, growing prices of battery minerals like cobalt, lithium and nickel resulted in the first-ever increase in battery costs by 10% in 2022 (International Energy Agency 2023).

Delays in investment in CETMs could result in a costlier clean energy transition, a risk that major economies cannot afford. There can be no energy transition without CETMs. Therefore, building resilient and responsible CETM supply chains has become a priority for many countries, including India.

Why are CETMs important to India?

India, like many other nations, faces the challenge of securing a stable supply of CETMs to meet its ambitious climate goals. At the 26th Conference of Parties (COP 26) in November 2021, India announced its target to achieve net-zero emissions by 2070. However, India's limited domestic availability of critical minerals, including those essential for clean energy technologies, could hinder this transition. Ensuring access to CETMs is not only critical for decarbonization efforts but also for India's economic competitiveness and its aspirations to become a key player in the global clean energy industry.

Unlike disruptions in oil and natural gas, which have immediate effects on energy security, CETM supply shocks do not cause immediate functional impairments but instead restrict future technological deployments. Therefore, the risks associated with CETM supply are closely linked to the pace of the clean energy transition and economic growth than energy security. Ensuring a reliable supply of CETMs is crucial for India's future competitiveness and the successful deployment of low-carbon technologies.

1.1 Objectives and Scope of the Report

This report looks into various aspects of ensuring resilient CETM supply chains, essential for India's quest to achieve its net-zero emissions target by 2070. The analysis focuses on emerging renewable energy and low-carbon technologies, (LCT) projecting developments up to 2050 and estimates India's CETMs future demand up to 2050.

To begin with, the report talks about key trends in achieving Net Zero, both globally and in India. The report establishes a criticality framework that is suited best for India as well as a short-listing methodology to identify six CETMs for India for a deep-dive into their value-chain assessment. These include nickel for electrolysers, lithium for lithium-ion batteries, silicon for solar energy, manganese for wind energy, copper for power grids, and neodymium for electric vehicles. The study then assesses demand for each of the CETMs until 2050. It also studies their extraction, refining, circularity, contracting, markets, financing, and procurement processes in great detail.

Providing an overview of geographic concentrations of CETMs globally, the report covers a comprehensive examination of global CETMs value chain starting from exploration, extraction, processing, manufacturing to end use. It also talks about impact factors that determine the availability and supply of these minerals. These impact factors include geopolitical and macroeconomic factors, policy and regulatory frameworks, contracting and finance practices, mineral markets, international agreements, recycling and circular economy practices as well as ESG trends and considerations.

In doing so, it focuses on international good practices that have enabled countries to efficiently harness their mineral wealth. It also offers insights into global market trends, financing, contracts, transactions, environmental and social considerations, and technology deployment along the value chains. It also mentions the methods used by stakeholders globally to procure long term access to CETMs. It emphasises the importance of studying substitutability, recyclability, emerging environmental concerns, and evolving geopolitical risks and conditions, all of which impact long-term projections up to 2050. It also aims to identify the vulnerabilities that exist in supply chains and highlights the uncertainties associated with demand and supply of CETMs.

The report also gives an in-depth scenario of CETMs in India, with respect to current policy framework, regulatory progress, value chain assessment, institutions, players, as well as progress in areas such as recycling and ESG. Value-adding insights on geopolitical dynamics has also been provided to guide future policy direction and trade agreements. The report also talks about sources of uncertainty and gives practical insights on how to address them.

Giving recommendations, the report identifies the required changes including policy levers and regulatory reforms that can transform India's mineral policy landscape. It highlights the need for increased exploration in India. It offers solutions for navigating the uncertainty in demand and supply, data availability issues and issues of technology access, build institutional capacity, and develop finance and markets. It also suggests methods to attract private investment as well as improve decision making, co-ordination among various government departments and stakeholders.

The report offers discussions on CETM demand signals and recommendations for international diplomacy, long-term investment requirements, substitution technologies, environmental safeguards throughout the value chains, material efficiency (reduce, reuse, recycle), leveraging India's potential in localising parts of the value chains, and strategies for risk mitigation and opportunities for both government and industry stakeholders.

To be sure, the report makes a strong case for increased impetus to recycling ecosystem in India and talks about specific policies and measures that can aid CETM recoveries. It also emphasises on environment, social and governance (ESG) measures to reduce the environment footprint and aim for sustainable development in the area. It talks about how India can not only mitigate mineral security but also gain a comparative advantage in the global mineral arena and the extent of value-additions India can make in the supply chain.

Compiling current knowledge on CETMs supply chains into a single report is expected to aid stakeholders and policymakers in developing a robust and proactive strategy for ensuring India's mineral security. This report can hopefully help raise the understanding and awareness within government, civil society organisations and CETMs upstream and downstream industries.

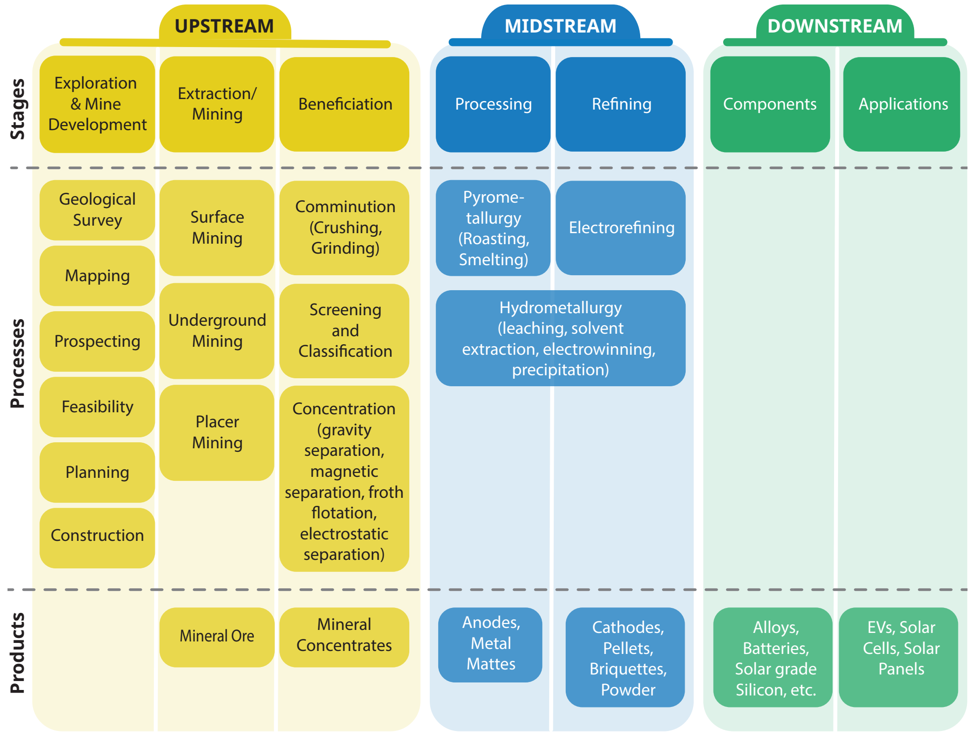
1.2 Elements of Mineral Value Chain

A value chain consists of three stages – upstream, involving the exploration and extraction of raw materials; midstream, involving the processing, refining, and transportation of these resources; and downstream, involving the production of finished goods and their distribution to consumers. In this report we refer to exploration, mine development, extraction of minerals and beneficiation as parts of upstream; further processing and refining as parts of midstream; and manufacturing components and finished products using the extracted minerals as downstream of the mineral value chain.

1.2.1 Upstream

Exploration and Mine Development: This stage involves geological surveys, mapping, and prospecting to identify potential mineral deposits. Techniques such as remote sensing, geophysical studies, and exploratory drilling are used to assess the geological characteristics of an area and to quantify the identified prospect/resource. Resources refer to all known quantities of a mineral that could potentially be extracted, encompassing various levels of certainty. This includes inferred (G3), indicated (G2), and measured (G1) resources, with inferred being the least certain or having low geological confidence, representing a low investment risk and measured being the most certain or high geological confidence, representing a low investment risk.

Figure 1: Elements of a Mineral Value Chain



Scoping or pre-feasibility and feasibility studies are conducted to determine the scope and economic viability of mining the identified resource. This is also the step where mining method and process technology are identified. Here the term reserves are used to refer specifically to the portion of resources that are economically viable for extraction, meaning they are not only identified but also quantifiable and feasible to mine under current market conditions. Reserves are categorised as proven (highly certain to be recoverable) and probable (less certain but still feasible for extraction).

Companies and governments worldwide are investing heavily in exploration projects to identify new mineral deposits and expand existing reserves. Capital investments in explorations are on the rise, primarily driven by lithium and other CETMs (IEA 2023b). However, challenges such as geological complexity, environmental concerns, and regulatory hurdles persist, underscoring the need for sustainable and responsible exploration practices.

The identified reserves are then auctioned for mining and mining licenses are issued. But to operate the mine, the interested party has to go through the process of attaining various permits and licenses from regulatory agencies including Environmental Clearance, Forest Clearance, Air Quality and Water Use/Quality Permits.

Mine development involves planning and construction of the mine and associated infrastructure. The operations include tunnelling, sinking, cross-cutting, drifting and raising and supporting infrastructure such as roads, water management systems, housing, offices and power. It sets the stage for the transition to commercial operations.

Extraction: The extraction stage involves the actual removal of minerals from the earth, which can be accomplished through surface mining, underground mining or placer mining techniques. Surface mining, such as open-pit mining, is employed for deposits located near the surface, while underground mining is used for deeper deposits. Placer mining involves extracting valuable minerals from placer deposits found in riverbeds, sandbanks, or other alluvial environments, which can employ commonly techniques such as suction dredging. Extraction processes often involve drilling, blasting, and hauling, utilizing heavy machinery and equipment. The choice of extraction method is influenced by the geology of the deposit, the ore grade, and economic considerations.

Mining projects must align with current and projected industry demand, but they have long lead times, starting from reconnaissance, prospecting, and exploration to lease acquisition and operationalisation. An analysis of major mines from 2010-2019 shows that the average lead time is 16.9 years

(International Energy Agency 2021). Lead times vary by mineral and location; for instance, lithium mines in Australia have a lead time of 4 years, compared to 7 years in South America. Nickel mines have some of the longest lead times, with laterite nickel mines taking over 19 years and sulphide nickel mines around 13 years. Copper mines have an average lead time of about 17 years. Notably, lithium mines have relatively short development lead times compared to other minerals, which makes the newly discovered lithium resources in Jammu & Kashmir potentially beneficial for India's future.

Figure 2: Lead Time from Exploration to Production

Source: (International Energy Agency 2021)

Beneficiation: Beneficiation refers to the various processes used to separate the mineral from waste material or impurities (gangue) to improve the economic value of the ore and prepare the ores for further refinement. This beneficiation process is usually completed at the mine and its goal is to increase the concentration of the valuable minerals in the ore, which can then be transported for further processing. Techniques employed in beneficiation include comminution (milling) and washing, screening, concentration techniques such as gravity separation, magnetic separation, froth flotation and electrostatic separation, and dewatering. Comminution is also one of the most energy-intensive processes in mineral beneficiation. Apart from these physical processes, sometimes hydrometallurgical and pyrometallurgical processes are also employed at this stage to extract concentrates.

1.2.2 Midstream

The midstream stage is often the most significant bottleneck due to its high geographical concentration (Evenett, Fritz, and Giardini 2023). It is a crucial stage in the global value chain of CETMs, as each end-use industry requires intermediate products with specific purity levels or grades. The degree of value addition through refining and processing varies based on the end-use industry and its market size. Consequently, nations may compete for positions in the global value chain based on their resources and national contexts.

Processing: The extracted ore concentrate undergoes processing to further extract the valuable minerals while preparing it for the refining process. This stage may involve the application of various pyrometallurgical, and hydrometallurgical techniques based on the mineral. Pyrometallurgy involves the use of high temperatures to extract and refine metals, including roasting, calcination and smelting. Hydrometallurgy, on the other hand, involves the use of aqueous chemistry, including acid or alkali leaching to dissolve valuable minerals from the ore. The leachate solution from hydrometallurgy is subjected to solvent extraction, electrowinning or precipitation of the dissolved minerals.

The output is typically intermediate forms of minerals, such as oxides or sulphides, which have not yet reached their final commercial form. These intermediates undergo further refining processes to achieve the purity levels required for use in component manufacturing.

Refining: Post concentration and processing of minerals, further refining is crucial for producing high-purity materials essential for various industries and typically employs various hydrometallurgical and electrometallurgical processes. Electrometallurgy utilises electric energy to extract, recover, and refine metals from ores and other raw materials through a process called electrorefining. This is often the last step of metal production and is used to obtain high-purity metals.

Capturing co-existing minerals: Various CETMs commonly occur within the same deposit and refining plays a crucial role in efficiently separating and recovering all the materials, while also enhancing the overall economic value obtained from the mining operation. For example, copper frequently coexists with other minerals such as gold, silver, selenium, tellurium, platinum, palladium, nickel, and sometimes even cobalt (International Copper Association 2021b). Sophisticated refining technology are essential in separating these minerals from the copper concentrate. Typically, anode slimes, a by-product of the electrorefining process of copper is subjected to pyrometallurgical or hydrometallurgical processes to capture and separate these coexisting minerals (Lee et al. 2020).

1.2.3 Downstream

Component Manufacturing and End Use: Processed minerals serve as raw materials for various manufacturing industries to produce a wide range of products. The manufacturers of solar photovoltaic (PV) industry, electrical applications and renewable energy infrastructure, battery technology, wind turbines, batteries and electrolysers, and electric vehicle (EV) motors, need a long-term, stable supply of CETMs. CETMs are subject to market volatility and price fluctuations influenced by global demand, supply disruptions, currency changes, and speculative trading. This makes managing price risks and forecasting market trends challenging, impacting inventory management and procurement strategies for manufacturers.

1.3 Alternate Sources of Critical Energy Transition Mineral Supply

Promising alternatives include remining waste and tailings, tapping small and mid-sized mines, deep-sea bed mining and recycling.

1. **Remining Waste and Tailings**

   Mining operations often leave behind significant waste and tailings containing residual minerals. Advances in mining technologies now allow for the extraction of CETMs from these discarded materials. This method is cost-effective and environmentally friendly, reducing the need for new mines and mitigating the environmental impact of mining activities. It also helps recover valuable minerals and addresses legacy environmental issues at abandoned mining sites (International Energy Agency 2021).

2. **Small and Mid-Sized Mines**

   While large mining operations are typically the focus for CETM extraction, small and mid-sized mines offer a viable and quicker alternative to meet growing demand. These mines can be developed and brought online faster than large-scale operations, which face longer lead times due to regulatory approvals and infrastructure development. Small and mid-sized mines are agile and responsive to market needs, providing a flexible supply source for critical minerals. Leveraging these mines as part of a diversified CETM strategy can help nations reduce dependence on a few large suppliers and enhance supply chain resilience (International Energy Agency 2021) .

3. **Deep-Sea Bed Mining**

   The ocean floor is a relatively untapped frontier for CETM extraction. Deep-sea bed mining has garnered attention due to the presence of vast quantities of polymetallic nodules, seafloor massive sulphides, and cobalt-rich crusts, which contain high concentrations of valuable minerals such as nickel, cobalt, and rare earth elements. While promising, deep-sea mining raises significant environmental and regulatory concerns. The potential ecological impact on marine ecosystems must be carefully weighed against the benefits of accessing these resources. As technology advances and international governance frameworks evolve, deep-sea bed mining could become an important contributor to the global supply of critical minerals (International Energy Agency 2021).

4. **Recycling and Circularity**

Recycling of CETMs are crucial strategies for ensuring a sustainable supply of these essential materials, which are especially vital for low-carbon technologies. Recycling involves recovering, reusing, and recycling CETMs already in circulation to reduce dependency on primary sources, mitigate supply chain risks, and promote sustainability. Examples include recovering of lithium and nickel from spent batteries through processes like hydrometallurgy (leaching) and pyrometallurgy (smelting) and recovering of REEs from discarded electronics and magnets. But recycling processes can be complex and require advanced technologies to efficiently recover and purify critical minerals. Moreover, absence of infrastructure for collection of e-waste, battery waste etc is a challenge for the recycling sector. This translates to the cost of recycling being high, making it less economically attractive compared to primary extraction for some minerals. Additionally, procurers are creating circular economies by recycling and reusing end-of-life products.

Circularity, on the other hand, is a broader concept that includes sharing, prolonging use/longevity, reuse, refurbishment/remanufacturing, and recycling. For example, retired batteries have been repurposed to power streetlights and stadiums, and General Motors is now designing batteries with second-life use in mind (Yeh 2022). Remanufacturing restores equipment to its original performance, potentially doubling the return on investment for large assets like wind turbines by extending their lifespan by up to 20 years. This process also significantly reduces the demand for virgin materials by utilizing equipment that already contains CETMs (Yeh 2022).

1.4 Source of Uncertainty

Uncertainties in the demand and supply of CETMs pose significant challenges, especially for net importing countries who are concerned with price predictability and stability for investment planning. Some of these sources of uncertainties are more predictable than other. Predictable sources of uncertainties are those such as technology evolution that will lead to substitution leading to reduction in demand of specific minerals. However, the same developments can also create new technology applications, generating new sources of demand. Additionally, advancements in technology can also lead to more efficient recycling, providing a viable source of CETMs that can reduce the need for new mining operations.

Conversely, unpredictable events such as natural disasters, armed conflicts, political instability, and social unrest can severely disrupt all global supply chains. The risk is particularly acute for CETMs because a substantial portion of the supply is currently concentrated in only a few countries. Among the various sources of uncertainties, substitutability is among the most important variabilities of demand along with varying climate ambitions of nations. On the supply side, geopolitics, ESG concerns, and recyclability are significant sources of variability. They are discussed in sections below.

1.4.1 Substitutability

The concept of substitutability refers to the ability to identify and develop alternative materials or technologies that can replace or reduce reliance on specific critical raw materials that may be scarce, expensive, or subject to supply chain risks. The pursuit for cheaper, reliable and more efficient technologies, drives innovation of technology alternatives, that are not as dependant on scarce materials. This development and adoption of substitute materials can mitigate demand for many CETMs, helping prices stabilise. However, the extent and speed of this substitution can be uncertain.

In addition, technological progress can also lead to new sources of demand from technology applications such as Artificial Intelligence (AI), that have not been considered in demand scenarios. The various applications of AI could lead to greater number of data centres being built which have their additional mineral requirements but also energy requirements.

Among low carbon technologies, several substitution materials are under consideration, such as in battery materials for EVs and BESS applications, high-energy magnets for motors in EVs and wind turbines and hydrogen electrolysers. The substitutability of materials can be of two kinds: replacement - where the mineral intensity within the technology is reduced or removed through developments in material design of the technology, or new technology - where an alternative technology can replace the current technology. Some examples of substitution potential are illustrated below:

Batteries: Recent developments in battery technology, have already decreased reliance on specific minerals like Cobalt through replacement. Li-NMC batteries with equal ratios of nickel, manganese and cobalt (NMC333) in the cathode were common prior to 2015. However, with rising cobalt prices and ethical concerns prompted replacement of cobalt with higher nickel and lower cobalt ratios - first with NMC622 and more recently with NMC811, where 8 parts of nickel and one part each of manganese and cobalt are in use. However, when nickel prices boomed at the turn of the decade, alternatives to the NMC chemistry were also sought. A move toward LFP (Lithium Iron Phosphate) chemistries were noticed, despite LFP batteries having lower energy densities compared to NMC batteries (International Energy Agency 2023a). Sodium-ion batteries (SiB) that replace the relatively rarer Lithium ions in batteries with the more abundant Sodium ions is an innovation in battery technology that is close to commercialisation at scale. While its lower energy density may limit its use in EVs, they are certainly a promising alternative to LiBs for grid and stationary storage purposes (Zhao et al. 2023).

Magnets for Motors: Electric traction motors and wind turbine generators are primarily composed of high rare-earth element based permanent magnets, that have either neodymium-iron-boron (NdFeB) or Samarium-Cobalt (SmCo) (Poudel et al. 2021). High REE magnets are almost 30% lighter than ferrite magnet batteries and are therefore preferred due to their higher efficiencies and smaller size (Rallabandi, Ozpineci, and Kumar 2024). NdFeB magnets are the strongest available and enjoy a larger share of the market (Gagarin and Eggert 2023). Due to the high cost of rare-earth elements and challenges in their supply chain, there is search for alternatives to rare-earth in magnets. Currently attempts to reduce RE in magnets include replacing a portion of the high-energy RE magnet with low-energy ferrite magnets, or by modifying the design of the motors to incorporate induced magnets (Poudel et al. 2021).

Hydrogen Electrolysers: The two most common Hydrogen electrolysers are Alkaline Electrolysers that use Nickel as the electrode material, and Proton Exchange Membrane (PEM) electrolysers that use titanium, with iridium and platinum as catalysts, and platinum also used as a coating to prevent oxidisation. Anion Exchange Membrane electrolysers are being developed that reduce the need for noble metals, however they are at early stages of development (Santoro et al. 2022).

1.4.2 Recyclability and Circularity

Given the constrained supply of upstream minerals, there is growing attention on advancing the recycling sector. This focus has led to the development of new mineral recycling technologies aimed at improving metal recovery rates through recycling systems (Yu et al. 2024). However, recyclability and circularity introduce uncertainty due to the variability in recycling rates, technological advancements, and policy implementation. While recycling and circularity can significantly reduce the need for new mining, their effectiveness depends on ongoing innovations and the economic feasibility of reuse, recycling, and refurbishing as well as designing and manufacturing for it. Additionally, fluctuating regulatory environments and varying public participation in recycling programs can affect the consistency and predictability of recycled or repurposed material supply. Thus, while recyclability and circularity present a promising way to mitigate supply chain risks, they also add complexity and uncertainty that must be managed to ensure a stable supply of CETMs (Yu et al. 2024).

1.4.3 Geopolitical Dynamics

Geopolitics is a significant source of uncertainty in the CETM value chain, profoundly influenced by domestic and international policies adopted by nations. The extreme geographic concentration of global mining and processing significantly influences the geopolitics of CETMs. This concentration provides substantial geopolitical and economic leverage to existing producers. Substantial disruptions to CETM supply chains could occur due to changes in government regulations related to mineral trade, geopolitical tensions, trade disputes, and macroeconomic conditions of supply chain actors. This can affect production costs, supply chain logistics, and market access for CETMs.

China's dominance in the CETM supply chain is of particular concern globally. Key factors in its rise as a mineral superpower are believed to be substantial subsidies, federal financing, and trade and investment partnerships with mineral-rich countries (Nayar 2021, Murphy and Elimä 2021). The country's demand for minerals, driven by its downstream manufacturing industries, enhances its processing capacity and economies of scale. As global competition intensifies, especially in clean energy technologies, China's market power serves its broader foreign policy objectives. It has occasionally leveraged this market power to impose export restrictions on minerals like gallium and germanium (Kharpal 2023). The EU and the US have begun efforts to reduce dependence on China and diversifying supply chains, through the Mineral Security Partnership (MSP) which includes India, and the EU Critical Raw Materials Act, among other policy actions. Besides these, there are several bilaterial MoUs that are being signed between countries to co-operate on CETMs, particularly in lithium mining and processing. Despite attempts to diversify, China's advancements suggest it will remain a dominant force in the critical minerals supply chain for the foreseeable future.

As global competition in clean energy technologies intensifies, the geopolitical contest over CETMs will continue to influence supply chains. Governments and corporations are reassessing vulnerabilities in critical mineral supply chains, implementing policies to mitigate risks and maximise strategic advantages. While China's near-term dominance remains intact, the push by the US, EU, and other advanced economies to secure more resilient and diversified supply chains will reshape the landscape. The success of initiatives like the MSP and the EU Critical Raw Materials Act, alongside the effectiveness of new MoUs, will determine how the global CETM supply chain evolves over the coming decades. The challenge of scaling supply has heightened concerns about scarcity, leading to renewed cooperation and competition among nations.

1.4.4 Environmental, Social and Governance concerns

In recent years, Environmental, Social, and Governance (ESG) considerations have become increasingly significant in the mining industry responding to stakeholder demand for greater transparency, accountability, and sustainability (IEA 2023f).

The **environmental** component of ESG addresses hazards and emissions, water stress, biodiversity loss, water, greenhouse gas emissions, pollutants, waste management, and mine closures. The **social** component considers the effects of mining on nearby communities' employment, health, and safety conditions. It emphasises engagement with local communities, respect for human rights and ensures mining activity benefit local stakeholders. The **governance** component comprises compliance with laws and regulations, procedures governing risks management, and ensures transparency within the supply chain. It is crucial to ensuring ethical, transparent and responsible mining practices.

The lack of comparability in ESG metrics and insufficient transparency makes it difficult to assess and compare performance across different operations (Boffo and R. Patalano 2020). Thus, while ESG aims to enhance sustainability, transparency and accountability, it requires companies to engage in meaningful due diligence to be able to identify and mitigate supply chain risks.

Failing to address ESG concerns in mining and mineral processing can lead to regulatory crackdowns, social unrest, operational disruptions, financial instability, and loss of market access. These issues collectively contribute to the uncertainty and unpredictability of mineral supply, affecting not only the mining companies but also the broader economy and industries dependent on these critical resources.

While the integration of ESG principles aims to enhance sustainability and accountability, it also introduces uncertainties in the demand and supply of minerals. This uncertainty stems from the evolving regulatory landscape, stakeholder expectations, and the inherent challenges in balancing ESG commitments with operational and economic goals. Balancing these factors requires careful management, transparency, and engagement with all stakeholders to ensure a stable and sustainable future for the mining industry.

1.5 Framework to Establish Criticality

A framework to establish the criticality of minerals refers to a methodology used to evaluate and prioritise the importance and risk associated with various minerals. This framework typically involves assessing both the economic importance and the supply risk of different minerals to determine which ones are critical for a country's economy, national security, and technological development. It helps governments and industries to manage resources, identify vulnerability in supply chains as well as encourage sustainable practices.

The economic importance is determined by industrial use, economic impact in case of a shortage as well as the role of mineral in emerging and critical technologies such as renewable energy and electric vehicles. Supply risk assessment comprises of geological availability, concentration of supply, recycling and substitutability as well as political and regulatory factors. It is worth noting that substitutability is an important indicator for both supply risk and economic importance.

High levels of substitutability dampen the supply risk as it would be relatively easy to acquire substitutes through mining. Similarly, better cost-performance of a substitute would dampen the economic importance of a mineral. Some of the limitations of this framework include not accounting for the critical minerals embedded in imported products and not considering the demand for new green technologies that are not currently being manufactured in the economy.

The key steps required in establishing criticality is compilation of a comprehensive mineral list used in various industries and technologies, gathering data on supply, demand, production, trade flows, recycling rates and potential substitutes, using quantitative metrics to score each mineral based on supply risk and economic importance and ranking the minerals according to the criticality scores to identify which ones are most critical.

1.5.1 Methodology

This section discusses the important concepts of economic importance and supply risk that are used to calculate criticality. The description in this section is reproduced from the author's earlier report (Chadha, Sivamani, and Bansal 2023a) in which a more detailed explanation may be found.

Economic importance: The economic importance (EI) dimension measures a mineral's importance for a country's manufacturing sector. It measures the impact on this sector if a mineral becomes unavailable in a country's supply chain. Four indicators are used to compute the EI of each mineral [Eq. 1]. The first indicator is the *disruption potential*, which measures the impact on the gross value added (GVA) if the mineral becomes unavailable in the country's supply chain. The *substitutability index,* the second indicator, measures the cost and performance of substitutes for the mineral, if any, in each of the mineral's end-use applications. The third indicator is the *GVA multiplier coefficient*, which measures the mineral's impact on manufacturing GVA (both direct and indirect), accounting for linkages between sectors of the economy and computed using sectoral GVA multipliers. The fourth is the *cross-cutting index*, which signifies the diversity of a mineral's use across manufacturing sectors.

$$EI = \left(\sum_{s} A_s Q_s\right) \times \sigma_{EI} \times \mu \times \kappa$$

Equation 1 is used to compute the economic importance of each mineral, where:

A_s is the share of the mineral's consumption in sector *s* to its total consumption;
Q_s is the GVA share of sector *s* to total manufacturing GVA;
σ_{EI} is the substitutability index of the mineral;
μ is the mineral's GVA multiplier coefficient;
κ is the mineral's cross-cutting index

Supply risks: The supply risk (SR) dimension of the criticality assessment seeks to measure the vulnerabilities a country may face from global mineral supply chains due to the geographic concentration of mineral extraction or processing in some countries and weighted by the quality of governance in the respective jurisdictions. The World Bank publishes the *World Governance Indicators* (WGI), which view the quality of governance by country (World Bank, 2023). Weights may also be assigned based on other factors, such as Yale University's Environmental Protection Index (EPI) (Yale Centre for Environmental Law & Policy, 2022) or the Mining Investment Attractiveness Index (Fraser Institute, 2022). Mineral supply risks are also impacted by end-of-life recycling rates, substitutability, and the degree of self-reliance.

Equation 2 is used to compute the supply risk of each mineral, where:

$$SR_G = \left[\left[\left(HHI_{WGI}\right)_{GS} \times IR/2 + \left(HHI_{WGI}\right)_{IS} \times (1 - IR/2)\right] \times (1-\rho) \times \sigma_{SR} \times \varepsilon\right]$$

SR_G is the supply risk accounting for governance indicators;
HHI_{WGI} is the Herfindahl-Hirschman Index of mineral concentration, accounting for governance indicators;
GS is the global supply of extracted or processed minerals;
IS is the Indian sourcing of extracted or processed minerals;
ρ is the end-of-life recycling rate of the mineral;
IR is the import reliance of the minerals;
σ_{SR} is substitutability in the supply risk dimension;
ϵ is the self-sufficiency adjustment factor

1.5.2 Criticality methodology adopted by India

In June 2023, the Ministry of Mines announced India's first list of critical minerals. The ministry identified 30 critical minerals for India including various Platinum Group Elements and Rare Earth Elements. The central government had set up a seven-member committee under the chairmanship of Joint Secretary, Ministry of Mines. The committee adopted a three-stage methodology to identify the critical minerals needed for India (Committee on Identification of Critical Minerals 2023). The following are the stages:

1. Comparative study of the Global Critical Minerals
2. Inter-ministerial Consultation
3. Critical Minerals based on Empirical Formula

The second stage was most instrumental as the committee prioritised minerals that were found to be critical by various ministries. The committee recognised the importance of an empirical study for evaluating critical minerals. The EU methodology followed by CSEP focused on two factors: economic importance and supply risks. The committee suggested that a detailed statistical analysis for mineral criticality must be carried out by a sub-committee adopting the EU framework.

1.5.3 Other factors impacting criticality

While criticality frameworks typically assess minerals at the economy-wide level, a bottom-up approach better suits technology-specific assessments, relying on technological progression as an indicator for mineral consumption. This approach involves evaluating market penetration of technology variants and criteria like substitutability, demand growth, and trade restrictions. The bottom-up approach is also covered in this section.

Some of these reasons for establishing a criticality framework are as follows:

- **Strategic Resource Management:** A criticality framework helps identify which minerals are essential for the economy and national security. By understanding the criticality of these minerals, governments and industries can prioritize the management and secure supply chains for these resources.
- **Economic Stability**: Critical minerals are often integral to key manufacturing sectors. Disruptions in the supply of these minerals can significantly impact the economy, especially in industries like electronics, renewable energy, and automotive manufacturing. A framework helps mitigate these risks by highlighting vulnerabilities and suggesting measures to ensure stability.
- **Technological Advancement:** Low-carbon technologies (LCTs) like solar panels, wind turbines, electric vehicles, and batteries rely heavily on critical minerals. Establishing a framework for criticality ensures that the supply of these minerals can meet the growing demand, supporting the transition to a sustainable and technologically advanced economy.
- **Policy Development**: A well-defined criticality framework provides a foundation for developing effective policies and regulations. It guides policymakers in creating strategies for mineral exploration, investment in mining infrastructure, and international trade agreements to secure critical mineral supplies.
- **Supply Chain Resilience**: Understanding the criticality of minerals aids in building resilient supply chains. It allows for the identification of potential bottlenecks and dependencies on specific countries or regions, enabling proactive measures such as diversification of supply sources and promotion of recycling and substitution technologies.
- **Environmental and Social Governance**: A criticality framework can incorporate environmental and social governance (ESG) criteria, ensuring that the extraction and processing of critical minerals are done sustainably and ethically. This helps address concerns related to environmental degradation, labour practices, and community impacts.
- **Investment and Innovation**: Highlighting critical minerals attracts investments in mining and processing technologies. It encourages innovation in developing alternative materials and improving extraction and recycling processes, thus enhancing the overall efficiency and sustainability of resource use.
- **International Cooperation:** Criticality frameworks can facilitate international collaboration by aligning countries on the importance of certain minerals. This can lead to joint ventures, shared research, and coordinated efforts to secure global supply chains.
- **Future Planning:** A framework for criticality provides a forward-looking perspective on mineral demands, considering future technological advancements and economic trends.
- **Support to consumer uptake:** By pre-emptively avoiding supply chain bottlenecks, prices of essential clean energy technologies can be kept at affordable levels, supporting enhanced and early uptake.

SECTION I: CRITICAL ENERGY TRANSITION MINERAL DEMAND

2

GROWING GLOBAL DEMAND FOR CETMs

2 GROWING GLOBAL DEMAND FOR CETMs

Greenhouse gas emissions resulting from human activities continue to increase. The International Panel on Climate Change (IPCC) reports that human-driven greenhouse gas emissions have led to a 1.1°C rise in global surface temperatures from 1850–1900 to 2011–2020 (IPCC 2021). Unsustainable energy use, land-use, and consumption patterns continue to drive up greenhouse gas emissions. CO_2 emissions from fossil fuel combustion and industry account for nearly two-thirds of global emissions. In 2019, 34% of emissions came from the power sector, 24% from industry, 22% from agriculture and land use, 15% from transport, and 6% from buildings (UNEP 2023). Given these pressing realities, transitioning the power supply industry and transport sectors to net-zero emissions is crucial for mitigating a significant portion of global CO_2 emissions.

The power sector is projected to be the first to achieve net-zero emissions as per most modelled pathways to reduce emission, followed by industry, buildings, and transportation (IEA 2021).

The six technologies crucial for these energy transitions are:

1. **Solar Photovoltaics** for energy generation.
2. **Wind turbines** for energy generation.
3. **Batteries** to facilitate greater integration of renewables into the grid.
4. **Electric vehicles** for electrification of the transport sector.
5. **Grid infrastructure** expansion to accommodate increased electrification of economy; and
6. **Electrolysers,** essential for green hydrogen production.

2.1 LCTs required to decarbonise Energy Sector

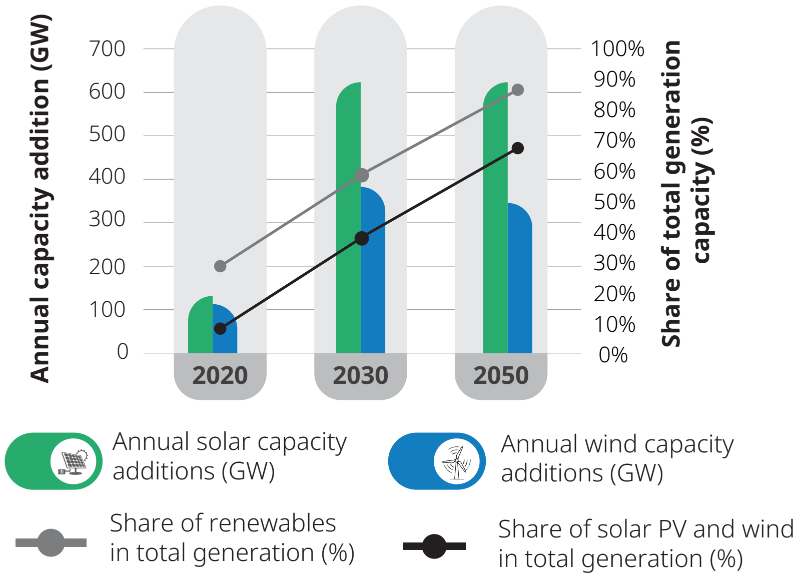
The IEA has devised a cost-effective, economically productive pathway to achieve global net zero emissions by 2050 (IEA 2021). This long-term projection outlines the expected deployment of various technologies and required investments until 2050. It sheds light on global trends in low-carbon technology deployment.

Annual additions of solar and wind capacity are projected to soar from 134 GW and 114 GW in 2020 to 630 GW and 350 GW, respectively, by 2050 (Figure 3). This growth aligns with other renewable technologies like hydroelectric power generation. Renewables are anticipated to constitute 88% of global generation capacity by 2050, with solar PV and wind accounting for nearly four-fifths of the total renewables capacity (IEA 2021).

As renewable energy sources like solar and wind become more prevalent in the energy mix, the need for effective energy storage solutions will become paramount. Demand for stationary battery storage is expected to surge. Global battery storage capacity is forecasted to escalate from 18 GW in 2020 to 3100 GW by 2050 as seen in Figure 4.

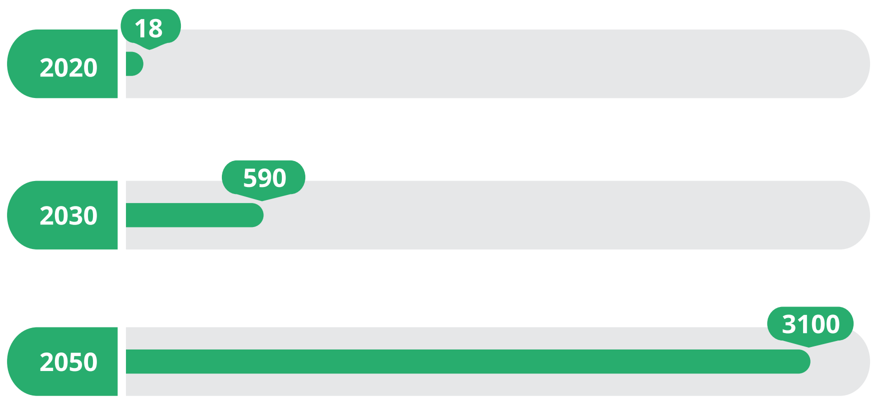
Growth in electric cars, buses and heavy trucks to be fuelled by increased battery manufacturing capacity. Electric vehicle (EV) deployment is also expected to grow rapidly as the mobility sector electrifies. In figure 5, we can see the share of electric vehicles in the overall stock of vehicles is set to increase over the years between 2020 and 2050. All vehicle categories are projected to see rapid growth, particularly electric cars, buses and heavy trucks, while

Figure 3: Projected global PV and wind capacity additions (Annual)



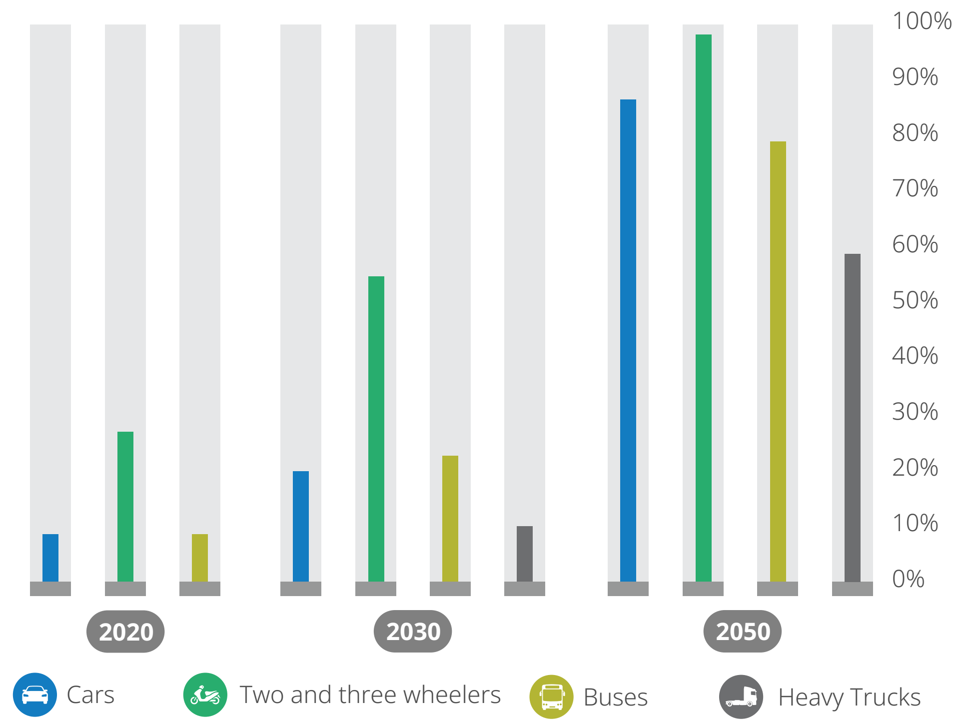
Source: (IEA 2021)

Figure 4: Projected global battery storage capacity (GW)



Source: (IEA 2021)

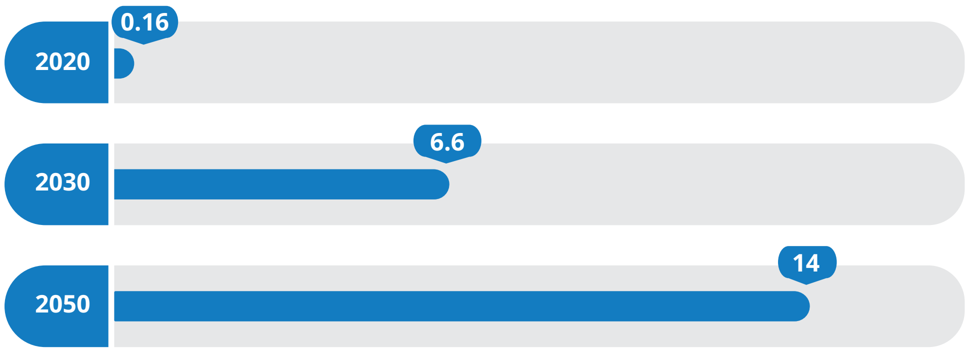
Figure 5: Share of electric vehicles in global stock (%)



Source: (IEA 2021)

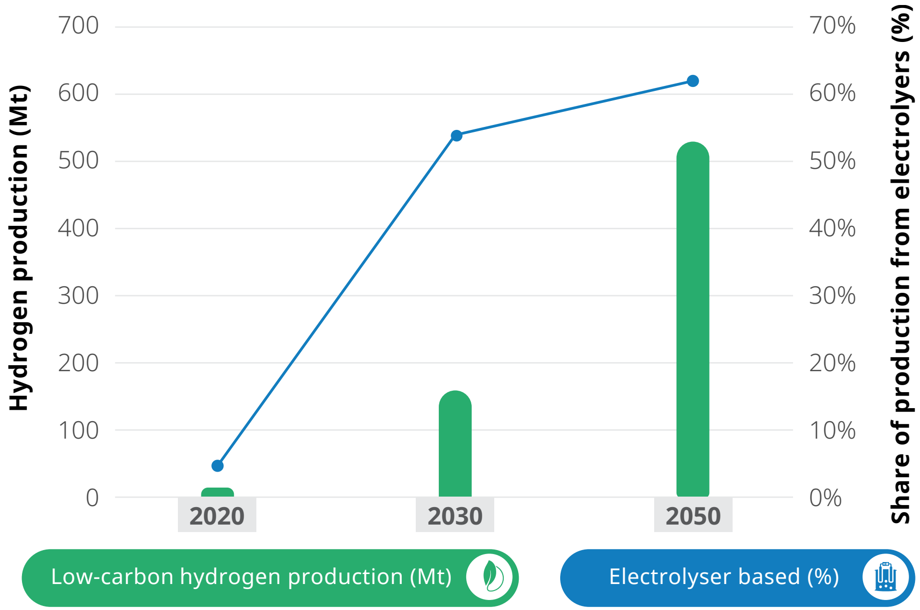
electric Two and three wheelers will steadily increase their share in the overall stock. By 2050, all categories of electric vehicles will make up more than 50 per cent of the stock of their respective categories. Two and three wheelers, especially, are expected to be 100 per cent electric by 2050, as presented in figure 5. This growth in electric vehicle stocks will require a scaling up of battery manufacturing capacity, as the annual demand for batteries for EVs is set to grow. Figure 6 depicts how EV battery demand is set to grow to 14 Terawatt hours (TWh) by 2050, from 0.16 TWh in 2020.

Figure 6: Projected global annual demand for electric vehicle batteries (TWh)



Source: (IEA 2021)

Figure 7: Projected global annual hydrogen production

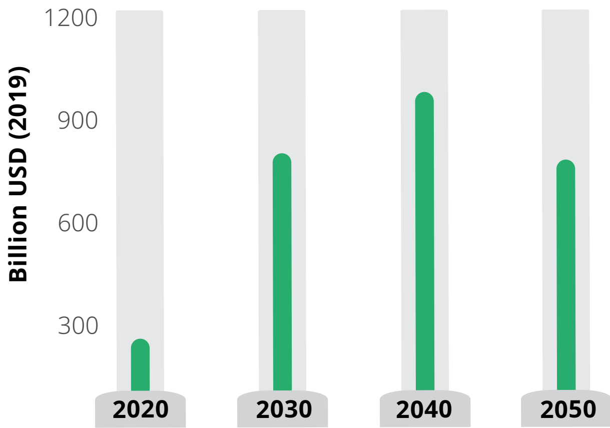


Source: (IEA 2021)

Increased hydrogen production is to be met by electrolysers. Hydrogen will play a key role in the energy transition for hard-to-abate sectors. The IEA predicts that low-carbon hydrogen production will surge from 9 million tonnes (Mt) in 2020 to 520 million tonnes (Mt) in 2050 (IEA 2021). By 2050, over 60% of this low-carbon hydrogen is expected to be generated using electrolysers (IEA 2021).

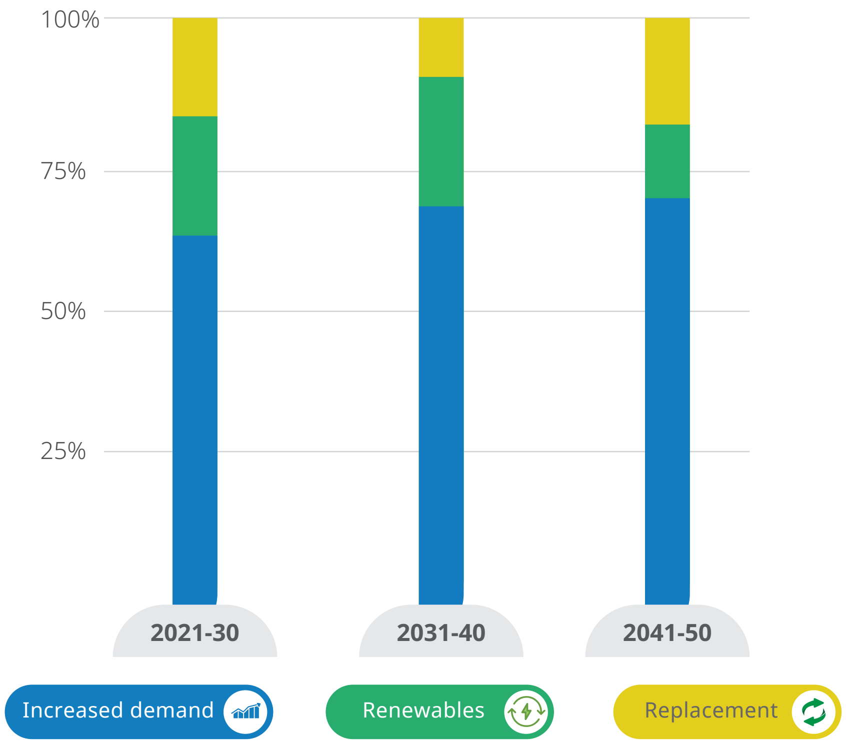
Expansion and upgrade of existing grid infrastructure: The IEA anticipates continued expansion of grid infrastructure, projecting investments to rise from USD 260 billion in 2020 to USD 820 billion by 2030. Following this, investments are expected to stabilise until 2050. A significant share of these investments will cater to meeting increased demand from electrification, while some investment will be allocated for integrating renewables or replacing aging grid infrastructure (IEA 2021).

Figure 8: Global investment in grid networks in the NZE Scenario



Source: (IEA 2021)

Figure 9: Drivers for global grid investment



Source: (IEA 2021)

2.2 Future Demand for CETMs from LCTs

As the world transitions to low carbon pathways, the demand for CETMs is expected to grow multi-fold – ranging from 2 to 3.5 times from current levels by 2030 across scenarios (International Energy Agency 2023a). Table 1 shows the projected demand for select CETMs across multiple low carbon technologies (LCTs) as the world moves to a net zero scenario.

Table 1: Total global demand for lithium, nickel, copper, rare earths elements (REEs), manganese and silicon in LCTs in the Net Zero Emissions by 2050 scenario (in kilo tonnes)

CRM	2023	2030	2040	2050
Lithium	92.1	615.6	1,307.9	1,573.2
Nickel	477.7	2,793.8	3,583.6	3,094.3
Copper	6,371.7	15,046.3	19,478.1	19,239.3
REEs	16.3	62.1	71.9	79.9
Manganese	181.7	861.3	2,119.5	3,051.4
Silicon	1,126.1	2,029.8	2,105.2	2,480.0

Note: *Total demand in low carbon technologies considers demand from multiple end-use industries such as solar PV, wind, electric vehicles, grid battery storage, hydrogen technologies, electricity networks etc. Each industry may require intermediate products with different purity levels/grades of each mineral.*
Source: Authors' calculation based on (International Energy Agency 2023a)

3

INDIA'S DEMAND FOR CETMs DUE TO THE NET ZERO TRANSITION

3 INDIA'S DEMAND FOR CETMs DUE TO THE NET ZERO TRANSITION

At COP26, India has set for itself the target to achieve a net-zero emissions by 2070. Fulfilling this target will require critical sectors such as power, industry, and transport to switch from current production methods to low-carbon technologies.

The total demand for low-carbon technologies in India will be heavily influenced by socio-economic changes and the country's climate and energy policies. Various assessments have been conducted to explore potential pathways for India's energy transition, with particular emphasis on achieving its 2070 net-zero emission targets set at COP26 (PIB 2022).

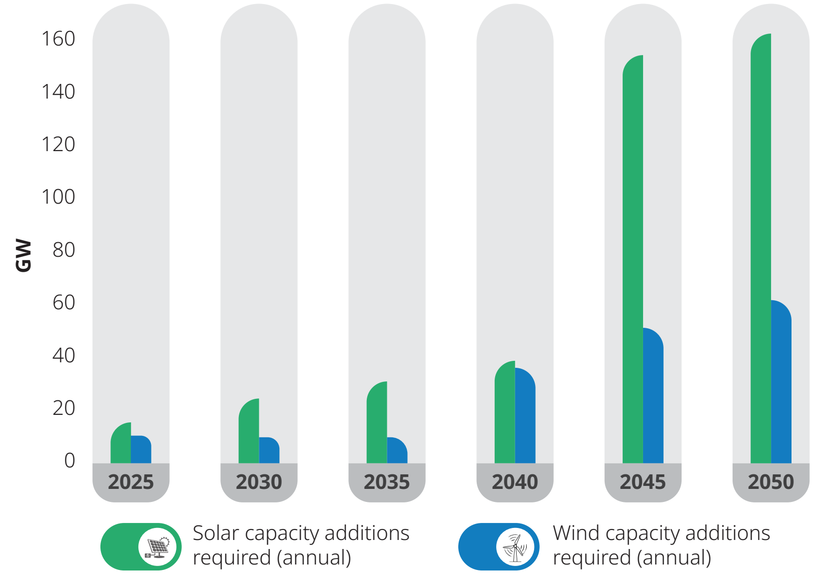
Several groups, including The Energy and Resources Institute/Shell and Lawrence Berkeley Laboratory, have tried to assess the potential pathways for India's energy transition to 2050 based on certain underlying assumptions (Abhyankar et al. 2023). In this study, we focus on the assessment conducted by the Council on Energy, Environment and Water (CEEW). The results are particularly relevant because they take into consideration India's 2070 net-zero emission targets. It should also be noted that this analysis was published in 2022 and since then, the annual deployment numbers across clean energy technologies have increased. However, despite the increase in numbers, we don't expect the annual embedded requirement to change significantly.

CEEW's assessment of the implications of the net-zero sector pathways for India's sectoral energy transition uses the Global Change Analysis Model (GCAM, CEEW version) to evaluate the implications of four alternative peaking-net zero scenarios for India (Chaturvedi and Malyan 2022). GCAM is an integrated assessment model that represents the behaviour of and interactions between energy systems, water, agriculture, land use, economy, and climate (Calvin et al. 2019).

3.1 LCTs necessary for decarbonising India's Energy Sector

Solar capacity additions to surpass wind capacity additions: According to the CEEW assessment, India's solar and wind generation installations

Figure 10: India's projected annual solar PV and wind capacity additions

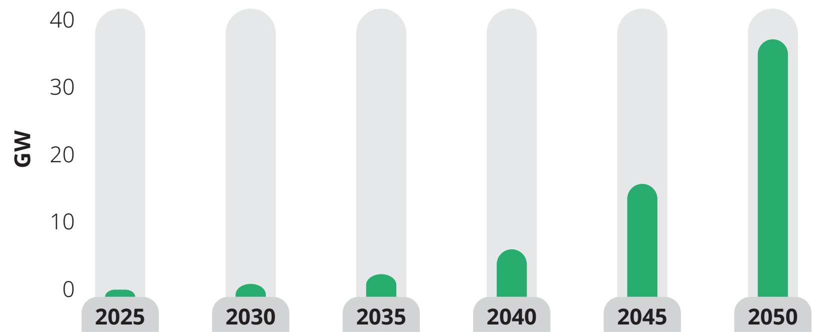


Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

are expected to accelerate in the coming years. These capacity additions take into consideration both new demand, as well as replacements of retired capacity. As evident in figure 10, Solar PV capacity additions are projected to surpass wind capacity additions due to greater economic competitiveness of Solar PV. By 2050, solar PV additions are expected to reach 140 GW annually, with a sharp uptick in installations after 2040 when solar PV is expected to begin to become the dominant energy source. Annual wind additions, on the other hand, are expected to only increase to 20 GW by 2050, with a similar sharp increase in installations after 2040.

Demand for hydrogen to increase: The demand for hydrogen from industrial and transport sectors is projected to significantly increase in the coming years. In this study, we assume that 100% of the hydrogen demand will be met by domestic electrolysers producing hydrogen, excluding technologies based on fossil fuels and Carbon Capture and Storage (CCS). In this case, the annual electrolyser capacity additions are expected to increase to 35 GW annually in 2050 from 0.6 GW in 2025.

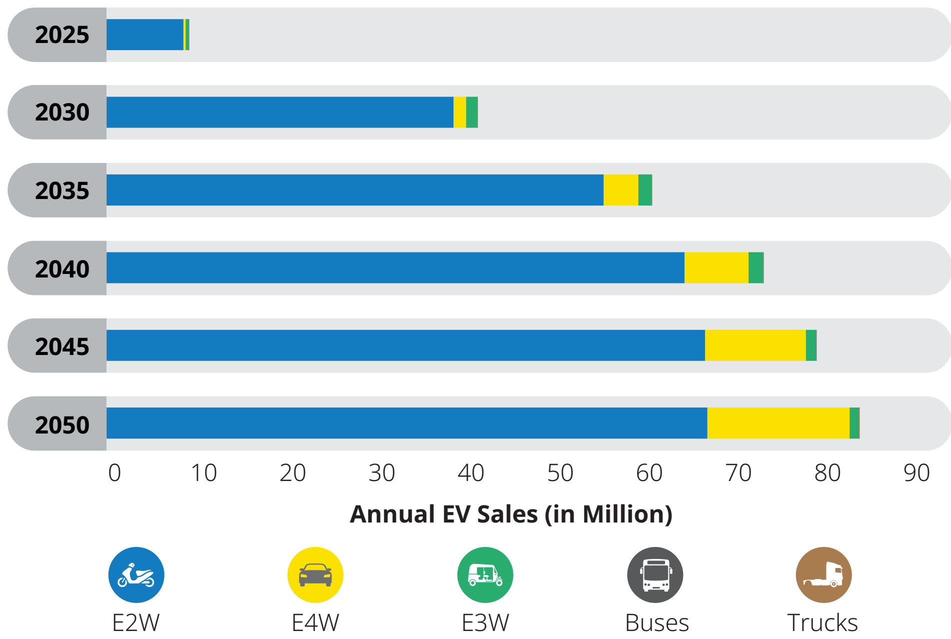
Figure 11: Expected annual electrolyser capacity addition



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

Electric two wheelers' sales to be more than other electric vehicle sales: The number of electric two-wheelers (E2W), which include electric bicycles, scooters, and motorcycles, are expected to be more than other electric vehicles by numbers. About 8.5 million E2Ws are expected to be sold in 2025, and 66 million E2W Annual vehicle sales, derived from the GCAM model, are provided in the figure 12 below.

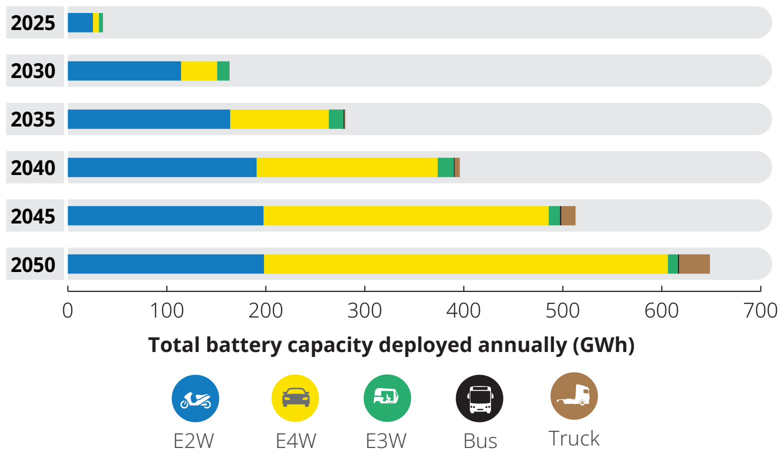
Figure 12: Expected annual electric vehicle sales



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

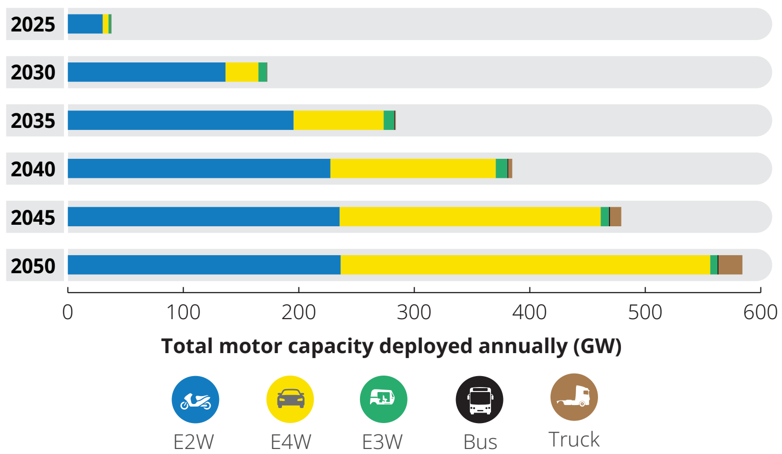
A shift towards larger batteries and motors: Based on the total electric vehicle sales, the annual demand for both batteries and motors used in these EVs has been estimated. In 2025, the aggregate demand in GW or GWh terms for motors and batteries primarily comes from electric two-wheelers (E2Ws). However, by 2050, over 600 GWh of battery demand and over 550 GW of motor demand come about equally from electric two-wheelers (E2Ws) and electric four-wheelers (E4Ws) due to the much larger batteries and motors used in E4Ws. Additionally, a small amount of demand for batteries and motors is generated by trucks and electric three-wheelers (E3Ws), as illustrated in the figure 13 and 14.

Figure 13: Expected battery capacity deployment from electric vehicle sales



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

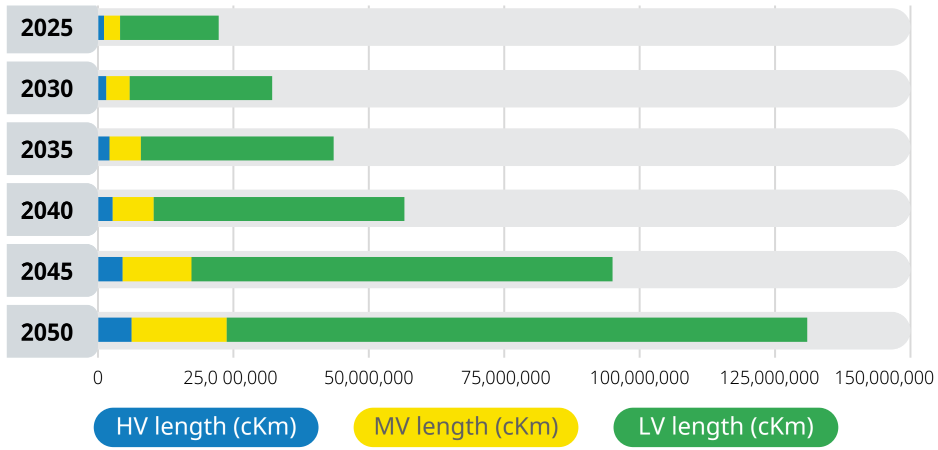
Figure 14: Expected motor capacity deployment from electric vehicle sales



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

Grid infrastructure to show a consistent increase: Given India's current grid length and the projected growth in generation capacity up to 2050, it is expected that the grid length will continue to expand until 2050. It is assumed that the ratio of generation capacity to grid length will remain constant (Deetman et al. 2021).

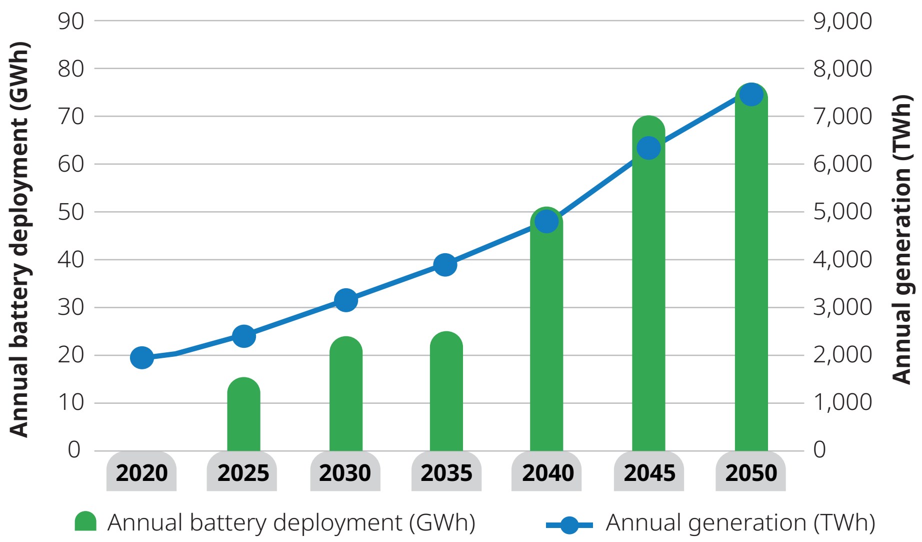
Figure 15: Projected increase in grid length till 2050



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.
Note: High-voltage (HV), low-voltage (LV), medium-voltage (MV), circuit kilometres (cKm)

A growing share of total generation to come from energy storage sources: For stationary storage demand, we use India's energy storage obligation trajectory till 2030, which requires a growing share of total generation to come from energy storage sources, reaching 4 per cent of total generation by 2030 (Ministry of Power 2022). We assume that this obligation will remain fixed at 4 per cent between 2030 and 2050, and energy storage demand will grow proportional to total energy generation. We also assume that 50 per cent of total stationary storage demand is met by battery technologies.

Figure 16: Projected battery storage annual demand till 2050



Source: Authors' analysis from Chaturvedi, Vaibhav, and Ankur Malyan. 2022.

3.2 Shortlisting of Minerals for this Study

It is difficult to estimate mineral demand since it depends not on deployment but on the scale of mineral processing and component manufacturing. Hence, instead of estimating demand, we estimate the minerals embedded in the clean energy products (solar, wind, batteries, EV, electrolytes, motors and grid wires) that should be deployed every year to meet India's 2070 Net-Zero ambition. For the analysis, we take into consideration the CEEW's high Hydrogen low CCS scenario for clean energy deployment.

An accurate assessment of India's CETM demand is not easy. For each of the six technologies being considered in this mineral estimation, the market shares of technology variants play a key role in determining the actual mineral demand. Accurately assessing mineral demand requires considering the mineral intensity of different technology variants, which can vary considerably. Technology foresight is essential for providing meaningful assessments of mineral demand, especially in medium- and long-term projections (Christmann and Lefebvre 2022). However, it's important to acknowledge the inherent uncertainty in such foresight exercises. Besides, for each technology, mineral intensities should be estimated prospectively till 2050 to capture potential changes accurately. This is important because the mineral intensity of these technologies can change over time. For instance, the silicon content of solar photovoltaic (PV) cells has undergone significant changes over the past decade, driven by advancements in manufacturing processes. Similar trends are likely to occur across other low-carbon technologies as well.

Furthermore, an accurate assessment of India's mineral demand is challenging due to the variability in technology variants and their mineral intensities. The study also highlights the extensive use of several minerals across multiple low-carbon technologies, either directly in the core technology or as part of the balance-of-system components. To determine the critical minerals for each technology, a bottom-up analysis was conducted, considering both the supply risk and economic importance of each mineral.

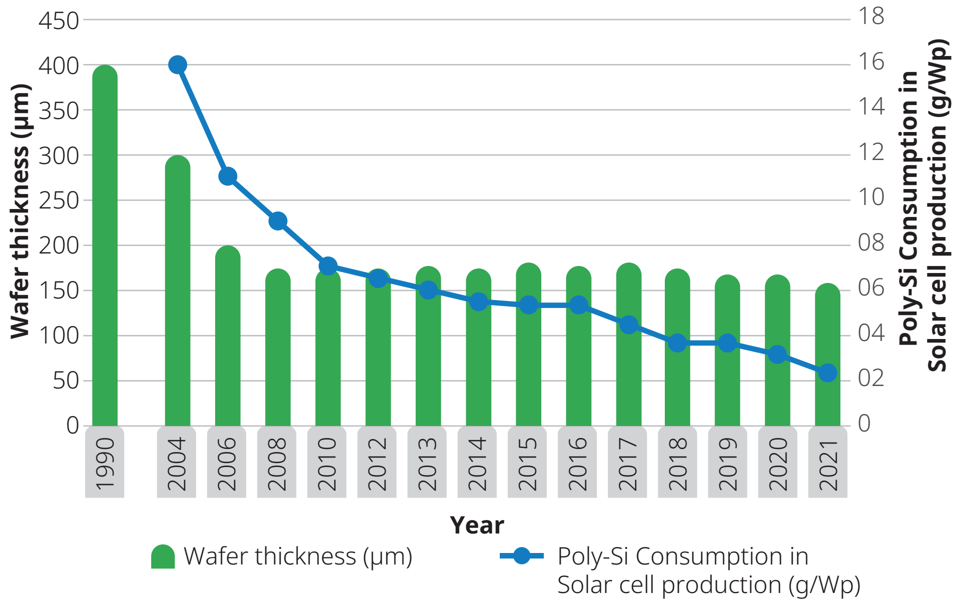
Technology variants will affect mineral demand: The actual demand for minerals will be significantly influenced by the market shares of different technology variants within each low carbon technology. As per Table 2, the technology variants considered in this study include passivated emitter and rear contact (PERC (c-Si)), silicon heterojunction (SHJ), copper indium gallium selenide (CIGS) (thin film) and silicon tandem cells for solar PV; direct-drive electrically excited synchronous generator (DD-EESG), direct-drive permanent magnet synchronous generator (DD-PMSG), gearbox permanent-magnet synchronous generator (GB-PMSG), and gearbox double-fed induction generator (GB-DFIG) for wind; high-nickel NMC (Nickel Manganese and Cobalt), low-nickel NMC, lithium iron phosphate (LFP), lithium titanate and lithium manganese oxide (LMO-LTO), sodium-ion, and vanadium flow for batteries (VFB); permanent magnet and induction for motors; and alkaline, proton-exchange membrane (PEM), and solid oxide for electrolysers.

Table 2: Technology variants considered for mineral estimation study

Clean energy technology	Solar PV	Wind	Battery	Motors	Electrolyser
Important technology variants	PERC (c-Si)	DD-EESG	High-nickel NMC	Permanent magnet	Alkaline
	SHJ	DD-PMSG	Low-nickel NMC	Induction	PEM
	CIGS (thin film)	GB-PMSG	LFP		Solid oxide
	Silicon tandem cell	GB-DFIG	LMO-LTO		
			sodium-ion		
			vanadium flow		

Mineral intensity of these technologies changes over time: For each technology, mineral intensities are estimated prospectively

Figure 17: Silicon content in solar PVs



Source: (Fraunhofer ISE 2024)

till 2050. This is important because the mineral intensity of these technologies can change over time impacting mineral demand. For instance, the silicon content in solar PV cells has drastically changed over the past decade, reflecting technological advancements and market trends. This prospective analysis is crucial for understanding the future mineral requirements and ensuring the sustainable supply of these critical resources.

Several of these minerals are used across more than one low-carbon technologies. These minerals used low-carbon technologies, either directly in the core technology, or as part of the balance-of-system components, are listed below:

Table 3: List of minerals used in low carbon technologies

Solar PV	Wind	EV (motor)	Battery (EV and stationery)	Electrolyser	Grid
Antimony	Bauxite (aluminium)	Boron	Bauxite (aluminium)	Nickel	Bauxite (aluminium)
Bauxite (aluminium)	Boron	Copper	Cobalt	Platinum	Copper
Copper	Chromium	Heavy rare earths	Copper		Iron (steel)
Gallium	Copper	Iron	Graphite		
Indium	Heavy rare earths	Light rare earths	Iron		
Nickel	Iron (steel)	Neodymium	Lithium		
Selenium	Light rare earths		Manganese		
Silicon	Manganese		Nickel		
Silver	Molybdenum		Vanadium		
Zinc	Neodymium		Zinc		
Tin	Nickel		Phosphorus		
Iron (steel)	Zinc		Fluorine		

Source: *Author's analysis* Shortlisting Critical Minerals for the study (Liang et al. 2022; IEA 2021)

List of 43 minerals: The minerals selected for this analysis have been chosen from a list of 43 critical minerals for India as identified by the Centre for Social and Economic Progress (CSEP) (Chadha, Sivamani, and Bansal 2023a). These minerals were assessed based on their criticality levels, which consider both economic importance and supply risks. Among the 43 minerals assessed using the criticality framework, lead and zirconium are deemed non-critical for India, as they do not pose significant economic importance or supply risks. However, the remaining 41 minerals are considered critical for India, either due to their economic significance or supply risk factors. (See Annexure 1)

Bottom-up assessment to look at mineral production/import scaling: Many criticality frameworks assess the criticality of minerals at the economy-wide level (Schrijvers et al. 2020), but some research has focused on specific technologies. A bottom-up approach, often better suited for technology-specific criticality assessments, relies on technological progression as an indicator of mineral consumption (V. Gupta, Biswas, and Ganesan 2016). This approach considers criteria such as substitutability, demand growth, and trade restrictions to evaluate the economic importance of minerals (Schrijvers et al. 2020).

Understanding future low-carbon technologies is challenging due to potential changes in technologies. A prospective economic importance evaluation can be carried out by considering the market penetration of specific technologies like solar, wind, or electrolysers. This requires bottom-up economic and energy models to provide baseline expectations for growing demand, as seen in previous studies on solar, wind, and mobility sectors.

To determine the critical minerals for each technology, a bottom-up analysis was conducted, drawing on a framework by CEEW (V. Gupta, Biswas, and Ganesan 2016). The methodology involves shortlisting up to six relevant minerals for each technology, assessing their supply risk and economic importance, and calculating economic importance using a specific formula.

Projected demand for these minerals is estimated every five years from 2025 to 2050, considering both a baseline technology scenario and a disruptive scenario. The disruptive scenario serves as a sensitivity analysis, envisioning significant shifts in market shares of low-carbon technology variants.

Bottom-Up Approach: The methodology of this bottom-up approach is outlined as follows:

1. Up to six relevant minerals for each technology were shortlisted from a list of 43 minerals, based on their essential role within the given technology. This determination was made by assessing the mineral usage across different variants of the technology, taking into account market share data from the most recent available year.

2. The bottom-up assessment of these six minerals was carried out by comparing their supply risk (SR) and their bottom-up economic importance (EI). The supply risk considered was the same as that identified by CSEP in their 2023 working paper, normalised using min-max normalisation.
3. The bottom-up economic importance value was calculated using the following formula:

   $EI_{\text{for mineral in tech}}$ = (Mass share of mineral in each technology variant * price of mineral * market share of technology variant)

Market share of technology variant refers to the deployed share of technologies in the market as on the latest date for which data is available. Technology variants considered for each technology are provided below:

Table 4: Technology variants considered for each technology

Technology	Technology variants
Electrolyser	Alkaline, PEM, solid-oxide
LIB	LFP, NMC 111, NMC 532, NMC 622, NMC 811.
Solar	Crystalline-Si, Thin film
Wind	Onshore, Offshore
Grid	Transmission, Distribution
EV motor	Permanent magnet, induction

(For More details, See Annexure-5)

Shortlisting six minerals, one for each technology: To conduct a comprehensive analysis of CETM supply chains essential for the energy transition, this study has identified six key minerals for detailed examination in subsequent chapters. The selection process considers both the supply risk of minerals from an Indian perspective and their significance in low-carbon technologies. Recognising the diverse applications of these minerals, each one has been assigned as the primary mineral for a specific low-carbon technology: copper for electrical applications and renewable energy infrastructure, lithium for battery technology, manganese for wind turbines, nickel for batteries and electrolysers, rare earth elements (REEs) for electric vehicle (EV) motors, and silicon for solar photovoltaics. This approach ensures a comprehensive understanding of the impact of CETM supply chains across all major low-carbon technologies, rather than focusing solely on specific ones.

Table 5: CETMs shortlisted for each technology

Technology	Critical Mineral selected
Electrolyser	Nickel
Lithium Ion Battery	Lithium
Solar PV cells	Silicon
Wind Generators	Manganese
Grid and connecting all technologies to the grid	Copper
EV motor	Neodymium

3.3 Assessing CETM demand until 2050

In this section, we estimate the expected demand for six key CETMs —copper, lithium, manganese, nickel, lithium, rare earth elements (REEs), silicon, — essential for the energy transition. The annual requirement for these minerals, in terms of their embedded mineral content in low carbon technologies, (LCTs), is projected every five years from 2025 to 2050. This prospective analysis is crucial for understanding the future mineral requirements and ensuring the sustainable supply of these critical resources.

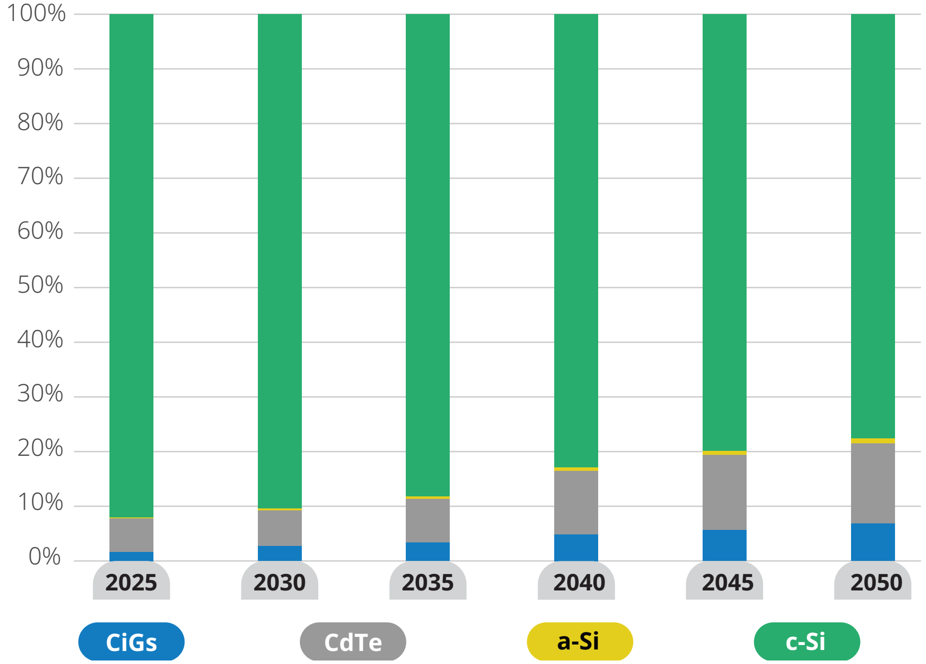
Market Share Shifts in Technology and Their Impact on Shortlisted CETMs: The objective of this analysis involves two distinct scenarios: the baseline technology scenario and the disruptive scenario. In the baseline technology scenario, it is assumed that there will be no alteration in the market shares of various technology variants from the latest available data until 2050. Conversely, the disruptive scenario involves identifying potential disruptive shifts in market shares of technology variants based on secondary research findings. Only technology changes with significant impacts on the demand for the six selected CETMs are considered in this scenario. The disruptive scenario serves as a sensitivity analysis, envisioning a substantial departure from the current market shares for all low carbon technology variants.

Disruptive scenarios:

I. Solar PV

The market share of thin-film technologies is projected to steadily increase from 5% of the total market share in 2020 to an estimated 23% by 2050.

Figure 18: Market of solar photovoltaic technology variants in the disruptive scenario



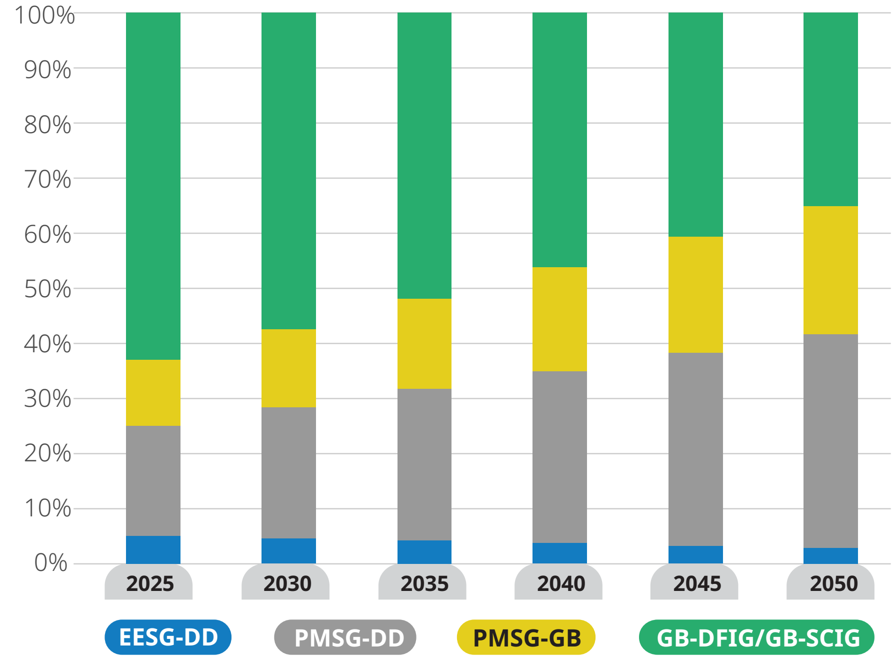
Source: Authors' analysis from multiple sources

Within this growth trajectory, the share of each type of thin-film technology variant is anticipated to remain constant until 2050. This scenario aligns with the European Commission Joint Research Centre high demand scenario, incorporating updated market share data from 2020.

II. Wind

In the disruptive technology scenario, the market shares of wind generation technologies mirror the expected market share change of onshore wind generation technologies until 2050, as outlined in the European Commission Joint Research Centre high demand scenario (Carrara et al. 2020). This scenario also accounts for potential growth in demand for permanent magnet-based wind turbines, similar to the market share change observed in solar PV technology variants.

Figure 19: Market of wind turbine technology variants in the disruptive scenario

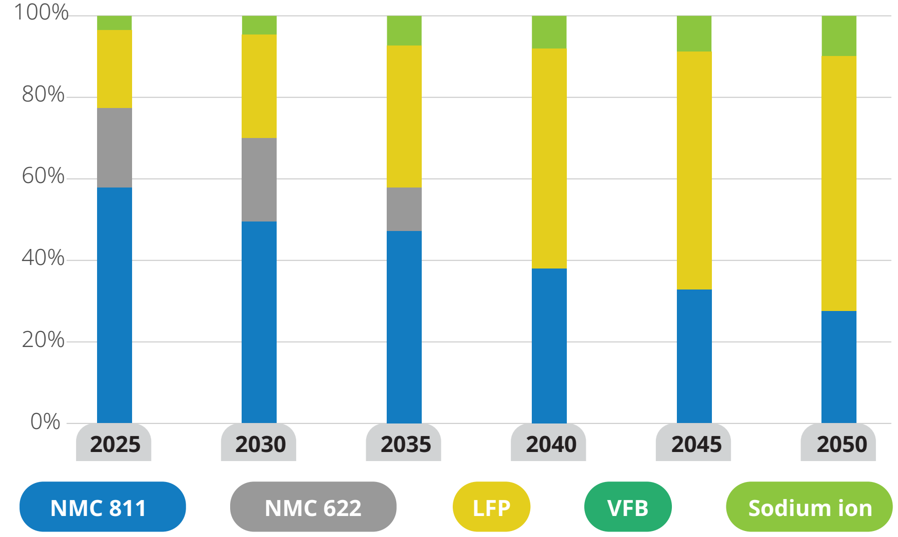


Source: Authors' analysis from multiple sources

III. Battery

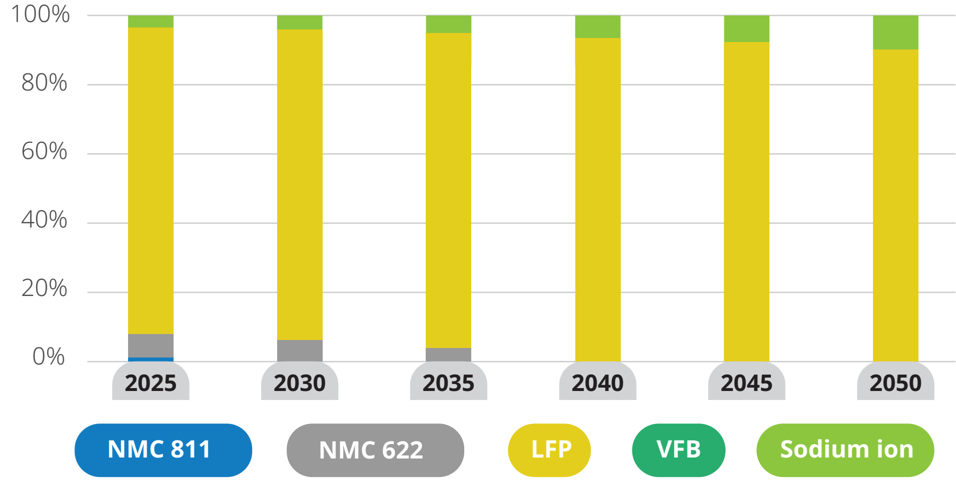
Battery market shares have been projected individually for light-duty vehicles (LDEVs), heavy-duty vehicles (HDEVs), and stationary storage technologies. In the disruptive scenario, the market shares of nickel-based battery variants decrease significantly, while lithium iron phosphate (LFP) and sodium-ion chemistries witness an increase for LDEVs. For HDEVs, LFP and sodium-ion chemistries are expected to dominate the market entirely by 2040. Market share scenarios for electric vehicle batteries have been developed based on estimates for 2030 and 2040 of various chemistries, with linear extrapolation used to estimate demand for other years. As most estimates indicate over 50% market share of solid-state batteries (without specified chemistries), it is assumed that 100% of solid-state batteries use LFP chemistries for HDEVs. For LDEVs, it is assumed that 50% of solid-state batteries use high-nickel chemistries, while the remaining 50% use LFP.

Figure 20: Market of light duty electric vehicle battery technology variants in the disruptive scenario



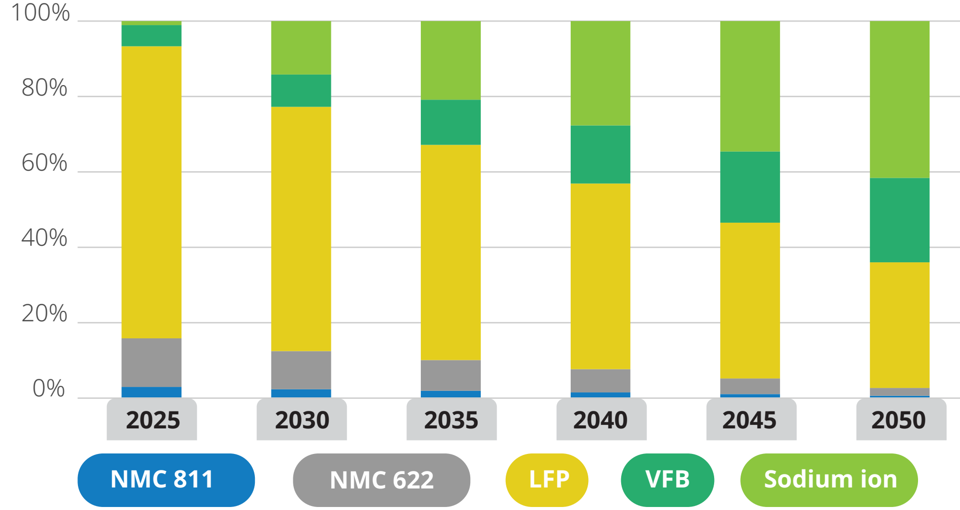
Source: Authors' analysis from multiple sources

Figure 21: Market of heavy duty electric vehicle battery technology variants in the disruptive scenario



Source: Authors' analysis from multiple sources

Figure 22: Market of stationary storage battery technology variants in the disruptive scenario



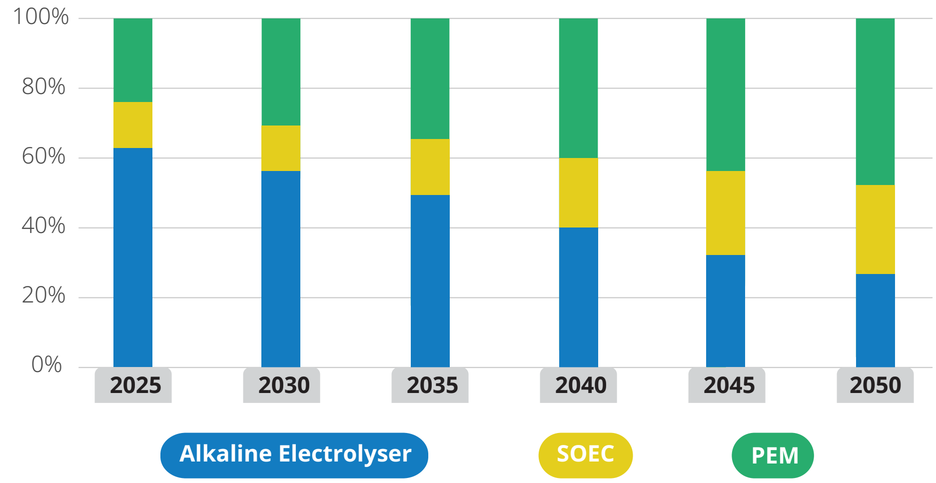
Source: Authors' analysis from multiple sources

In the disruptive scenario for stationary storage battery technologies, the market share of sodium-ion and vanadium flow batteries sharply increases, while lithium-ion batteries face a decline in market share till 2050, based on scenarios by IEA (IEA 2021) and Rystad Energy.

IV. Electrolyser

In the disruptive scenario, the market share of solid oxide electrolysers and PEM (Proton Exchange Membrane) electrolysers is projected to increase to 20% and 40% respectively by 2040, with continued linear growth until 2050. Conversely, alkaline electrolysers are expected to decrease to a 40% market share by 2040, with further reduction thereafter until 2050. This analysis focuses solely on three technologies and does not include anion exchange membrane (AEM) or other novel electrolyser technologies.

Figure 23: Market of electrolyser technology variants in the disruptive scenario



Source: Authors' analysis from multiple sources

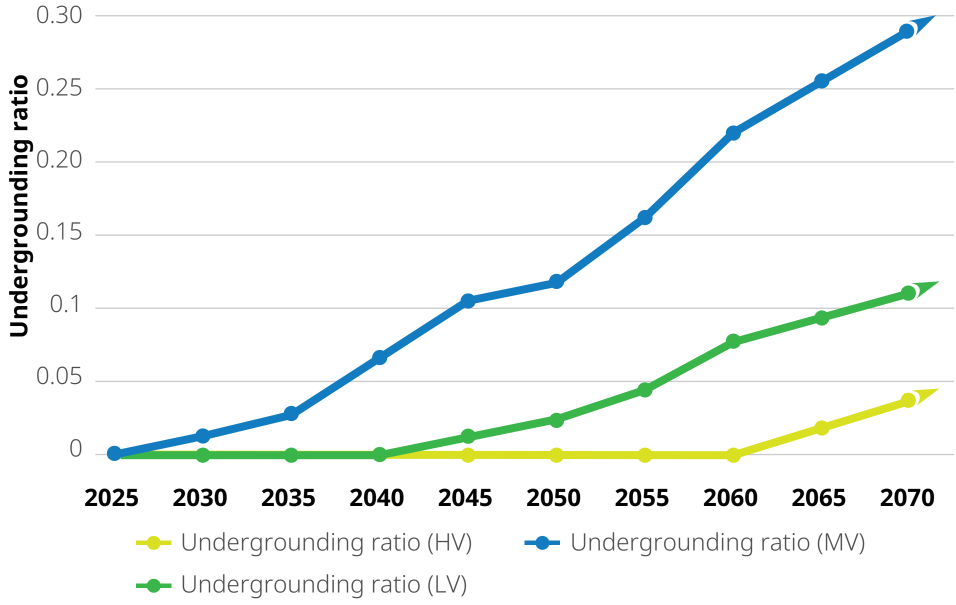
V. Electric motors

In the disruptive scenario, the share of permanent magnet motors is expected to decrease to 60 per cent of the market share by 2050, while the share of wound/induction motors increases to 40 per cent of the market share.

VI. Grid

In the disruptive scenario, the undergrounding ratio of the grid is projected to increase proportional to India's expected GDP growth rate (Chaturvedi and Malyan 2022), based on an undergrounding ratio model developed by Leiden University (Deetman et al. 2021). At higher GDP per capita, India is expected to have a larger proportion of its grid underground in the disruptive case.

Figure 24: Undergrounding ratio for India's grid in the disruptive case



Source: Authors' analysis from multiple sources

Material intensity changes: Material intensities for solar PV and wind generation technologies have been collated based on projections by Fraunhofer ISE and Leiden University between 2020 and 2050 (Fraunhofer ISE 2024; Deetman et al. 2021).

The material intensities for electric vehicle motors were collated for current intensities from multiple sources (IEA 2021). Future material demand of magnetic components is assumed to decrease by one per cent per annum.

Material intensity of batteries was collated from data provided by Fraunhofer ISE and Argonne National Laboratory (Winjobi, Dai, and Kelly 2020; Fraunhofer ISE 2024). Material intensity is assumed to be constant till 2050 for lithium-ion technologies, while the material intensity of vanadium flow and sodium ion batteries is assumed to decrease by one per cent per annum.

Material intensity of electrolysers was collated based on projections by Fraunhofer ISE and the International Energy Agency for 2020 to 2050 (Fraunhofer ISE 2024; IEA 2021).

Grid material intensities were collated based on secondary research by Leiden University (Deetman et al. 2021).

For technologies where material intensity trends were not available, material intensity was assumed to reduce by 0.5 per cent per annum.

Demand estimation results: Below is an overview of the results of annual CETM demand estimation for India from 2025 to 2050. The tables provide the total annual demand for minerals in tonnes, at five-year intervals between 2025 and 2050. Table 6 assumes baseline market shares remain unchanged, while Table 7 presents a disruptive scenario with changing market shares based on assumptions outlined in earlier sections.

The depiction in Figure 25, underscores the substantial surge in demand for all six identified CETMs from 2025 to 2050, along with the varying demands for each mineral. Although copper demand remains dominant, the demand for silicon and nickel surpasses that of specialty minerals like lithium, neodymium/REE, and manganese.

Table 6: Annual embedded CETM demand (2025 to 2050) in the baseline scenario (in tonnes)

CETMs	2025	2030	2035	2040	2045	2050
Lithium	4,936	18,087	28,686	40,788	51,730	62,742
Copper	769,257	1,117,873	1,308,537	1,550,239	4,103,001	3,883,172
Neodymium	913	1,516	2,079	3,912	4,922	5,623
Manganese	5,032	17,263	27,529	39,672	49,295	59,043
Silicon	56,467	88,800	111,731	136,094	556,308	587,824
Nickel	35,739	109,988	171,186	258,661	349,974	467,055

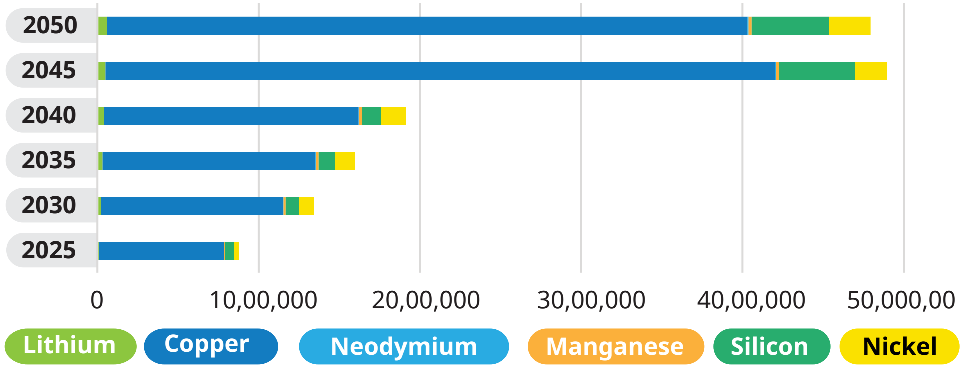
Source: Authors' analysis

Table 7: Annual embedded CETMs demand (2025 to 2050) in the disruptive scenario (in tonnes)

CETMs	2025	2030	2035	2040	2045	2050
Lithium	4,715	17,040	26,488	35,692	43,896	52,193
Copper	769,612	1,121,952	1,310,157	1,567,500	4,126,332	3,946,893
Neodymium	913	1,535	2,256	4,525	6,154	7,482
Manganese	4,637	13,621	18,239	16,704	18,397	19,288
Silicon	54,737	83,330	101,349	119,202	469,399	477,331
Nickel	32,820	91,120	123,988	151,598	195,838	255,676

Source: Authors' analysis

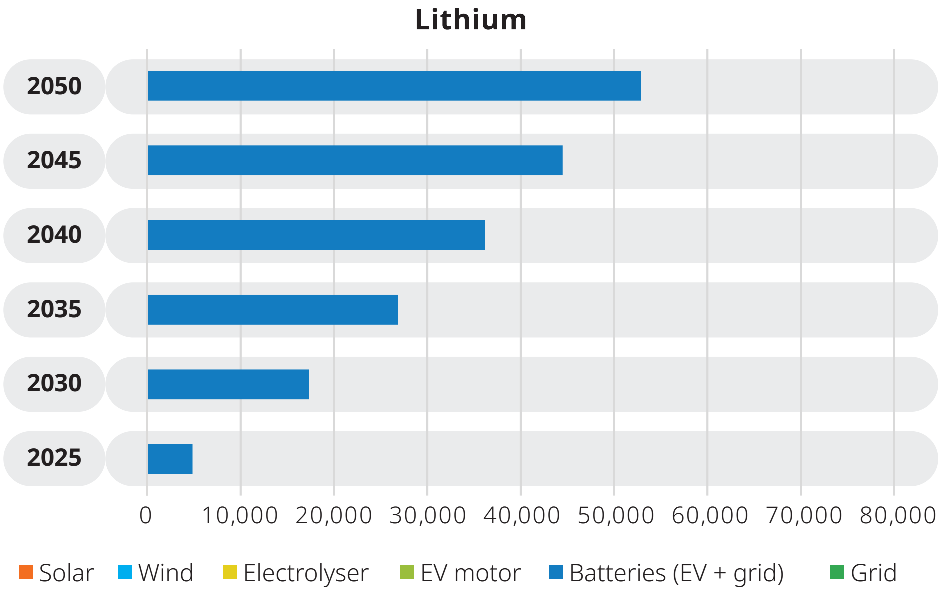
Figure 25: Annual embedded CETMs demand in 2025 and 2050 in the disruptive scenario

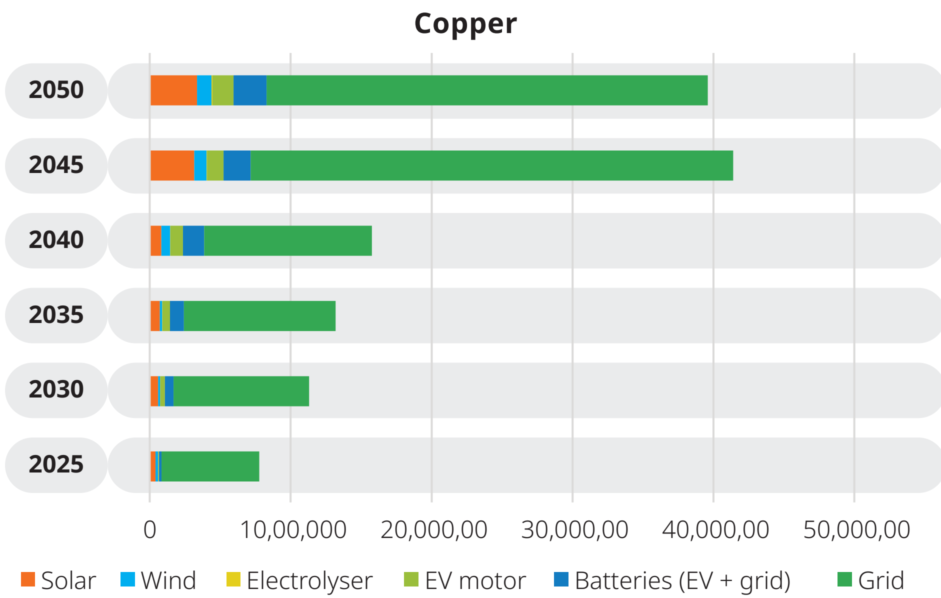


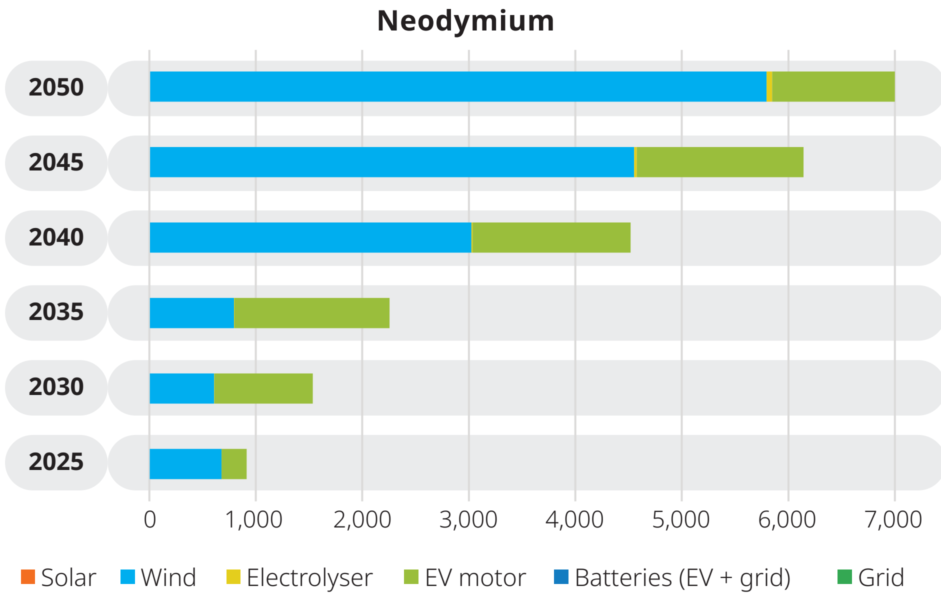
Source: Authors' analysis from multiple sources

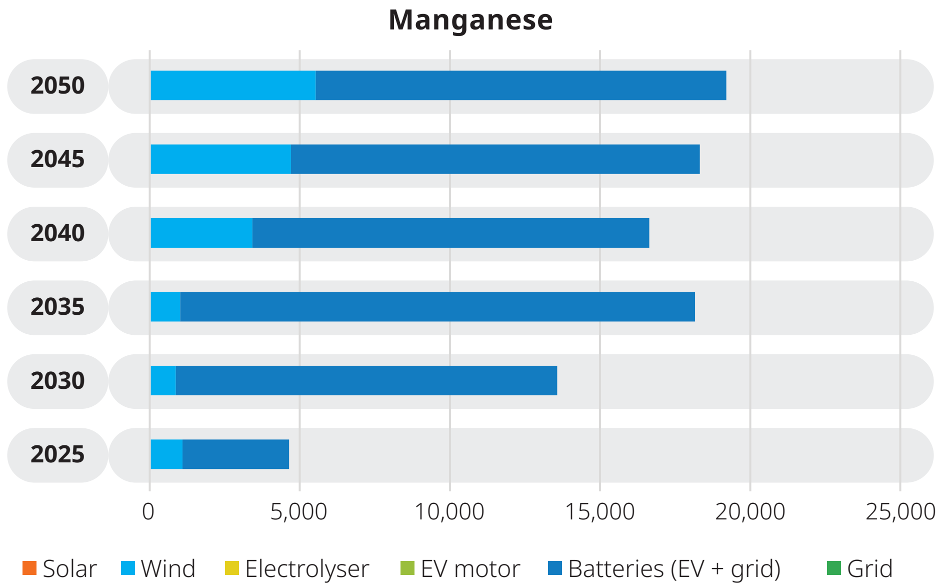
The technology-wise contribution of increased demand for various technologies is provided in Figure 26, in the disruptive scenario.

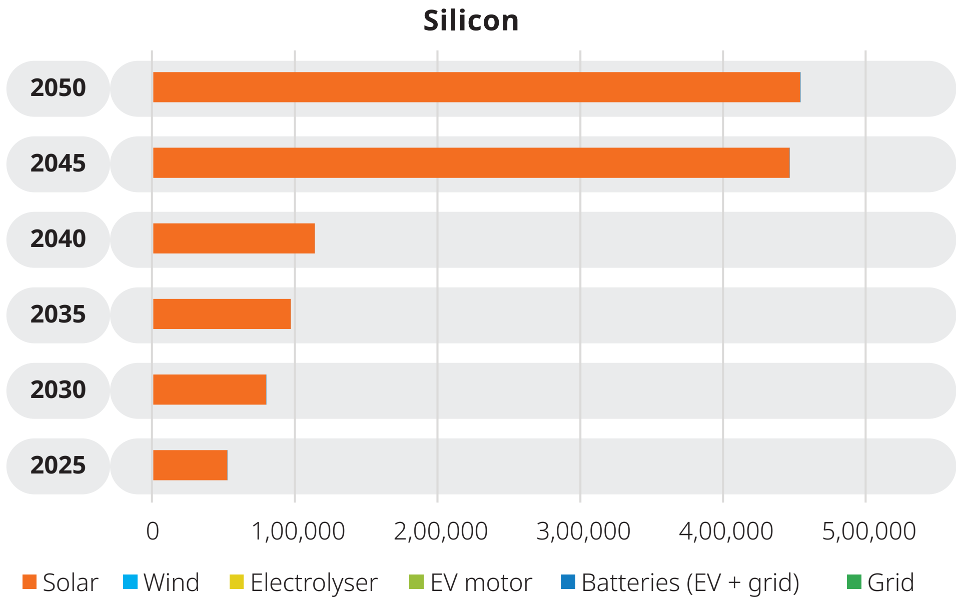
Figure 26: Annual embedded CETMs demand (2025 to 2050) in the disruptive scenario, technology-wise (in tonnes)











Source: Authors' analysis

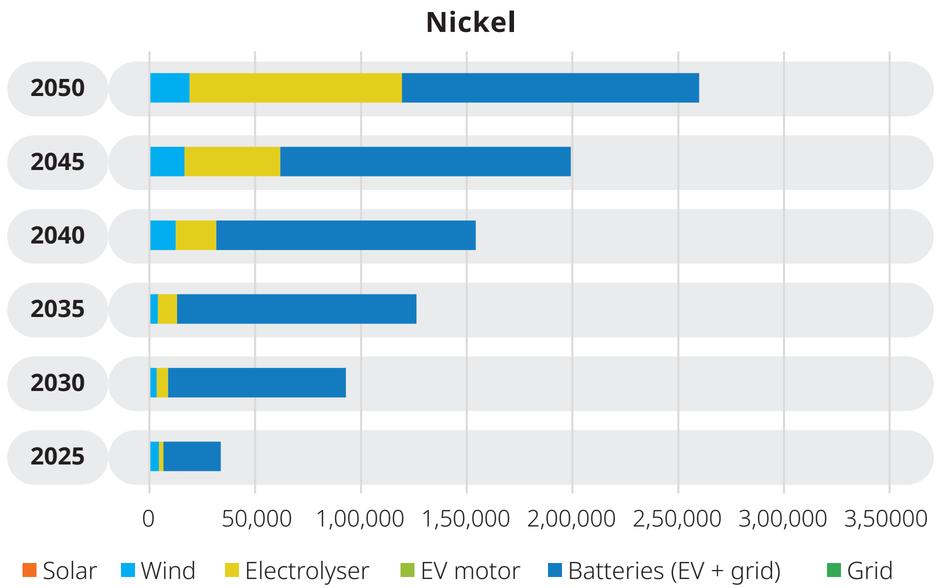
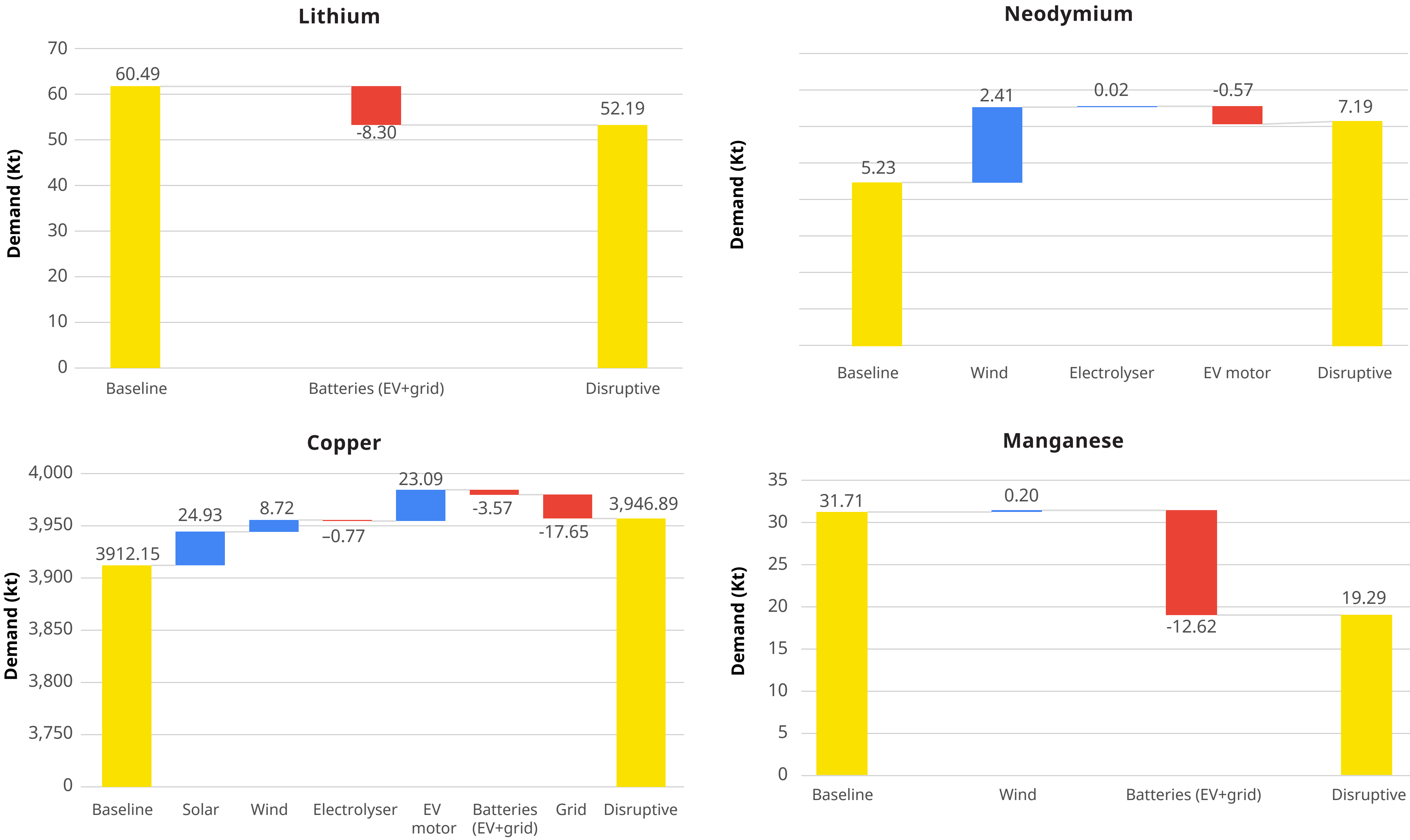
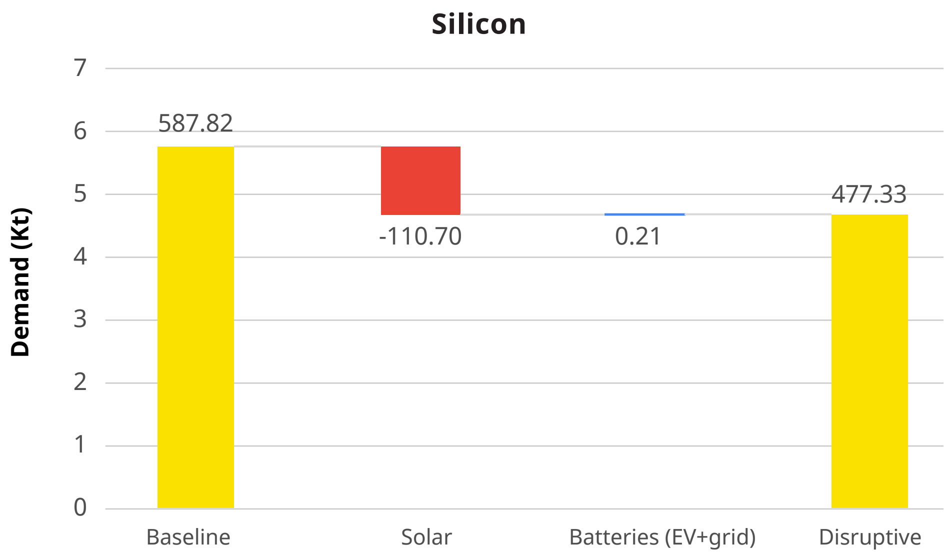
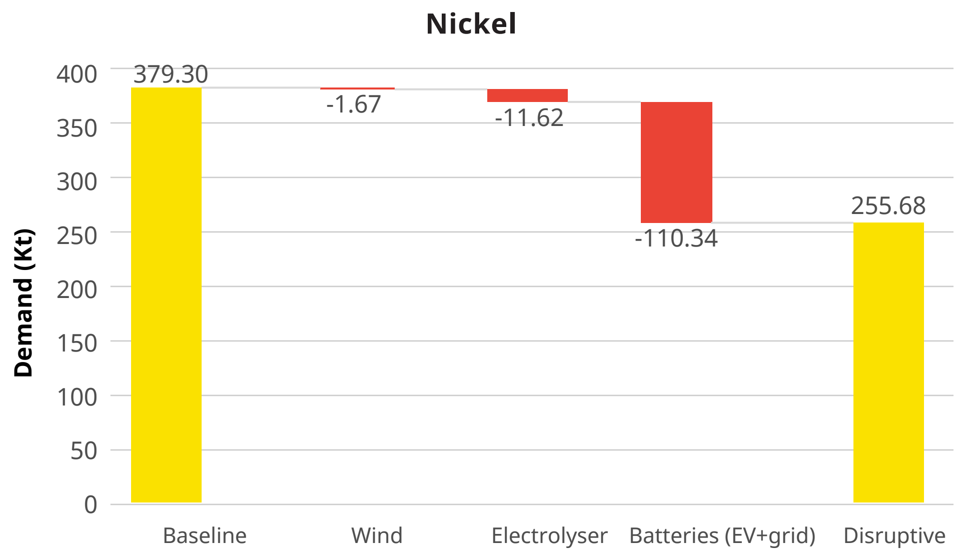


Figure 27: Difference in embedded CETMs demand (2050) between baseline and disruptive scenario, and technology-wise contributions to change in demand





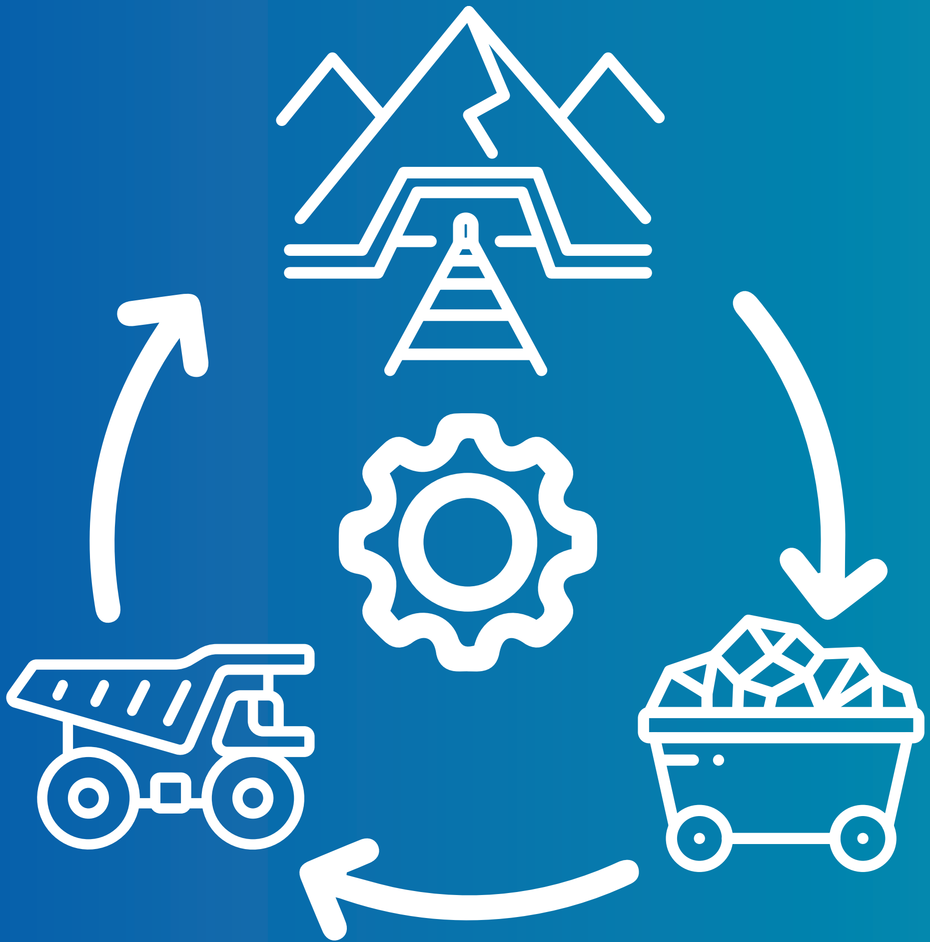


Source: Authors' analysis

SECTION II: CRITICAL ENERGY TRANSITION MINERALS SUPPLY CHAIN

4

SUPPLY CHAIN OF SIX PRIORITY CETMs



4 SUPPLY CHAIN OF SIX PRIORITY CETMs

The chapter attempts to provide a baseline of the CETM industry, focusing on the value chain, supply chain dynamics, ESG concerns, and challenges associated with mineral extraction and processing. It explores the upstream, midstream, and downstream activities of the six shortlisted CETMs, detailing their production, refining, and end-use. Additionally, the chapter addresses the dominant players and countries in the global supply chain, highlighting the significant environmental and social impacts related to mining, and examining the various challenges that complicate efforts to secure responsible and reliable CETMs supply chains.

4.1 Value Chain

The value chain describes a series of stages including all the activities and processes that result in the creation of the finished product. It begins with the mining of the material to its processing and refining until it is ready for use in manufacturing the low carbon technology. Understanding the stages of the value chain is important to appreciate the challenges, and to identify opportunities for intervention.

4.1.1 Upstream of Value Chain

Resources

Copper: Copper is typically extracted via open-pit or underground mining methods. In its natural state, copper exists in two oxidation states (Cu2+ and Cu+), with isotopes like 63Cu and 65Cu. The primary copper ores are chalcopyrite and bornite. As of 2015, global copper deposits contained 2.1 billion tonnes of copper, with undiscovered resources estimated at around 3.5 billion tonnes (USGS 2023). In 2022, copper exploration budgets increased by 21% to $2.79 billion, the highest level since 2014, primarily driven by high market prices (S&P Global 2022a). However, this increase in exploration spending has not resulted in significant new discoveries in recent years. Consequently, the industry continues to focus on older, established deposits.

Lithium: Lithium occurs naturally in two isotopic forms—6Li and 7Li—and is found in various minerals such as spodumene, petalite, lepidolite, and amblygonite. Hard rock or spodumene is the most commonly used source for lithium extraction, accounting for 60% of the global mined lithium supply (Benchmark Source 2023b). It is primarily extracted from brines in Chile and processed into lithium carbonate and lithium hydroxide. Due to the very dilute nature of lithium concentrates, brines are further solar evaporated in large ponds. Direct Lithium Extraction (DLE) is a fast-growing technology in lithium extraction that aims to address the environmental and lead time concerns with other prevalent methods (Cleantech Lithium, n.d.). While there are ample lithium resources in the earth's crust, many are not yet economically recoverable. Owing to continuing exploration, measured and indicated lithium resources have increased substantially worldwide and total about 105 million tonnes (USGS 2023).

Manganese: Manganese (Mn) is the 12th twelfth most abundant element, known for being a hard, brittle, silvery metal. It commonly occurs in minerals with iron, silicon, and laterites. Manganese ores are mainly classified as oxides, silicates, and carbonates. Examples include pyrolusite (MnO_2), braunite ($3Mn_2O_3$, $MnSiO_8$), and rhodochrosite (MnCO3), respectively (Indian Bureau of Mines 2023). Global manganese (Mn) resources are estimated to be around 17 billion metric tonnes.

Nickel: Nickel (Ni) exhibits oxidation states of 3, 2, and 0, and has isotopes including 58Ni, 60Ni, 61Ni, 62Ni, and 64Ni. Some of Earth's nickel originated from meteorites, including a significant impact near Ontario, Canada, which now contributes 15% of global production. Most mined nickel comes from two main ore types: laterites (60%), used for Class II products in steel production, and magmatic sulphide deposits (40%), which provide feedstock for Class I nickel used in battery cathodes. Nickel laterite ore, making up a significant portion of global resources, contains iron and other contaminants such as copper that must be separated (McKinsey 2020). By 2022, land-based resources with a nickel content of 1% or higher were estimated to total at least 300 million tons of nickel, with laterites accounting for 60% and sulphide deposits for 40% (USGS 2023).

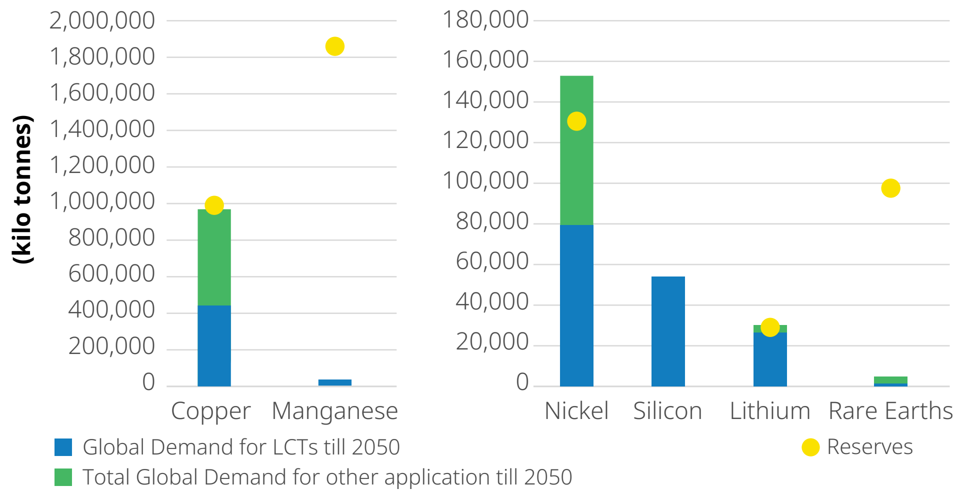
REEs: Rare Earth Elements (REEs), comprise 17 elements including Neodymium, Scandium, and Yttrium. These 17 elements naturally occur together and are classified into two groups based on atomic weight: Light Rare Earth Elements (LREEs) and Heavy Rare Earth Elements (HREEs). Commercially important REE minerals include bastnaesite (a carbonate mineral), monazite and xenotime (both phosphate minerals), and ion-adsorption clays. Neodymium is mainly sourced from the minerals monazite and bastnaesite. Neodymium exists in multiple isotopes (142Nd, 143Nd, 144Nd, 145Nd, 146Nd, 148Nd, 150Nd) and has an oxidation state of +3. Global resources of oxides of rare earth elements (REEs) are estimated to be 20.6 billion metric tonnes, with undiscovered resources projected to add approximately 30 million tons (USGS 2023). However, mineable deposits are less common compared to other elements.

Silicon: Silicon (Si) commonly exhibits an oxidation state of 4 and -4 and occurs in isotopic forms (28Si, 29Si, 30Si). Silicon constitutes 27.7% of the Earth's crust by mass, making it the second most abundant element after oxygen. Silicon (Si) occurs naturally as silica or quartz (SiO_2) and silicates. Common examples of silicon oxide include sand, quartz, rock crystal, amethyst, agate, flint, and opal. Silicate materials encompass asbestos, granite, hornblende, feldspar, clay, and mica. Though silicon itself is abundant, the production of high-purity silicon involves complex and energy-intensive processes. High-purity quartz, often containing impurities like oxides of Fe, Al, K, Ca, and Na, is the raw material for producing metallurgical grade silicon (MGS). High-quality quartz is mined from riverbeds and quartz veins, and enrichment techniques such as milling, washing, size classification, gravity and magnetic separation, and acidic leaching are used to achieve the desired purity.

Reserves and Production

As per the USGS Mineral Commodity Summary 2023, the reserves of the six priority CETMs appear to be more than sufficient to meet the demand from low-carbon technologies even until 2050. However, when the cumulative demand until 2050 for all applications are considered, lithium and nickel reserves fall short. Nickel especially falls short by almost 20 million tonnes. Additionally, an estimate for silicon reserves is unavailable since it is abundantly available in nature.

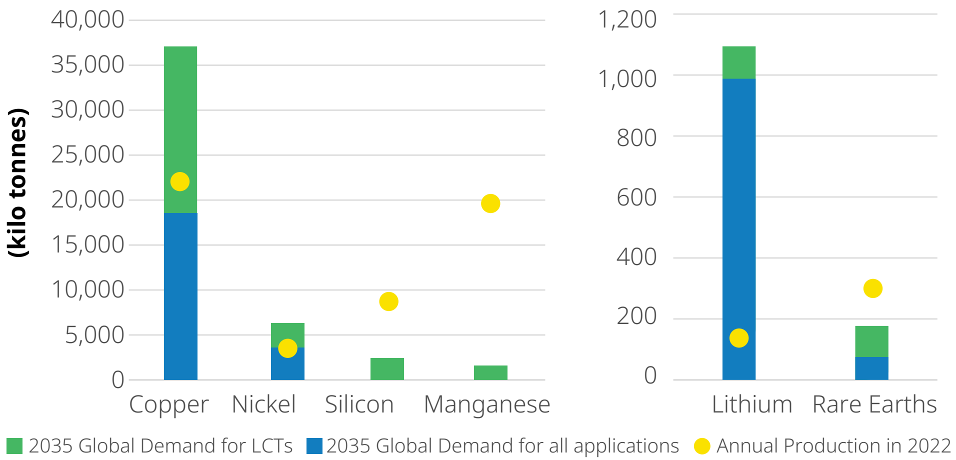
Figure 28: Global cumulative demand till 2050 vs Reserves



Source: (USGS 2023a). Cumulative demand estimated based on values as per IEA Mineral Outlook 2024 Data for 2050 NZE Scenario (International Energy Agency 2024).

The annual production of minerals in 2022 would meet the annual demand for CETMs in 2035, except for lithium and nickel. However, when the overall demand for minerals in both LCT and non-LCT applications are considered, most annual production rates fail to meet the demand. The same cannot be concluded for silicon since a reliable source for the overall global demand estimate could not be identified. Current annual consumption of manganese is around 16 million tonnes globally, while production is around 20 million tonnes (HAlMan, n.d.; USGS 2023).

Figure 29: Annual demand for CETMs in 2035 vs Annual production in 2022



Source: (USGS 2023); Annual demand values as per IEA Mineral Outlook 2024 Data for 2050 NZE Scenario (International Energy Agency 2024).

4.1.2 Midstream of Value Chain

Copper: There are two primary types of copper ore: copper sulphide, which accounts for approximately 80% of production, and copper oxide, which makes up about 20%. Smelting is used to process sulphide ore concentrates which then gets melted and cast into anodes. Solvent extraction is preferred for oxide ores and the solution is used for electroplating. To produce high-purity copper cathodes, the processed copper from the smelter is further refined using electrorefining techniques (Copper Development Association, n.d.). The depletion of less capital-intensive oxide ore bodies has led to a 44% increase in the processing of sulphide ores over the past decade (McKinsey 2023a). The production of refined copper is expected to double between 2020 and 2050, leading to an annual production of 50 million tonnes, with 10 million tonnes of the total originating from copper scrap (International Copper Association 2023).

Copper concentrates are converted into copper cathodes with 99.7-99.9% purity, where the maximum value addition occurs. Miners pay treatment charges (TC) and refining charges (RC) to smelters for processing the copper concentrate into refined metal, offsetting the cost of the ore (Liu and Nguyen 2022). TC/RCs are therefore a crucial revenue source for smelters.

Refined copper is shipped to fabricators, who melt it to produce semi-finished copper and copper alloy products, such as wire, rod, tube, sheet, plate, strip, castings, and powder. These semi-finished products are then further processed by downstream industries (International Copper Association 2023).

Lithium: Hardrock or spodumene concentrate is processed using hydrometallurgical processes involving leaching to produce lithium sulphate solution, and further refined using ion exchange, to produce either lithium hydroxide or lithium carbonate. Lithium from brine concentrates is often processed into lithium carbonate using solvent extraction and precipitation, which is used in EV batteries but is less suitable for high-nickel content batteries that offer higher energy densities and longer driving ranges (The Raw Material Outlook, n.d.). These premium batteries typically require lithium hydroxide, which is more easily processed from hardrock lithium.

The volatility in lithium prices makes it challenging to precisely gauge the value added at the midstream processing level for merchant refiners. Nevertheless, projections and recent studies suggest that the value addition for the lithium processing and refining sector could range from 8% to 37%, with the lower end based on conservative price estimates and the upper end reflecting the exceptional prices seen in 2022 (with 8% based on conservative prices and 37% based on 2022 prices). It's worth noting that contrary to common perception, the primary cost driver is not mining but the availability of processing infrastructure, even with the higher conversion margins (Ewing and Krauss 2023).

The two commercial lithium compounds for LCTs are high purity 'battery grade' lithium carbonate (Li_2CO_3) and lithium hydroxide monohydrate ($LiOH.H_2O$). Lithium hard-rock operations typically cost lower than brines (S&P Global 2019). However, the price hard-rock producers receive for their end-product, usually spodumene concentrate, is significantly lower than that received for lithium carbonate, chloride and hydroxide, which are produced at brine operations (S&P Global 2019). Therefore, for countries with hard-rock deposits (such as Australia and now potentially India), value capture at the processing and refining stage can be critical. Given the recent price trends and high geographical concentration in lithium processing, there is also a growing interest from miners, merchant refiners and lithium producing countries to capture value by taking strategic positions in the midstream segment.

Manganese: The processing route for manganese ore depends on the ore's grade and the impurities present. Ores with over 46% manganese are either sold directly and processed into ferromanganese or silicomanganese alloys by smelting in a blast furnace or an electric arc furnace. Low and Medium-grade ores undergo pyrometallurgical reductive roasting or melting followed by hydrometallurgical processes to produce chemical manganese dioxide (CMD), electrolytic manganese (EM) or electrolytic manganese dioxide (EMD) (Zhang and Cheng 2007).

Significant value can be gained from manganese mining and processing. For example, ferromanganese, which is a combination of manganese and iron, can command prices up to three times higher than manganese ore. Similarly, manganese steel, an alloy of manganese and carbon known for its strength, can be sold for prices up to ten times greater than manganese ore (Shanghai Metals Market, n.d.).

Nickel: Over the past decade, global nickel production has surged by over 65%. Approximately 46% of the finished nickel products worldwide are classified as Class I nickel, with the majority being Class II nickel (Azevedo, Goffaux, and Hoffman 2020). Class I nickel which is of high purity (>99.8% purity) is produced from sulphide ores using hydrometallurgical processes followed by electrorefining. Class II nickel which is of lower purity is produced from laterite ores through pyrometallurgical processes. High Pressure Acid Leaching (HPAL) is another emerging process that is used in the extraction of nickel from laterite ores and has high recovery rates. It utilises high temperatures and pressures in combination with sulphuric acid to separate nickel and cobalt.

To explore the extent of value addition through refining and processing, it is important to note that currently, nickel continues to be a stainless-steel driven market. To serve the EV battery industry, Class I nickel or nickel sulphate (Ni_2SO_4) is required. However, the process to extract sulphate from sulphide ore is more direct and generally lower cost thereby reducing the extent of value addition for LCTs. On Shanghai Metals Market (SMM), high-purity nickel can attract up to 360 times the price of the laterite ores with minimum 1.5% nickel content (Shanghai Metals Market, n.d.).

REEs: Commercially important REE minerals include bastnaesite (a carbonate mineral), monazite and xenotime (both phosphate minerals), and ion-adsorption clays. The primary steps in processing REE ore involve mining, beneficiation, chemical treatment, separation, reduction, and refining. Further processing of REEs typically involves hydrometallurgical processes starting from acid/alkali leaching, which is followed by solvent extraction or ion exchange, and precipitation. It is further refined by electrorefining. When transforming ore into high-purity REE compounds, the current mining and processing operations generally yield low recovery rates, ranging from 50–80%. Some of this inefficiency is due to the low intrinsic value of the resource in relation to the high processing costs (McNulty, Hazen, and Park 2022). High-purity neodymium oxide and neodymium metal attracts 10 to 13 times the price of RE carbonate and RE chloride concentrates on SMM (Shanghai Metals Market, n.d.).

Silicon is extracted from silica in two forms – ferrosilicon and metallurgical grade silicon. Two grades of silicon are mainly used by manufacturers, electronic-grade silicon (high purity) and solar-grade silicon (lower purity). Both these grades of silicon are recovered from metallurgical-grade silicon (Sati, Powell, and Tomar 2022). An essential process is the reduction of high purity quartz (SiO_2) to extract metallurgical grade silicon. The reduction process decreases the number of oxidants by charging the electrons with further purification methods. The most widely used technology for the reduction of SiO_2 is carbothermal reduction (A. Gupta 2022).

While the carbothermal reduction process was invented in the nineteenth century, it remains the most prominent technology. This reduction process requires large quantities of graphite carbon to convert the quartz to Si in electric arc furnaces. Additionally, arc furnaces that extract Si require about 14-16 kWh/kg of energy (PVEducation, n.d.). Higher energy is consumed in extracting purer grades of Si for solar cells in the form of polysilicon. Polysilicon is produced from further refining metallurgical-grade silicon using a chemical process known as the Siemens process or other advanced methods like fluidized bed reactor (FBR) processes. In comparison to high grade silica, silicon metal attracts a value that is 30 times greater. Silicon metal to PV Polisilicon can be 9 times the price and electronic-grade polycrystalline silicon price 18 times more than silicon metal on SMM (Shanghai Metals Market, n.d.).

4.1.3 Downstream Uses

Copper: Copper is an excellent electrical conductor, making it indispensable in the energy transition. It plays a key role in renewable energy technologies (such as wind and solar photovoltaic), the electrification of energy end uses (including heat pumps and electric vehicles), and expanding the grid through cables to meet the increased electrification (International Copper Association 2023). Fabricators melt refined copper to create semi-finished copper and copper alloy products, such as wire, rod, tube, sheet, plate, strip, castings, and powder. These semi-finished products are subsequently used by end-use product manufactures to create cables, connectors, electric motors, transformers, and photovoltaic panels.

Lithium: It is primarily used in battery storage accounting for 74% of its end-use consumption in 2021 (International Energy Agency 2021).

The rapid pace adopted by electric vehicle manufacturers to decarbonise the transportation sector has accelerated the global demand for lithium, earning it the nickname "white gold" in the industry. Lithium-ion batteries are favoured for their high energy density, which allows them to store substantial energy in a compact and lightweight form, driving their market demand.

Lithium-ion batteries use two primary high-purity "battery-grade" lithium compounds - lithium carbonate (Li_2CO_3) and lithium hydroxide monohydrate ($LiOH.H_2O$). Ordinary nickel manganese cobalt (NMC) cathode materials (NMC111, NMC442, NMC532, NMC622) and LFP battery tend to use lithium carbonate, while Ni-rich NMC811, NCA and select LFP cathode materials preferably use lithium hydroxide (Huang et al. 2020).

Manganese: It is crucial in battery production, especially in lithium-ion batteries where Electrolytic manganese dioxide (EMD), which contains a minimum of 90% MnO2 and minimal impurities, is essential to enhance energy density and longevity. Around 90-95% of global manganese production is used in the iron and steel industry to improve strength, hardness, and toughness as a deoxidizer and desulfuriser.

Nickel: Nickel is primarily used in the manufacturing of steel, batteries and electrolysers. Class II grade nickel goes into the manufacturing of steel, while only Class I nickel is suitable for batteries and electrolysers. Nickel is crucial in the production of batteries with NMC cathode chemistries as it increases the energy density and battery life. Two technologies are most prominent in the installed electrolysers capacity: Alkaline Electrolysers (AEL Units) and Proton Exchange Membrane (PEM) electrolysers. Manufacturing of different components of PEM electrolysers requires materials like iridium, platinum, gold, and titanium. These materials are emission-intensive and have limited supply, making the manufacturing process expensive. Nickel is the main component in the manufacturing of Alkaline electrolysers. Nickel has a more diverse supply than the rare earth elements used for PEM electrolysers. Using nickel in alkaline electrolysers makes them 50% - 60% cheaper than PEM electrolysers (Raj, Lakhina, and Stranger 2022) **.**

REEs: REEs are used in the production of storage batteries, electric vehicles and permanent magnets. Neodymium is primarily used as an alloy with iron and boron to create powerful permanent magnets. Neodymium magnets have been scaled up for use in electric vehicle motors and wind turbines due to their high magnetic strength relative to mass. This allows for more efficient power generation and reduces the weight and raw materials needed, minimising environmental impact (IEF 2024).

Silicon: A significant portion is used in alloy production, such as ferro-silicon (iron-silicon) and aluminium-silicon, which are vital for deoxidising steel and making machine tools, cylinder heads, engine blocks, and parts for transformers and dynamos. Silicon effectively remove oxygen from molten steel, thereby preventing the formation of unwanted oxides that can cause defects and compromise the quality of the steel. Ferrosilicon is made in two grades: 50% silicon and 75% silicon. In clean energy technologies, ultra-pure silicon acts as a semiconductor in solid-state devices.

Polysilicon manufacturing requires substantial capital and energy. The solar cell is central to the silicon photovoltaic (PV) value chain. Passivated Emitter Rear Solar Contact (PERC) cells are the most widely used globally. According to the 2022 International Technology Roadmap for Photovoltaic (ITRPV), PERC and similar cells are expected to dominate the market, exceeding 80% by 2025 (Bhambhani 2023).

In 2023, ITRPV estimates projected that silicon heterojunction technology (HJT), and Tunnel oxide passivated contact (TOPCon) cells will capture 19% and 60% of the market by 2033, respectively (Bhambhani 2023). TOPCon is an enhanced version of PERC technology. Each solar cell technology has different capital costs, with PERC estimated at approximately USD 22 million per gigawatt (GW) (Shiradkar et al. 2022).

4.1.4 Recycling and Circular Economy

Valuable minerals used in products or manufacturing scrap to create new products, can be recovered through the recycling process. The recycling rate refers to the percentage of a commodity that is recycled from used products or manufacturing scrap. A higher recycling rate can significantly mitigate supply risks by reducing reliance on newly mined materials, decreasing the environmental impact of extraction and processing and stabilising supply against geopolitical and market fluctuations. High recycling rates contribute to lower operating costs, making recycling economically viable. However, achieving these rates often requires substantial capital investment in advanced recovery technologies.

Advances in recycling technology can enhance the ability to recover CETMs from end-of-life products. Developing and scaling up advanced recycling technologies that can efficiently recover critical minerals from end-of-life products and standardising materials and components to facilitate recycling can help improve mineral supply and decrease uncertainties. Improvements in efficiency and cost-effectiveness of recycling processes can also make a significant impact. Developing an economically viable model that facilitates the efficient collection of e-waste and battery waste can be useful. Implementing policies and regulations that encourage recycling and the use of recycled materials including mandating for recycling rates, incentives for using recycled content, and support for recycling infrastructure development is the key. Besides, increased public awareness about the importance of recycling and proper disposal of electronic waste can ensure more end-of-life products enter the recycling stream.

Recycling of Six Priority Metals

Copper: It faces a relative supply risk rating[1] of 4.3 but boasts a recycling rate exceeding 30%. Globally, copper is among the most recycled metals, retaining its performance qualities through recycling. When scrap copper is received for recycling, it undergoes visual inspection, grading, and, if necessary, chemical analysis. Scrap not immediately required is bale-stored. The scrap is directly melted, sometimes followed by fire purification for increased purity. Chemical analysis is conducted on the molten copper to ascertain its purity level before casting into intermediate shapes like billets, cakes, or ingots for further processing.

The scrap, often purified through electrolysis to achieve desired purity levels, may undergo preliminary fire refining before being cast into anodes. This meticulous recycling process ensures that recycled copper meets quality standards for its diverse applications, contributing significantly to sustainable resource management and reducing reliance on primary copper sources. Over the decade from 2009 to 2018, around 32% of the 26.7 million tonnes of copper used annually worldwide came from recycled sources (International Copper Association 2021a).

Lithium: The recycling of lithium-ion battery (LiB) cathodes involves various technologies, each suited to different types of cathode chemistries. These technologies include hydrometallurgy, pyro metallurgy, and direct recycling which are common to recycling of other minerals as well except silicon. Pyrometallurgical and hydrometallurgical processes can have significant environmental impacts if not managed properly, including the release of hazardous substances. At present, only 3% of lithium demand is fulfilled from recycled sources (International Energy Agency 2024).

Manganese: Although recycling manganese is feasible, it is not as widespread as with other metals. Recycling methods include pyro metallurgical processes, where manganese-containing scrap is melted and refined, and hydrometallurgical techniques, involving the dissolution of manganese from scrap using acids. With the growing use of manganese in lithium-ion batteries, recycling spent batteries has become an essential source of high-purity manganese. Hydrometallurgical processes are particularly useful for recovering manganese from battery scrap, where high-purity manganese is required. The recycling of manganese, especially from complex products like batteries and the requirement of high purity, in applications such as battery-grade manganese, requires advanced technologies and processes that can be technically challenging and expensive to implement.

Nickel: Recycling of nickel is predominantly conducted through pyrometallurgical recovery, an intermediate process that precedes the final extraction and refining stages at hydrometallurgy facilities. The primary advantage of the pyrometallurgical phase is its ability to eliminate undesirable materials such as electrolytes (which contain fluorine), phosphorus, graphite, and plastics. This results in a metal alloy with significantly fewer impurities, enhancing the performance and efficiency of the subsequent hydrometallurgical processes. Consequently, the overall metal recovery efficiency is typically high, exceeding 90%, due to the reduced presence of impurities. The majority of recycled nickel is utilised in the production of new alloys and stainless steel. Recycled nickel made up close to 57% of apparent consumption in (USGS 2023).

1 An integrated supply risk index from 1 (very low risk) to 10 (very high risk). This is calculated by combining the scores for crustal abundance, reserve distribution, production concentration, substitutability, recycling rate and political stability scores.

REEs: It has a high relative supply risk of 9.5 and recycling is rare with a recycling rate of less than 10%. Although recycling and reusing end-of-life REE products is feasible, the processes involved are complex and require significant energy (McNulty, Terry, Nick Hazen, and Sulgiye Park. 2022). Hydrometallurgy is the most common route for recycling REEs considering its effectiveness in selectively dissolving and separating REEs from complex mixtures found in end-of-life products like magnets, batteries, and electronics. At present, only 2% of REEs are recovered through recycling processes, with permanent magnets having a recycling potential of about 7% (Patil et al. 2022). The cost-effectiveness of recycling can also be influenced by market prices for neodymium and the availability of recyclable material.

Silicon Innovations in chemical processes, automation, and circular economy models are improving the efficiency and feasibility of silicon recycling. However, high-tech applications require extremely pure silicon, which can be challenging to achieve with recycled material. Its recycling involves reclaiming and reprocessing by crushing, chemical and physical separation, smelting and refining and casting and re-crystallisation of silicon from various waste sources, notably electronics and solar panels. However, currently the amount of silicon recycled worldwide is insignificant. Recycling silicon helps conserve natural resources by reducing the need for virgin silicon production, which requires significant energy and raw materials which is also the case in recycling manganese as it is generally more energy-efficient than extracting and processing new ore, leading to lower energy consumption and reduced carbon footprint.

4.2 Supply Chain

This section details the geographical distribution of mineral resources, reserves, processing facilities, and component manufacturing facilities. Upstream discusses the countries with significant mineral reserves and resources. It highlights geopolitical considerations and mineral resource concentration. Midstream focuses on the processing and production facilities that turn raw minerals into refined materials. This includes smelters, refineries, and intermediate processing plants. Downstream looks at how countries and companies consume refined minerals in the production of end products, particularly in clean energy technologies necessary for NZE transition.

4.2.1 Upstream of Supply Chain

Resources

Copper: Chile and Peru have accounted for 43% of the global copper found since 1990 (S&P Global 2023). As per the latest study in 2014 by USGS, assessing global undiscovered copper resources, South America holds the highest share (21%) followed by South Central Asia and Indochina (15%), North Central Asia (14%) and North America (13%). But currently in the world the majority of identified copper resources are shared between South America (39%) and North America (23%) (International Copper Study Group 2020).

Lithium: The "Lithium Triangle" of Argentina, Bolivia and Chile, contain more than half of the world's lithium resources. Bolivia has the largest lithium resource in the world, followed by Argentina, and Chile. Australia, has the 4th largest resources (USGS 2023). Recently, significant lithium discoveries have been made but are yet to be categorized as resources or reserves. Noteworthy examples include Iran's discovery of deposits equivalent to 8.5 million tons of lithium carbonate and India's identification of 5.9 million tons of inferred lithium resources (Financial Tribune 2023; Press Information Bureau 2023b).

Manganese: Land-based manganese resources are large but irregularly distributed. Although the world's largest manganese resources are found in South Africa, accounting for approximately 70% of these resources, significant deposits also exist in Australia, Ukraine, and United States. The resources in United States are very low grade and have potentially high extraction costs (USGS 2023). South Africa's Kalahari Manganese Field is considered the largest and richest manganese deposit in the world. In India, manganese resources were estimated to be 503.62 million tonnes in 2020 (Indian Bureau of Mines 2021).

Nickel: Nickel is naturally abundant, primarily recovered from iron/nickel sulphide minerals like pentlandite and garnierite. The most commonly found nickel sulphide mineral, pentlandite, is primarily extracted from iron and magnesium igneous rocks located in Russia, South Africa, Canada, and Australia. These four countries collectively hold over 50% of global nickel resources. But Indonesia holds the largest share with approximately 40% of global nickel reserves. However, the declining discovery of new sulphide deposits in conventional mining areas has prompted exploration efforts to expand into more challenging regions such as east-central Africa and the subarctic (Calvo et al. 2016).

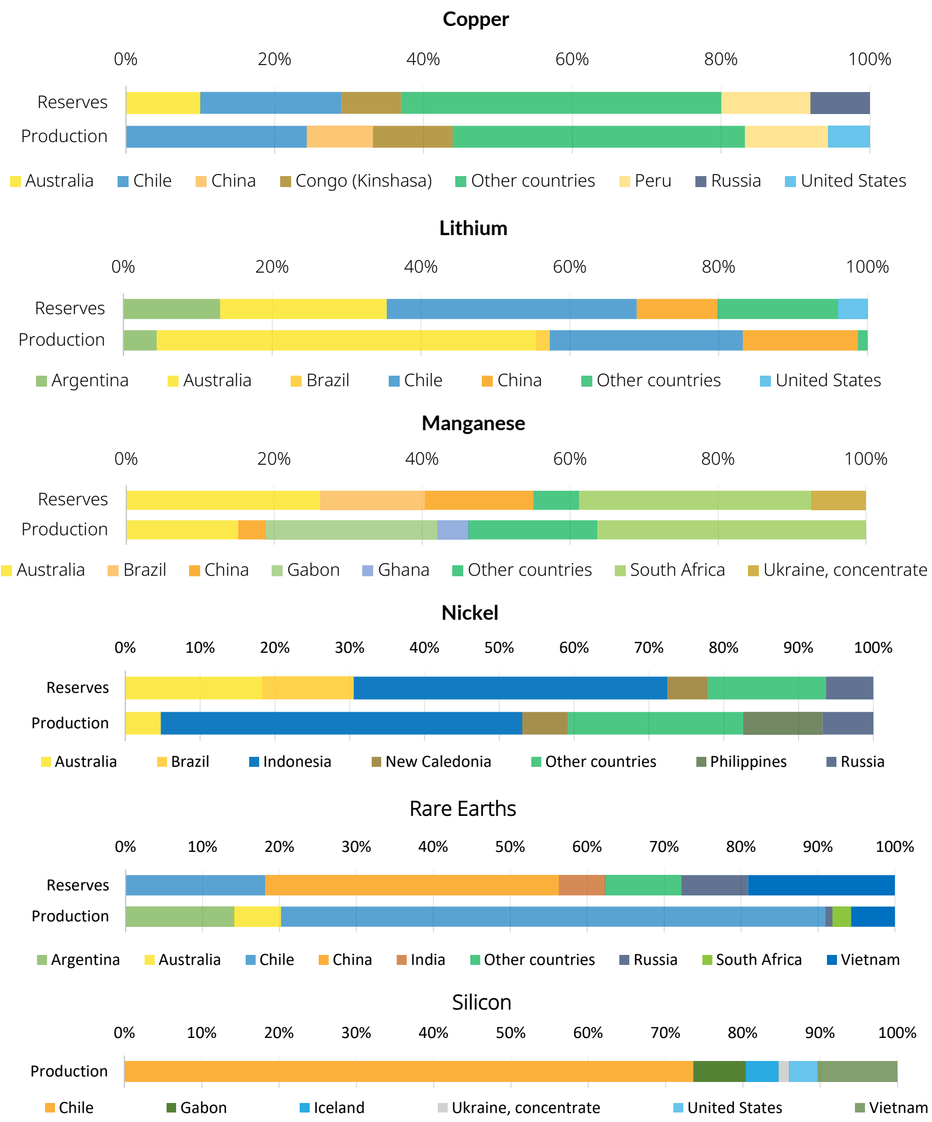
REEs: Significant REE deposits are located in Bayan Obo (China), Mountain Pass (USA), Mount Weld (Australia), and ion-adsorption deposits in Southern China (Yin and Song 2022). In the US measured and indicated resources of REEs are estimated to be 3.6 million tonnes and in Canada it is estimated to be over 14 million tonnes.

Silicon: As of 2023, silicon resources are abundant, with silica (SiO_2), the mineral from which silicon is derived, being one of the most common minerals in the Earth's crust. Economically viable silicon reserves are found in several countries, with China, Russia, Brazil, and the United States holding significant deposits (USGS 2023).

Geographical Concentration and Diversity

Copper: The geographical diversity of copper production is broader than that of other CETMs. In 2022, the top four producing countries were Chile (24% of global production) Peru (10%) Democratic Republic of Congo or DRC (10%) and China (9%) (USGS 2023). Despite a decline in the average copper ore grade in recent years, Chile remains the world's largest producer and holds a fifth of the global economically recoverable copper reserves.

Figure 30: Share of countries in global reserves and production



Source: (USGS 2023)

Lithium: Lithium production, on the other hand, is highly concentrated, with 90% coming from Australia, Chile, and China (USGS 2023). Most of the world's exploitable lithium reserves are in salt-lake brine found in the United States of America, China, Chile, Argentina and Bolivia and processed into lithium carbonate and lithium hydroxide. While there are ample lithium resources in the earth's crust, many are not yet economically recoverable. This creates a tight market despite the geological abundance, as current production is limited and concentrated in a few countries.

Manganese: South Africa leads in reserves and exports, while China is a significant producer and refiner. Major producers include China, South Africa, and Australia, with South Africa holding the largest reserves and leading exports (USGS 2023). In 2021, South Africa exported $2.9 billion worth of Manganese (The Observatory of Economic Complexity, n.d.). China is a major producer and importer, refining 97% of the global supply. After importing and beneficiating manganese ores, China produces various manganese alloys and other products. China (57%), India (14%), and Ukraine (5%) are the leading producers of manganese alloys (USGS 2023).

Nickel: Indonesia and the Philippines dominate nickel production, contributing 45% of the global output. Currently, nickel-containing ores are extracted in more than 25 countries worldwide. Their dominance in nickel production is expected to grow in the coming years (USGS 2023). Countries like Canada, Russia, and South Africa primarily mine sulphide-type deposits, while Indonesia, the Philippines, Brazil, Cuba, and New Caledonia focus more on laterites. Due to their geological formation, equatorial regions are the primary locations for laterite-type deposits and mines. In Australia, both laterite and sulphide mining operations are carried out. Collectively, these nine countries hold about 75% of global nickel reserves (USGS 2023).

REEs: China dominates both production and reserves, though there is growing interest in projects in Australia, Canada, and the United States. The top producers are China, USA, and Burma (Myanmar), with the largest reserves in China, CIS countries (including Russia), Brazil and Vietnam. While China remains the largest producer of neodymium, there is increasing interest in neodymium projects in countries like Australia, Canada, and the United States.

Silicon: China is the largest producer, accounting for nearly 68% of global production. China, Russia, Norway, and Brazil are the leading producers of silicon (USGS 2023). In 2022, China alone accounted for nearly 68% of the global silicon production. However, the production of steel, the primary application for ferrosilicon, declined by 4% compared to 2021. This decline was due to supply chain disruptions from the Russia-Ukraine conflict and intermittent lockdowns in China due to the COVID-19 pandemic. While silicon reserves are ample in most major producing countries relative to demand, there are no quantitative estimates available (USGS 2023).

Other Trends

1. **Economic Viability and Market Tightness**: Despite ample geological reserves, the economic viability of extracting certain minerals like lithium and manganese remains a challenge. For example, while lithium is abundant in the Earth's crust, only a fraction of these reserves is currently economically recoverable, leading to supply tightness. Manganese and silicon, though widely available, are subject to production and market volatility due to geopolitical and economic factors.
2. **Declining Ore Grades**: The average grade of copper ore has declined, particularly in Chile, the world's largest producer. This trend necessitates more significant investments in mining technology and efficiency to maintain production levels.
3. **Shifting Dominance in Specific Minerals**: The dominance of laterite deposits, primarily mined in equatorial regions like Indonesia and the Philippines, is shifting global production dynamics for Nickel. While China remains the largest producer of REEs, there is an emerging interest in

developing REE projects in other countries, such as Australia and Canada, to diversify supply chains.

4. **Impact of Global Events**: The production of certain minerals, such as silicon, has been affected by geopolitical events like the Russia-Ukraine conflict and China's COVID-19 lockdowns, disrupting supply chains and impacting global production levels.
5. **Resource and Supply Chain Security**: The concentration of production in a few countries for minerals like lithium, rare earth elements, and nickel raises concerns about supply chain security, prompting efforts to diversify sources and invest in alternative projects globally.

These trends highlight the critical balance between geological abundance and economic viability, the importance of geographic diversity for supply chain security, and the ongoing challenges posed by declining ore grades and geopolitical risks.

4.2.2 Midstream of Supply Chain

Copper: China, the largest copper refining nation, accounts for 36% of smelting and 35% of refining capacity respectively (and an even higher share for actual smelting/refining), despite making up just 7% of mined copper capacity (S&P Global, 2022). China's dominance in copper processing is expected to grow, driven by its substantial share of global refined copper consumption, which rose to 54% in 2021. After China, Chile and DRC have the next highest share of copper refining worldwide.

Lithium: China, Chile, and Argentina are the top countries in lithium refining, with China holding approximately 60% of the world's lithium processing capacity. Chile and Argentina follow, accounting for around 29% and 10%, respectively, where lithium from brines is processed domestically into lithium carbonate (Kevin Brunelli, Lee, and Moerenhout 2023). Although Australia is the world's largest lithium producer, it processes only a small fraction domestically. According to the Australian Bureau of Statistics, 85% of the value of Australian lithium concentrate was exported to China for processing every month in 2021 (Australian Bureau of Statistics 2022). By June 2022, this export figure had reached 97%, underscoring the global dependence on China for lithium processing. China's processing capacity is expected to more than triple by the end of the decade, solidifying its dominant position in the global lithium supply chain.

Manganese: China is responsible for 90% of global manganese refining (IRENA 2023). There are only two refineries outside China that produce battery-grade manganese sulphate - one in Japan and one in Belgium. In India, Manganese Ore India Limited (MOIL) established a plant in Bhandara district, Maharashtra, with a capacity of 1,000 tpa. Later it has undertaken capacity expansion of the plant to 2,000 tpa in view of the good demand for EMD in the domestic market. This plant produced 1,070 tonnes and 925 tonnes of EMD in 2020-21 and 2019-20, respectively (Indian Bureau of Mines 2021).

Nickel: Nickel ores are mined in about 33 countries and are smelted or refined in about 30 countries. However, three countries namely Indonesia, China and Japan are responsible for more than 50% of nickel refining. While in the case of China, interest in nickel refining is mainly driven due to rising demand for stainless steel and non-stainless applications such as LCTs (backward linkages), in Indonesia it is driven by resource availability (forward linkages). So far, China is the largest nickel consumer and according to statistical data, China's demand for nickel in 2020 has reached 1.31 million tons.

REEs: China has been dominating the refining sector of REEs, consistently accounting for almost 90% of global refined REEs production. Malaysia and Vietnam have a significant share in the rest of the refining capacity.

Silicon: In 2022, China accounted for about 70% of global silicon processing capacity. The top producers of silicon metal, in descending order, are

China, Russia, Norway, and Brazil, where quartzite is directly processed into ferrosilicon and silicon metal (USGS 2023).

4.2.3 Downstream of Supply Chain

In low-carbon technologies (LCTs) downstream activities typically involve the manufacturing, assembly, and integration of components into final, market-ready products. Similar to upstream and midstream, there is high geographical concentrations in component manufacturing.

Solar PV: In 2021, the manufacturing capacities at every stage of the solar PV value chain, namely module, cell, wafer and polysilicon manufacturing, were concentrated in a few countries. China had the highest share, particularly in wafer manufacturing. Europe, Southeast-Asia, Europe, North America, India and Japan were other regions that held significant shares in the manufacturing capacities (International Solar Alliance 2023).

Wind turbines: In 2020, the total nacelle manufacturing capacity was 120 GW (GWEC 2022). China, Europe, the USA and India held major shares of the manufacturing capacities (58%, 18.5%, 10% and 8.5% respectively). China and the EU had the highest share of the manufacturing capacity of generators, blades, and gearboxes. While the USA had a small share of the manufacturing capacity of blade and generator (Tyagi et al. 2023).

Batteries: Battery cell–component manufacturing is dominated by China, Japan, Republic of Korea and the USA (Federal Consortium for Advanced Batteries 2021). More than 90 percent of manufacturing capacity of cathode material, anode material, and separators is concentrated in only these three countries. As of 2020, battery manufacturing was concentrated in China and this trend is expected to continue over the coming years.

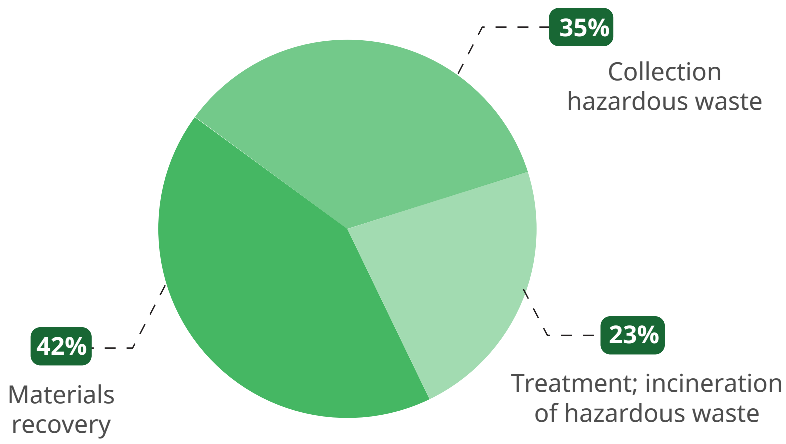
Electrolysers: The electrolyser-manufacturing plants are concentrated in Canada, the USA, the EU, China, and Japan. India too has a PEM and Alkaline Electrolyser manufacturing plant. The concentration in the manufacturing of electrolysers is largely due to the limited access to sophisticated manufacturing technology and expertise in the process (Tyagi et al. 2023).

4.2.4 Recycling

The global capacity for recycling batteries is around 180 kilo tonnes per annum. China accounts for almost 50% and is expected to retain its dominant position considering the large amount of additional capacity it has announced. Although, a majority of the companies involved today are independent refiners, there is an increasing interest among a number of players from battery manufacturers, original equipment manufacturers, miners and processors to enter the market, especially in Europe.

Employment potential in the recycling sector: Batteries form a critical component of the hazardous waste segment in India. An insight into the existing employment in the hazardous waste collection, treatment, and increasingly popular material recovery sector can help to draw parallels for the battery recycling sector. Data from the latest Periodic Labour Force Survey (PLFS) for 2021-22 reveals the *material recovery* sector has the highest share of employment at 42 per cent in the considered waste sector, followed by the collection segment as shown in Figure 31. The treatment of waste category forms the smallest share. With an expected accelerated rise in the quantum of spent batteries, the relatively smaller share of the workforce for the treatment of hazardous waste can prove to be a critical gap that needs to be accounted for.

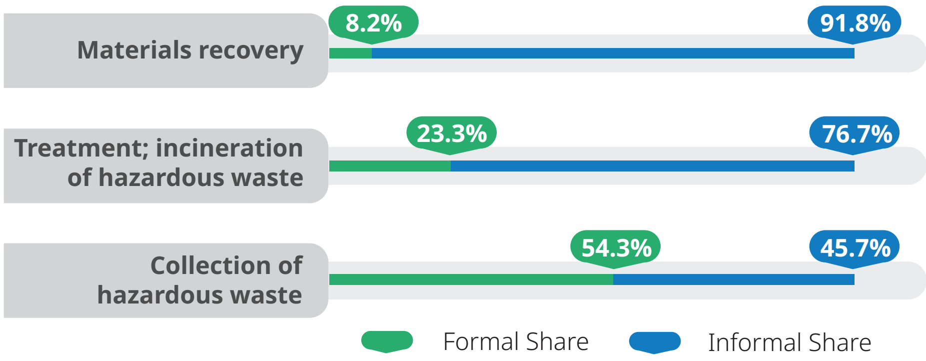
Figure 31: Employment share in hazardous waste sector in 2021-22



Source: Authors' construction based on (Ministry of Statistics and Programme Implementation 2022)

Discussions on waste management invariably highlights the role of the informal sector. According to the guidelines from the 15th and 17th International Conference of Labour Statisticians (ICLS), the PLFS database allows for a clear distinction between formal and informal enterprises. Analysis of this data reveals that 72.3 percent of total employment falls within informal enterprises. Notably, two out of the three industry divisions in this sector show a significant concentration of employment in informal setups, as illustrated in the accompanying Figure 32. This high concentration of employment in a few industry divisions, coupled with the reliance on informal enterprises, suggests an increase in waste accumulation. Furthermore, the dominance of the informal sector means that waste is often treated or segregated under hazardous environmental conditions due to improper handling practices, as these processes are typically carried out with minimal regulation or oversight (Biswas and Singh 2020).

Figure 32: Employment share of formal and informal enterprise in hazardous waste sector in 2021-22

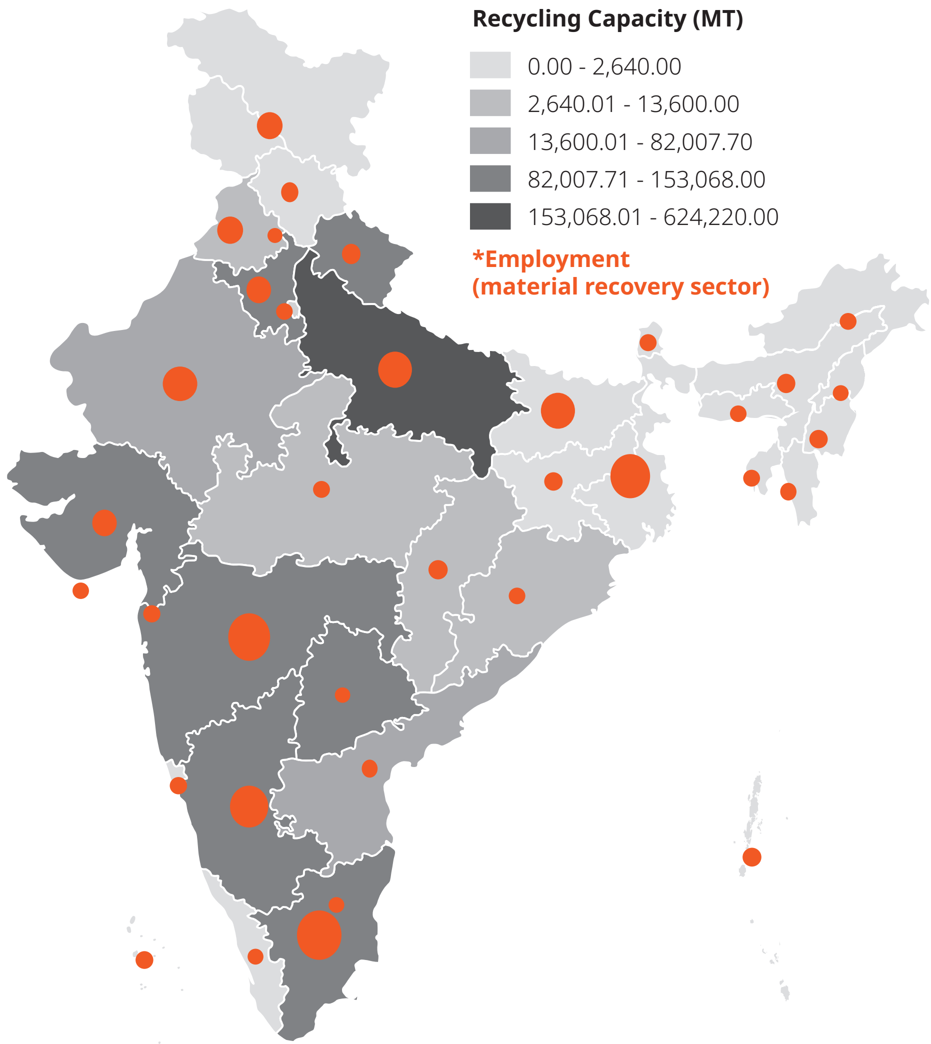


Source: Authors' construction based on (Ministry of Statistics and Programme Implementation 2022)

The use and development of recycling technologies is greatly influenced by the informal sector. For the development and uptake of recycling, the informal sector is an invaluable resource. Its collection efficiency is much higher than the formal sources and if leveraged well it can provide the critical mass needed for efficient recycling technology deployments (Moerenhout et al. 2022). The treatment and recycling sector is poised for growth with the introduction of Extended Producer's Responsibility (EPR). In the EPR regime, role of the recyclers is paramount as it provides final proof of the waste being recycled. The effectiveness and efficiency of the recycling sector can be increased, and a more sustainable future can be built by utilising recycling technology in the informal sector.

According to the data, on the list of E-waste recyclers as per the authorisation issued by SPCBs/PCCs under E-waste (Management) Rules, 2022 (as of 08-06-2023). In India, as shown in Figure 33, the state with the highest E-waste recycling capacity is found to be Uttar Pradesh (624219.47 MT), followed by Gujarat (158604.92 MT) and Haryana (157187.67 MT). The material recovery sector is operational in 12 states within India and the highest employment in

Figure 33: State wise e-waste recycling capacity and employment



Source: Authors' construction based on (Ministry of Statistics and Programme Implementation 2022)

this sector has been observed in the State of Tamil Nadu (32962) followed by Karnataka (4378) and West Bengal (4255).

4.3 Environmental, Social, and Governance (ESG) Practices

Environmental, Social, and Governance (ESG) practices in CETM mining and processing are increasingly vital in shaping the future of sustainable development. 70% of cobalt reserves are located in high to very high ESG risk contexts, mainly in the DRC, which faces notable social and governance challenges. 98% of cobalt resources with high social risks also are located in areas with high governance risks. In contrast, 65% of lithium's resources are located in areas of medium to very high water risk, presenting significant environmental concerns, particularly in South America. 53% of lithium resources with high environmental risks were also located in areas with high governance risks. Platinum was highlighted as having the highest overall risk, with 84% of its reserves found in regions with high ESG risk, concentrated in Southern Africa. (Lèbre et al. 2020).

As the global demand for CETMs surges, driven by the transition to renewable energy and advanced technologies, there is a growing imperative to ensure that these resources are extracted and processed in a manner that minimizes environmental impact, respects human rights, and fosters economic inclusion.

4.3.1 Environment

The metals and mining sector has several environmental impacts including on land, water, air, climate and biodiversity. It causes emission of greenhouse and toxic gases, water stress and pollution, disruption and loss of biodiversity and creation of large amounts mine tailings and other waste. The sector contributes 10% of global greenhouse gas emissions, with steel production accounting for 7%, aluminium production for 2%, and the remaining emissions arising from the production of other metals, including the mining and processing of critical materials (KU Leuven 2022). Energy consumption and greenhouse gas emissions per tonne are particularly high for CETMs like aluminium, cobalt, nickel, silicon, and rare earth elements.

Environmental challenges

Upstream: Exploration activities like geophysical surveys, drilling, trench blasting, exploration camp development, and road construction can lead to sediment runoff, disrupt wildlife and communities, and cause fuel spills. Similarly, mining operations—including mine and well construction, infrastructure development (such as power lines, pipelines, and roads), mine camp construction, waste rock piles, ore stockpiles, waste impoundments, and ore blasting—can result in surface and groundwater contamination, CO2 emissions, dust and fumes, erosion, increased demand for water and power, and declining species populations (Potts et al. 2018).

Different mining methods have distinct environmental impacts. For instance, open-pit mining is prone to groundwater contamination due to the large surface area of the pits and the chemicals used. In contrast, underground mining can lead to subsidence, damaging the surface environment and lowering the water table due to dewatering. The extraction of brines can significantly reduce water availability for other purposes, such as drinking, irrigation, and industrial production in water-stressed areas.

Post-operation mines can continue to impact the environment and communities due to the widespread neglect of proper mine closure practices. Mine closure, which is necessary when a mineral resource is depleted or mining is no longer financially viable, involves decommissioning infrastructure and rehabilitating land disturbed by mining activities. Rehabilitation efforts include geotechnical and geochemical stabilization and restoring ecosystems to a sustainable state. Failure to properly close mines can lead to severe environmental degradation, harm to local communities, financial liabilities, and long-term hazards. Consequences include severe soil erosion, reduced land fertility, dust and particulate pollution, and acid mine drainage (AMD), which can contaminate groundwater and surface water, posing ongoing risks to community health and safety.

Midstream: Midstream processing activities, such as smelting and refining, account for the majority of greenhouse gas emissions in the mining sector. During stages like milling, grinding, and ore concentration—using methods such as chemical leaching, flotation, electrowinning, or gravity separation—chemicals can be released into surface waters, along with emissions of sulphur dioxide and heavy metals like lead, arsenic, and cadmium (Potts et al. 2018).

High-Pressure Acid Leach (HPAL) technology which is commonly employed for nickel processing faces challenges in terms of its environmental impacts (Ribeiro, Holman, and Tang 2021). The most widely used technology for the reduction of SiO_2 is carbothermal reduction to produce silicon (A. Gupta 2022). This process has however often been criticised for emitting gases containing large quantities of dust. Lithium either exists as hard rock or brine. However, traditional extraction methods from both have vast environmental impact.

Downstream: Manufacturing activities present significant environmental risks, including emissions from fuel and energy consumption, air pollution from direct emissions, and high-water usage. Efforts are being made to adopt cleaner technologies and innovative processes in mineral processing and manufacturing to enhance energy efficiency, lower emissions, and reduce water consumption (Potts et al. 2018).

Environmental impacts along the supply chain: As the largest producer of lithium, primarily extracted from spodumene in Western Australia, Australia accounted for about one-fifth of global lithium production in 2021. However, the country faces challenges such as the higher emissions intensity of hard rock lithium mining compared to brine operations, and public backlash due to pollution concerns. These concerns include the production of sulfuric acid, waste, and the mixing of metals with water during rainfall.

In Portugal, the village of Covas do Barroso, recognised by the UN for its agricultural heritage and landscape, is strongly opposing plans for an opencast lithium mine. Residents fear the project will cause irreversible damage to their agricultural heritage and environment. Despite receiving conditional approval from Portugal's Environment Agency, local leaders and residents are pursuing legal action to block the project (Bayley 2023). The situation has been further complicated by the resignation of Prime Minister Antonio Costa, who is accused of graft and influence peddling related to two lithium projects, including the one in Barroso, as well as a hydrogen project. This has led to uncertainty about the future government (Demony and Goncalves 2023).

A similar situation is unfolding in western Serbia, home to one of Europe's richest lithium reserves. Thousands of people are protesting the government's plans for mining due to concerns over potential environmental damage.

With the depletion of high-grade manganese ores and the rising demand for manganese, there is an increased reliance on low-grade ores for extraction. However, this shift is associated with greater environmental impacts. The primary concern is water contamination, particularly in developing countries where effluents and leachates are often discharged into waterbodies without proper treatment (Nkele, Mpenyana-Monyatsi, and Masindi 2022).

Rare earth element (REE) ores contain metals that, when combined with chemicals in leaching ponds, can contaminate air, water, and soil. Of particular concern is the presence of radioactive thorium and uranium in these ores, which pose significant health risks. For every tonne of rare earth extracted, approximately 2,000 tons of toxic waste are generated. Although China holds only 35% of the world's REE reserves, it dominates the market due to its lax environmental regulations and low-cost, high-pollution methods that give it a competitive edge (Nayar 2021). The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas provides a framework for companies to assess and address potential environmental impacts throughout their supply chains (OECD 2016).

4.3.2 Social

Mining can lead to habitat destruction, community disruptions, community resettlement, human conflict, and worker accidents. Labourers, who are often on the front lines of mineral extraction, must be treated fairly and have their rights protected to promote more sustainable and ethical mining practices globally. According to OECD Due Diligence Guidance, businesses in the minerals supply chain should conduct risk-based due diligence to uphold human rights and avoid contributing to conflict through their sourcing decisions (OECD 2016). The OECD also offers a framework for companies to identify, mitigate, and address the risks of child labour in their mineral supply chains. The extraction of these minerals frequently depends heavily on artisanal mining, particularly in isolated or difficult-to-reach places. For local communities, especially those with few job options, it might be a source of revenue. Addressing Artisanal and Small scale mining (ASM) will require a collaborative approach. These alternative approaches will need to be explored by those with decision making powers in government, the companies in the supply chain, especially OEMs, along with those helping set standards in international organisations, financial and lending organisations, and civil society organisations. The cross-sectorial OECD Guidelines for Multinational Enterprises on Responsible Business Conduct (RBC) (OECD 2023a) and the OECD Due Diligence Guidance for RBC (OECD 2018) cover comprehensive social, environmental and governance risks such as human rights, labour rights, bribery, consumer interests, taxation, disclosure, science and technology, competition, etc. These standards can be used by companies to conduct risk-based due diligence concerning wider ESG risks.

There are various social concerns that can be considered in mining activities which are listed below:

1. **Health and safety** – As mining is a dangerous occupation, and CETM mining can be particularly hazardous due to the use of toxic chemicals and the presence of unstable ground conditions. Miners are at risk of accidents, injuries, and illnesses, and they may also be exposed to dust, fumes, and other pollutants that can have long-term health effects. The pollutants in the air and water around mines can also have a negative impact on the population living in the vicinity.
2. **Working conditions** - Mining can be a physically demanding and stressful occupation, and CETM mining can be even more so due to the long hours, rotating shifts, and remote locations of many CETM mines. Miners may also be exposed to discrimination and harassment, and they may have difficulty forming unions or bargaining for better wages and working conditions.
3. **Child labour** - The mining of CETMs is occasionally linked to child labour, particularly in developing countries. Children may be forced to work in dangerous and exploitative conditions, and they may be denied education and other opportunities.
4. **Displacement and Loss of Livelihoods** – Mining often leads to the loss of land, livelihoods, and cultural ties for local communities. Although rehabilitation and resettlement practices aim to address these issues by ensuring fair compensation and support, including the restoration or enhancement of livelihood opportunities, provision of alternative land, and development of essential infrastructure, instances of displacement due to mining continue to persist.
5. **Indigenous rights** - The mining of CETMs can also have a negative impact on indigenous communities, who may be displaced from their land or lose access to their traditional resources. Indigenous peoples may also be subjected to discrimination and harassment, and they may have difficulty asserting their rights to their land and resources.

Table 8: Health hazards for labour associated with mining

Hazards	Description
Biological	Miners are exposed to a variety of bacteria, viruses, and parasites, as well as venomous wildlife and insects. These biological hazards can cause a variety of health problems such as infectious diseases, skin and eye problems, etc.
Physical	These hazards constitute a broad category of actions that includes vibration, loud noise, heat and humidity, and radiation that can cause ailments such as overexertion and physical trauma
Chemical	Miners are exposed to a variety of chemicals such as silica dust, heavy metals, organic solvents, acid & bases and pesticides. The effects of chemical exposure can vary depending on the type of chemical, the amount of exposure, and the individual's health.
Psycho-social	Psycho-social health hazards are the non-physical aspects of work that can have a negative impact on a worker's mental and emotional health which includes various concerns about job demands, low job control, lack of role clarity, poor organisational management, inadequate reward and traumatic events. The effects can vary depending on the individual and specific hazard.
Ergonomics	Despite the growing mechanisation of mining, there is still a sizable amount of physical handling. The majority of occupational diseases in the mining industry still fall under the category of cumulative trauma illnesses, which frequently cause long-term disability.

Source: Authors compilation

Social impacts along the supply chain: Several instances highlight the challenges faced by labourers in the mining industry. In Peru, a major exporter of copper, miners have protested against low wages and poor working conditions. Notably, in 2019, a group of miners staged a hunger strike to demand better pay and benefits. In Australia, where mining is a significant employer, concerns have been raised about the industry's impact on indigenous communities. A 2017 report by the Australian Government's Productivity Commission found that while Indigenous people were more likely to be employed in the mining sector compared to non-indigenous people, they were also at a higher risk of injury or death on the job.

Chile, a key player in global lithium production with its rich Atacama salt flats, faces significant local and environmental opposition despite producing about 61% of the world's lithium carbonate, essential for LFP cathodes. The country has experienced serious concerns from local communities and environmental groups about the equitable distribution of benefits and environmental impacts.

The mining of lithium and copper in Chile has also fuelled a broader movement advocating for a new constitution that emphasizes environmental protection and the recognition of Indigenous rights. The proposed constitution seeks to introduce stricter environmental regulations, holding mining companies accountable for any environmental damage they cause (Rostás and MacKenzie 2022).

In the DRC, which holds two-thirds of the world's cobalt production, child labour is rampant. According to the International Labour Organization, an estimated 40,000 children work in cobalt mines in the DRC, often in dangerous and exploitative conditions, and are denied the opportunity to receive an education. Globally, it is estimated that 168 million minors are engaged in child labour (International Labour Organization 2015).

A 2023 report by the Business and Human Rights Resource Centre in London documented 102 cases of alleged human rights abuses across various stages of the supply chains for critical CETMs, including lithium, copper, manganese, nickel, and rare earth elements (REEs). These cases span from exploration to mining and processing, with Indonesia reporting the highest number of allegations (27), followed by Peru (16), and the DRC (12). Many developing countries rich in copper, such as Peru, and those abundant in nickel, like Indonesia and the Philippines, increasingly rely on Chinese companies for mining and processing investments. These companies often operate with fewer regulatory standards to prevent human rights violations abroad. The report indicated that 42% of these cases occurred in the Asia-Pacific region, 27% in Latin America, and 24% in Africa, with over a third involving labour rights violations (Business & Human Rights Resource Centre 2023). Another report by the Helen Kennedy Centre in the UK highlighted the Chinese government's systematic exploitation of Uyghur labour in global supply chains, particularly in the production of polysilicon and other minerals (Murphy and Elimä 2021).

Child labour: Child labour in mining being a particularly serious issue. Children are often forced to work in dangerous and unhealthy conditions, and are denied the opportunity to go to school to get an education, Factors contributing to child labour in mining include poverty, lack of access to education, and family pressure. Poverty is a primary driver, forcing families to send their children to work to supplement household income. Lack of access to education exacerbates the problem, as children who do not attend school are more likely to be employed in mining. Furthermore, family pressure plays a significant role, with parents often relying on their children's income to survive. In some cases, children are lured by the promise of high wages or the opportunity to learn new skills, only to find themselves in exploitative situations.

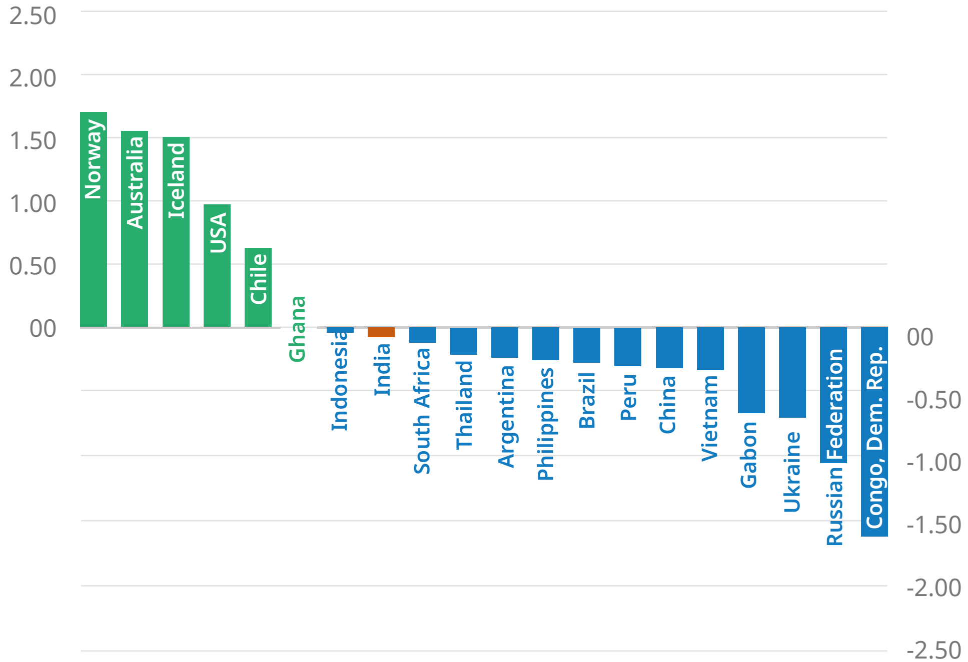
Addressing child labour in mining requires a multifaceted approach. OECD report on Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas provides a framework for companies to identify, mitigate, and account for the risks of child labour in their mineral supply chains (OECD 2016). Legal frameworks must be strengthened and enforced to protect children's rights and ensure that mining companies adhere to ethical practices. Further, "Practical actions for companies to identify and address the worst forms of child labour in mineral supply chains" report by OECD indulges deep into this critical issue of child labour (OECD 2017). Based on the findings from the global reports, there is a need for governments and international organisations to collaborate to improve access to education and provide financial support to families, reducing the economic necessity for child labour. Initiatives like the International Labour Organization's conventions on child labour and various corporate social responsibility programs aim to mitigate these issues, but their implementation and enforcement are crucial for real progress.

Additionally, raising awareness about the detrimental impacts of child labour in mining is vital. Consumers, companies, and policymakers must understand the human cost of the minerals used in everyday products, such as electronics and electric vehicles. Ethical sourcing and supply chain transparency can pressure companies to adopt better practices and avoid materials produced through child labour.

4.3.3 Governance

Governance encompasses the institutions, laws, and regulations through which authority is exercised in a country. It involves the processes by which governments are selected, monitored, and replaced, the government's capacity to effectively formulate and implement sound policies, and the respect that citizens and the state have for the institutions that govern their economic and social interactions (World Bank Group, n.d.-b). In the mining sector, governance includes adherence to these laws and regulations, the procedures for managing risks, and ensuring transparency within the supply chain. However, examining the risks in the supply chain of CETMs reveals several instances of bribery and corruption, which can significantly disrupt the functioning of the system (OECD 2023a).

Figure 34: Average governance scores of major producing countries



SOURCE: (Kaufmann and Kraay 2023)

The Worldwide Governance Indicators (WGI) project constructs aggregate indicators of six broad dimensions of governance namely, Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption (World Bank Group, n.d.-b). The six aggregate indicators are based on over 30 underlying data sources reporting the perceptions of governance of a large number of survey respondents and expert assessments worldwide. The governance scores range from -2.5 to 2.5, with -2.5 being the weakest and 2.5 being the strongest (Kaufmann and Kraay 2023).

A comparison of average governance scores across the six WGI indicators was undertaken. The scores were calculated for the top five mineral producing countries for each the six shortlisted CETMs reveals that 13 out of the 19 countries have weak governance scores. India, with a score of -0.07 ranks 8th from the top. However, the disparity between the best and worst-performing countries in governance scores is striking.

Countries with the strongest governance scores, such as Norway and Iceland, play a significant role in silicon production, while Australia ranks among the top five producers of lithium, manganese, nickel, and REEs. On the other hand, countries with the weakest governance scores, like the DRC, Russia, and Gabon, are major producers of CETMs. The DRC is the third-largest producer of copper, Russia holds a significant share in global nickel and silicon production, and Gabon is the second-largest producer of manganese. China, which dominates the mining and processing of these critical minerals, also has a weak governance score, ranking sixth from the bottom.

4.4 Challenges in the Supply Chain

This section delves into the current and emerging challenges faced by the mineral extraction and processing industries, including the geographical concentration of resources, technological barriers, environmental concerns, declining ore quality, and geopolitical risks. It will also address industry-wide efforts to diversify supply chains and improve extraction technologies.

4.4.1 Geographical Concentration

China's stronghold over the global supply chains for critical minerals such as copper, lithium, nickel, manganese and REEs places it in a highly strategic position, with significant implications for global trade, geopolitics, and the transition to clean energy. It is set to maintain its dominance in copper smelting, refining, and consumption in the medium term, accounting for 56% of refined copper consumption, 48% of refined copper production, and 43% of smelted copper globally in 2022. China's advancements suggest it could produce up to one-third of the world's lithium by 2025. This underscores the importance of ensuring resilient supply chains for these critical minerals. Some of the major areas of China's dominance are:

- China continues to dominate the global copper market, accounting for the majority of refined copper consumption, production, and smelting. This dominance is likely to persist in the medium term, underscoring China's critical role in the global copper supply chain.
- China is also on track to significantly increase its production of lithium, potentially producing up to one-third of the world's supply by 2025. Despite efforts by the US and EU to reduce reliance on China, especially in midstream processing, it is unlikely that these efforts will succeed in the short term, given China's established capabilities.
- In nickel, China historically dominated refining, but Indonesia's 2020 export ban on nickel ore has shifted some of this dominance. With Indonesia now contributing a significant share of global refined nickel and driving much of the global growth in nickel production, the balance of power in nickel refining is evolving. However, China remains influential through its investments in Indonesia's downstream processing capacity.
- China currently dominates the global extraction and processing of REEs. In 2022, China was responsible for 70% of global REE production and processed nearly all Heavy REEs and 85% of Light REEs. This concentration underscores the importance of ensuring resilient supply chains for these critical minerals.
- China is responsible for 90% of global manganese refining. There are only two refineries outside China that produce battery-grade manganese sulphate: one in Japan and one in Belgium. China, however, dominates this market, producing 97% of the global supply.
- US and EU are trying to reduce China's dominance in the lithium supply chain but in the short term, it is unlikely, especially in midstream processing.

Challenges for Other Countries

- The US, Bolivia, and Argentina face challenges in scaling up their own lithium production due to the uncertainties surrounding the development of Direct Lithium Extraction (DLE) technologies. This technological uncertainty further entrenches China's dominance in the lithium supply chain in the short term.
- The global market dynamics in these critical minerals highlight the urgent need for alternative sources and processing capabilities outside of China. However, developing these alternatives will require significant time, investment, and technological innovation.

4.4.2 Technological Barriers and Complexities

The supply for Rare Earth Elements (REEs) remains constrained due to the geographical concentration of production, prompting various countries to invest in REE mining and production development. But the primary challenge lies in scaling up the mining and processing operations of REEs across the entire value chain to meet the growing demand, despite ample known rare earth resources available to satisfy the requirements of the energy transition.

Moreover, the metallurgy involved in rare earths, encompassing separation, metal production, casting, and magnet production, is highly complex, posing a technological barrier for new entrants into the market. Similar is the case for manganese, as the production of high-purity manganese is complex and requires customisation for different ore types, making it challenging to diversify the supply chain. Nonetheless, China has developed significant expertise and knowledge in this area (International Energy Agency 2023a).

4.4.3 ESG Concerns

Ensuring sustainable and responsible practices meeting Environmental, Social, and Governance (ESG) standards, is not only important in protecting people, communities, and the environment but is essential for reducing the risk of disruptions ultimately contributing to a more responsible and reliable supply of critical minerals.

Currently, mining operations, particularly those involving critical minerals, pose severe environmental and social challenges. These issues are compounded by frequent labour rights abuses, highlighting the human cost of mineral extraction. Cultural heritage is another casualty of mining operations, as seen in Portugal and Serbia, where local communities strongly oppose mining projects due to concerns over environmental damage and the loss of cultural identity. Governance issues further complicate the environmental and social impacts of mining. Weak regulatory frameworks and political instability in some countries increase these challenges. The lack of robust governance mechanisms in many regions makes it difficult to address the negative impacts of mining effectively. However, the amount of CETMs needed for the future is insignificant in comparison to the amount of fossil fuels mined today. It is projected that the total amount of CETMs needed until 2040 is 30 million tonnes, while in 2021 alone, 7.5 billion tonnes of coal was extracted from the ground (IEA 2020a; International Energy Agency 2021). Additionally, for every gigawatt of a clean energy technology installed, millions of tonnes of CO_2 can be avoided (IEA 2020b). Although mining for CETMs is not entirely emission-free, it is negligible compared to the emissions from burning fossil fuels, making them a key component of the transition to a low-carbon future.

4.4.4 Declining Ore Quality

Declining ore quality affects the efficiency and cost-effectiveness of mining operations, necessitating greater investment, technological innovation, and strategic planning to maintain and expand production in response to global demand. Low-grade ores require more sophisticated technology and processes to extract usable materials, which adds to the challenge of scaling up production to meet rising demand.

Copper Production in Chile: Chile, the world's largest copper producer, is facing challenges due to declining ore quality. Chile's copper ore concentrate grades have dropped by 30% since 2005, leading to a 5.4% production decline in 2022. This decline in ore quality means that more quantity of raw material must be processed to extract the same amount of copper, increasing production costs and operational difficulties. The aging of deposits and the need for significant investment to maintain production levels are directly tied to this decline in ore quality.

Lithium Production in China: China plans to become the world's second-largest lithium producer, overtaking Chile within the next five years. The government supports new lithium mining capacity development to reduce import reliance, with 24 projects underway. Although half of China's current production is from brines, future projects will focus on hard rock mining. Despite these plans, China faces challenges, such as insufficient domestic reserves to meet demand, leading to continued reliance on imports. Domestic resources are often low grade and scattered, complicating extraction and increasing environmental harm. Illegal mining also presents challenges, and crackdowns could reduce domestic supply. These factors make it difficult for China to meet its ambitious production goals.

5

SUPPLY AUGMENTATION NEEDS AND TRENDS IN INVESTMENTS AND PRICING

5 SUPPLY AUGMENTATION NEEDS AND TRENDS IN INVESTMENTS AND PRICING

In an increasingly interconnected global economy, the dynamics of mineral supply, investment strategies, and pricing mechanisms have evolved significantly. This chapter explores the global mineral markets, with a particular focus on emerging pricing and investment trends and other influential factors shaping the industry.

With the rise of clean energy installations, the demand for critical raw minerals has surged, making them a focal point in the mining and metals markets (DeCoff et al. 2022). Supportive global policies have spurred increased investments by mining companies in critical minerals development. Strengthened cash flows and the momentum behind the clean energy transition have boosted spending on exploration activities. For instance, investments in lithium development rose by 20% to 30% from 2021 to 2022, while investments in copper and nickel development increased by up to 50% (IEA 2023b).

However, price volatility in critical raw minerals has been a persistent issue due to supply chain bottlenecks and geopolitical concerns. This volatility underscores the need for financial instruments like spot transactions, futures contracts, and forward contracts to hedge against price risks.

We begin this chapter by examining the price trends for six shortlisted CETMs, providing insights into recent fluctuations and long-term patterns that influence market stability. Following this, we delve into global investment trends in mining and processing, highlighting shifts in capital flows and strategic investments that are driving the industry forward. For instance, increased agreements between OEMs, manufacturers, and miners are expected to lead to greater market concentration, potentially driving prices up by reducing buyer choices and new market entrants.

Contracting and financing practices are crucial for the successful execution of mining projects. We explore the complexities of business-state and investor-state agreements, emphasising how these frameworks impact the operational and financial landscape of the sector. The bankability of contracts and agreements is also addressed, shedding light on how financial viability and risk management affect investment decisions.

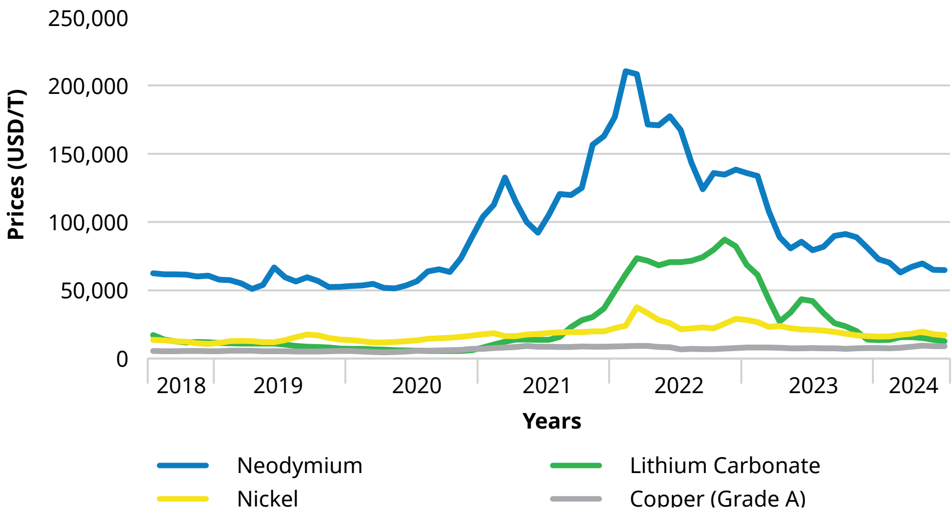
Furthermore, this chapter investigates the factors impacting mineral prices, with a particular focus on geopolitical developments and the influence of environmental, social and governance (ESG) considerations. These elements are increasingly shaping trade patterns and market behaviour, presenting both challenges and opportunities for stakeholders.

5.1 Price trends for six shortlisted CETMs

The pricing trends of these six shortlisted CETMs reflect a complex interplay of supply and demand dynamics, geopolitical influences, and market fluctuations. These trends highlight the need for strategic planning and risk management in navigating the evolving mineral markets.

Copper: Copper markets have experienced significant unpredictability in recent years due to variable mining rates in countries like the US, China, Chile, and Peru, with decreasing ore grades and political unrest further disrupting supply chains and leading to price volatility.

Figure 35: Variability in prices of critical minerals



Source: (Trading Economics, n.d.)

Lithium: The demand for lithium in electric vehicle production has surged, driving global prices, with companies like Stellantis NV securing long-term supply agreements, while market fluctuations, influenced by factors like China's dominance and geopolitical tensions, have seen prices rise and fall, notably recovering due to increasing electric vehicle sales and supportive policy frameworks.

Manganese The manganese market faced uncertainties and depressed prices from 2018 to early 2020 due to increased production in Africa, expanded silicomanganese capacities in China, higher ore shipments from South Africa, and COVID-19 disruptions, but saw price volatility driven by resumed steel production and high battery-grade manganese demand.

Neodymium: It faces unpredictable prices due to supply chain issues and geopolitical risks from major producers like China, the largest exporter of rare earth elements, whose policy changes significantly impact prices, highlighting the need for supply chain resilience and risk management strategies.

Nickel: Between 2017 and 2022, nickel demand surged 40% due to clean energy transitions, yet geopolitical tensions and supply chain disruptions caused price fluctuations. Russia's invasion of Ukraine in 2022 spiked nickel prices from $25,000 to $100,000 per ton, prompting a week-long suspension of trading on the London Metal Exchange (Fastmarkets 2022), despite increased production efforts in Indonesia and China to meet global demand

Silicon: Silicon prices have fluctuated significantly due to production cuts in China, which produces 64% of global silicon (Bloomberg 2024). These fluctuations are especially impacted by seasonal factors and electricity curbs in Yunnan province, causing delays in new production facilities and affecting the automotive and electronics industries.

5.2 Global investment trends in mining and processing

Investment needs for 2030: By 2030, an annual augmentation of $300 billion to $400 billion per year ($3-4 trillion) in investments encompassing mining, refining, and smelting is anticipated (Creamer 2023). This includes funding for exploration, ongoing projects, and new ventures. This projection represents a 50 percent increase compared to the previous decade, amid a backdrop of declining mining investments in recent years (from approximately $260 billion in 2012 to about $150 billion in 2019, constituting a decline of approximately 40 percent). Moreover, capital will need to be redirected towards new materials, with investments in copper expected to double and investments in lithium anticipated to surge eightfold (McKinsey 2023b). As countries and companies actively diversify their raw material supply portfolios, the quest for strategic access to these essential resources is poised to continue, fostering a more resilient and sustainable global economy.

Recent Investment Trends: Recent years have seen a notable uptick in investments directed towards lithium, nickel, manganese, neodymium, and silicon mining and production. In 2022, global investment in lithium mining projects surged to $4.67 billion, up from $1.93 billion in 2021 and global investments in, nickel and silicon mining and processing projects exceeded $10 billion and $2 billion (Shofa 2023; IANS 2022). In 2021 alone, global investments in manganese projects soared to $1.2 billion, marking a substantial increase from $800 million in 2020 (Hua and Wexler 2023) and the global investment in neodymium projects surged to $2 billion, up from $1 billion in 2020. Several factors contribute to this surge in investment, including the escalating demand, growing scarcity, and the imperative to secure long-term supplies. This surge in investment augurs well for the global economy, ensuring sufficient supply to meet escalating demand. Nevertheless, it's worth noting that these mineral markets still grapple with volatility, raising the possibility of sharp price hikes in the future.

Investments by Geography: The majority of investments in lithium mining are being directed towards projects in Australia, Chile, and Argentina, which collectively hold the world's largest lithium reserves (USGS 2023). While South Africa remains the focal point of manganese investment as the largest global producer, there is a growing interest in manganese projects in other nations such as Australia, China, and India. The majority of these investments have been directed towards Indonesia and Australia, which possess the world's largest nickel reserves, as well as the Philippines, which has robust nickel processing facilities. While the majority of neodymium investment is centred in China, the world's largest producer, there is growing interest in neodymium projects in other countries like Australia, Canada, and the United States. While the majority of silicon metal investment remains concentrated in China, the world's largest producer (Indonesia Business Post 2023), there is a burgeoning interest in silicon metal projects in other regions such as the United States, Europe, and India.

Investment trend and challenges: The capital required to establish a medium-sized quartz sand beneficiation plant typically ranges from 1 to 5 million USD (Shirley 2023). Notably, in 2022, start-ups focusing on commercializing silicon materials for battery anodes raised over 0.5 billion USD (Blois 2022). Meeting the global lithium requirements by 2035 will necessitate the opening of an additional 74 mines, considering projected recycled lithium volumes, and the sector requires over $116 billion in investments by 2030 to meet automaker and policy goals (Benchmark Source 2023c). To meet the projected nickel demand by 2035, an additional 72 mines need to be built (Atkins 2023). Furthermore, approximately $66 billion in investments is required to produce battery-grade nickel by 2030. The focus of these investments is on developing new mines and expanding existing operations (Benchmark Mineral Intelligence 2023).

However, regulatory uncertainty and an outdated concession system are currently hindering the expansion of the mining sector in Chile. Under the current system, concession holders are not required to develop the minerals or make any investments, leading to a low exploitation rate of the country's concessions. Changes are anticipated in 2024, with plans to introduce investment targets and revoke concessions from holders who fail to develop them. Additionally, in May 2023, Chilean lawmakers approved a new mining royalty bill, which includes an increased tax rate on large copper producers. While a third of the funds raised by this tax will be allocated to social programs, the higher tax rate may deter new investments (Cambero 2022).

In the Democratic Republic of Congo (DRC), Africa's largest copper producer, copper production saw a 15% increase in 2021, and the country holds the second-largest copper reserves globally. However, production in the DRC faces significant challenges. From July 2022 to April 2023, the CMOC Group faced export restrictions from its copper-cobalt mine in the DRC due to a dispute over royalty payments with the state-owned mining company Gécamines (Mining Technology 2023).

This trend is expected to continue in the coming years, driven by several factors including increasing demand for nickel from the electric vehicle industry, the geographical concentration of nickel suppliers, rising nickel prices, and the potential for nickel to be used in other applications, such as fuel cells and wind power, which is boosting investor confidence due to the anticipated growth in demand for these technologies in the future. However, for neodymium, there is also a growing interest in developing substitutes, beyond investment in mining and production. These substitutes could mitigate reliance on neodymium in certain applications and contribute to stabilising the neodymium market.

Chinese investments: From 2019 to 2022, Chinese companies have invested a staggering $4.5 billion to acquire stakes in lithium mines, predominantly located in Latin America (Pickrell 2022). Bolivia, with the largest lithium resources globally, signed a $1 billion agreement with Chinese firms in 2023 to apply Direct Lithium Extraction (DLE) methods (Wischer and Villasmil 2023). However, significant lithium production has yet to begin. Argentina, known for its investor-friendly environment and low royalty rates, is set to surpass Chilean production by the end of the decade, attracting substantial foreign direct investment in several projects. Chinese investment in Indonesia's nickel production has also surged, surpassing investments from other countries by a significant margin. In the past decade, Chinese companies have poured $14.2 billion of investment into nickel production in Indonesia. In comparison, the combined total investment from Australia, Canada, and South Korea is just $1.5 billion (Ho and Listiyorini 2022). China aids Indonesia's shift from stainless steel processing to mixed hydroxide precipitate (MHP) production through the provision of labour, materials, and technology.

Electric Vehicles (EV): Further, downstream EV makers have often expressed concerns that lithium midstream processing and refining continues to remain one of the biggest bottlenecks for the EV supply chain. As a result, EV makers are increasingly looking to secure lithium supplies directly. In May 2023, Tesla announced its plan to build a new lithium hydroxide refinery on the Texas Gulf Coast, making it the first US EV maker to refine its own lithium and create backward linkages (Bellan 2023). In January 2023, General Motors announced it would invest USD 650 million in Lithium Americas to help the developer progress their Thacker Pass lithium mine in Nevada (General Motors Company 2023).

Investments through Mergers and Acquisitions: Copper witnessed high merger and acquisitions (M&A) activities in the last few years. Rio Tinto's acquisition of Turquoise Hill Resources (USD 3.1 billion), which included Mongolia's Oyu Tolgoi mine, was a notable example. BHP's acquisition of OZ Minerals (USD 6.4 billion), which was completed in May 2023, is another example (IEA 2023b).

5.3 Contracting and Financing practices

Several types of contracting and financing practices exist in the supply of critical minerals. They respond to varying consideration of mineral producers, OEM or intermediate manufacturers in the supply chain. The primary considerations are:

1. Price Stability: Buyers ensuring predictable pricing to manage costs and revenues effectively.
2. Supply Security: Buyers guaranteeing a reliable and consistent supply of critical minerals to avoid disruptions in production.
3. Quality Assurance: Buyers maintaining high standards for the quality of minerals to meet industry specifications and regulatory requirements.
4. Financial Viability: Producers securing financing for new mining projects.
5. Risk Management: Mitigating risks associated with price volatility, geopolitical factors, and supply chain disruptions.
6. Sustainability and ESG Compliance: Adhering to environmental, social, and governance standards to ensure sustainable and responsible sourcing of minerals.

5.3.1 Contracting Practices

1. **Offtake Agreements**: Also known as long term supply agreements, offtake agreements are contracts between mineral producers and buyers where the buyer agrees to purchase a portion of the producer's future output. Mining companies often use offtake agreements to secure funding for new projects from financiers, showcasing the guaranteed revenue from buyers. This provides financial stability to the producer and secures supply for the buyer.

   Offtake agreements tend to be the norm in the mining sector, and especially in critical minerals like lithium, cobalt and rare earth elements. As the supply of critical minerals can be volatile, buyers benefit from secured future availabilities and stable prices. Thus, offtake agreements help in securing financial stability and reliable supply for both buyers and producers.

2. **Streaming Agreements**: In these arrangements, investors provide upfront capital to mining companies in exchange for a fixed amount or percentage of actual minerals produced (streaming)**.** The price at which the streaming company purchases the minerals is typically lower than the market price, providing them with a financial advantage.

   Streaming agreements benefit both parties: producers receive financial support for mine development when traditional financing might be difficult to secure. Buyers secure their supply chains with potentially high returns. Streaming agreements were commonly used to fund extraction of precious metals like gold and silver that would be present along with the primary mineral, such as with copper.

   A notable example is the cobalt streaming agreement between Cobalt 27 Capital Corp. and Vale S.A. for the Voisey's Bay mine in Canada. Cobalt 27 provided an upfront payment of $300 million to Vale in exchange for a portion of the future cobalt production from the mine. This deal helped Vale finance the expansion of the mine while securing a long-term supply of cobalt for Cobalt 27 (Resource World Magazine 2018).

3. **Joint Ventures (JVs)**: Companies often form joint ventures to share the risks and costs associated with mining projects. This can involve partnerships between mining companies, or between mining companies and governments. These JVs can be in the form of a Special Purpose Vehicle (SPV) with its own governance or through a contract known as contractual joint ventures (De Bernier and Wolf 2023).

   JVs are quite common in mining and is responsible for more than 40% of the output from the 10 largest mines in the world (Bamford et al. 2022). JVs allow companies to share the financial and operational risks associated with mining projects. This is crucial in the critical minerals sector, where projects often require significant upfront investment and face various uncertainties.

   General Motors and POSCO Chemicals entered into a JV in Canada to produce EV batteries. They jointly planned to invest USD 400M in Bécancour, Quebec, Canada, to set up Ultium CAM to produce high-nickel cathode material used in GM's EV batteries (Posco Future M 2022). In 2023, the Canadian Government announced an investment into the JV through its Strategic Innovation Fund (Government of Canada 2023b).

Responsible Mining Practices: Supply contracts are evolving to incorporate guidelines for responsible mining practices. Trafigura's five-year cobalt supply agreement with Enterprise Generale du Cobalt (EGC) in Congo includes efforts to implement OECD guidelines on responsible mineral supply (OECD 2018). While there has been progress, issues such as child labour and safety risks remain, leading to initiatives aimed at formalising the sector. Under this agreement, EGC and Trafigura are working with miners' cooperatives to implement OECD guidelines on responsible mineral supply.

Price setting: The price points of these agreements vary based on geography, minerals, and the companies involved. Prices often have a floor and ceiling range, are determined by stakeholder formulas, or are pegged to indices like the London Metals Exchange (LME). In the lithium market, surging demand had shortened supply deals, with prices increasingly linked to the spot market.

5.3.2 Metal Exchanges

The metal exchange platforms provide a venue for the players to trade critical minerals often through standardised contracts. Along with this, metal exchange platforms help in determining the prices for critical minerals through supply and demand dynamics. Furthermore, investors, companies and traders use these platforms to manage price risks and secure supply. Metal exchange platforms offer liquidity and transparency to the market participants, as they maintain transparent pricing and trade information.

The metal exchange platforms such as the LME, the Shanghai Metals Market, etc., use various specialised instruments or mechanisms that include futures contracts, options contracts, and spot transactions, etc.

1. **Futures Contract:** A futures contract is a legal agreement to buy or sell a specific quantity of a commodity (like critical minerals) at a predetermined price on a specified future date. It's standardised, meaning the terms, such as the quality, quantity, and delivery date, are fixed and known in advance. They help determine the future price of a commodity based on current supply and demand expectations.

   Futures contracts are essential for providing stability and predictability, allowing companies to plan better and reduce the uncertainties associated with fluctuating prices. By locking in a price now for a future transaction, buyers and sellers can protect themselves against unexpected price changes (price volatility). Since these contracts are standardised and traded on public exchanges (like the Chicago Mercantile Exchange or London Metal Exchange), everyone has access to the price information in a future date, making the market fairer and more transparent.

   Futures contracts can be easily bought or sold, making it easier for participants to enter or exit the market. There are several metal exchange platforms such as the Chicago Mercantile Exchange (CME), the London Metal Exchange (LME), and the Guangzhou Future Exchange (GFEX) in China, etc., which offers futures contract on critical minerals such as lithium, nickel and cobalt.

2. **Options Contracts**: These give the buyer the right, but not the obligation, to buy a metal at a specific price before a certain date. Options are used for both hedging and speculative purposes. Companies use options contracts to hedge against adverse price movements. For example, a battery manufacturer might purchase a call option on lithium to lock in a maximum price they would pay in the future, protecting against price spikes. Traders and investors can use options to speculate on future price movements of critical minerals.

   By buying call or put options, they can potentially profit from price changes without having to hold the physical commodity. Options provide flexibility as they give the holder the right, but not the obligation, to buy or sell the underlying asset at a specified price before the contract expires (Skeet et al. 2024). By allowing market participants to hedge and speculate, options contracts contribute to overall market stability and liquidity.

   The LME offers options contracts both on Lithium and Cobalt:

   Lithium: The LME offers options contracts for lithium hydroxide. These contracts allow market participants to hedge against price volatility in the lithium market, which is crucial for industries like electric vehicles and energy storage.

   Cobalt: Similar to lithium, the LME provides options contracts for cobalt. These contracts help manufacturers and investors manage the risks associated with fluctuating cobalt prices, ensuring a more stable supply chain for battery production.

3. **Spot Transactions**: Spot transactions involve the immediate purchase and sale of minerals at current market prices. These transactions are typically settled "on the spot," meaning delivery and payment occur shortly after the trade is executed, usually within a few days. Spot transactions provide a transparent view of the current market price for the mineral, which is

essential for price discovery and market efficiency. It adds liquidity to the market, allowing participants to quickly transact as needed.

Examples of market traded critical minerals include lithium and nickel:

Lithium: To hedge against price volatility, many players involved in lithium trading have introduced lithium futures contracts on exchanges such as the London Metals Exchange (LME). In July 2021, LME launched the LME Lithium Hydroxide CIF contract in partnership with Fastmarkets to enhance price transparency (London Metal Exchange, n.d.-a). These contracts are typically designed in consultation with industry players to meet their risk-management needs. More recently, CME Group launched its Lithium Hydroxide CIF CJK Fastmarkets futures contract on LME, with pricing assessments based on trading in the active Chinese, Japanese, and Korean markets (CME Group, n.d.).

In the first half of 2023, the volume of lithium traded globally increased by 10.81%, making it one of the fastest-growing commodities (Holmes 2023). The market volume for lithium was 239,900 tonnes in 2017 and is expected to reach 570,000 tonnes by 2025 (Statista 2024b).

Nickel: The nickel trading system is well-established but has its complexities. Nickel has a longer trading history than most battery metals, and its commodity ecosystem is more mature, though not without its challenges. Only Class I nickel, which has a purity greater than 99.8%, is deliverable against the London Metals Exchange (LME) contract. Other forms of nickel—such as nickel pig iron, nickel matte, ferronickel, and nickel sulphate—need to be price-hedged on the LME but cannot be delivered (Home 2022). These same restrictions apply to other global markets, like the Shanghai Metals Market (SMM). According to the International Nickel Study Group, nickel is a smaller market compared to other base metals, with global consumption around 2.77 million tonnes in 2021. While this amount is more than lithium, it is still smaller compared to metals like copper.

Trends and challenges: Nickel and lithium prices have experienced significant volatility in recent years, with some moderation in 2023 following two years of sharp increases. Between 2021 and 2022, lithium prices soared due to supply disruptions from COVID-19 and increased demand from government incentives. However, prices began stabilising in late 2022 and declined in 2023, with ample cathode inventories allowing buyers to negotiate lower prices or delay purchases (Williams 2024). According to the IEA (2024), battery materials saw particularly large declines with lithium spot prices plummeting by 75% and cobalt, nickel, and graphite prices dropping by 30-45% (International Energy Agency 2024). Increased agreements between OEMs, manufacturers, and miners are expected to lead to greater market concentration, potentially driving prices up by reducing buyer choices and new market entrants. In this context, exchange markets like the LME and SMX are actively creating hedging and trading opportunities for battery metals by introducing new instruments to help stabilise prices (London Metal Exchange, n.d.-c).

The exchange markets for critical minerals are still developing and are not as mature as those for traditional commodities like oil or gold. Unlike traditional commodities, critical minerals often lack standardised contracts and benchmarks. This can lead to less transparency and higher volatility in pricing. There is scope to build more market infrastructure, including trading platforms and warehousing facilities. Since these markets are dominated by buyers and producers in east Asian countries, the prices in these markets are representative of economic conditions in this region. Emerging players from other regions can find it challenging to base their transactions on prices that don't relate to their context (Datta and George 2024). Increasingly stringent ESG obligations require suppliers to comply with legal and voluntary commitments, adding complexity to contract negotiations. LME for instance has introduced the LME Passport to introduce transparency to sustainability of the material traded, along with digitisation of certificates of analysis.

5.3.3 Financing Practices

Effective financing ensures that critical minerals projects can be initiated and sustained, contributing to the stability and growth of supply chains for these resources. Here are three key financing practices seen in the critical minerals sector:

1. **OEM investments and acquisitions:** Clean energy technology companies, especially OEMs and battery cell manufacturers, are increasingly investing in direct vertical integration by acquiring stakes in mining and processing companies. Beyond securing offtake agreements to ensure a consistent supply, these companies are actively investing in various stages of the critical minerals value chain—mining, refining, precursor materials, and cathode production—particularly since 2021. By acquiring stakes in mining companies, clean energy manufacturers can exert greater control over supply chains and tailor projects to meet their specific needs. The critical minerals mining sector has experienced a significant rise in acquisitions since 2021. With the introduction of ethical sourcing and ESG standards for critical mineral mining, such ownership also provides better long-term traceability within the supply chain.

   For instance, General Motors (GM) invested $650 million in equity to secure future lithium supplies from Lithium Americas, marking the largest investment by an automaker to produce battery materials (Clifford 2023; Krauss and Ewing 2023). Similarly, Hyundai Motor Group announced in 2023 its investment of $398 million to procure a 5% stake in Korea Zinc under an MoU that covers acquisition of critical minerals and recycling processes (Duri 2023) This partnership allows Hyundai to meet the IRA's requirements for claiming tax credits by sourcing 50% of its raw materials domestically from the US or US allies. Other global automotive manufacturers like Tesla, Toyota, Volkswagen, and Ford are adopting similar strategies, acquiring stakes in critical minerals mining and processing companies (Krauss and Ewing 2023).

   Automakers from Korea, Japan, Germany, and the United States have also rapidly partnered with established mining companies in mineral-rich countries like Australia, which offers both high-quality minerals and political and economic stability. For example, LG Energy Solution (LGES), one of the world's largest battery manufacturers, holds a 7.5% stake in Queensland Pacific Metals (QPM), which, under a 10-year contract, will supply 71,000 tonnes of nickel and 7,000 tonnes of cobalt annually starting in late 2024 (Randall 2021).

   The industry has also seen mergers to facilitate greater flows of critical mineral supplies. A notable example is the merger between US-based Livent and Australia's Alkem Ltd, creating a supply chain spanning America, Europe, and Australia (Attwood and Steel 2023). Since Livent Corp. already has offtake agreements with automakers such as BMW and GM, this merger will enable the lithium manufacturing company to meet its promised supply commitments. The tables in Annexure-10 and Annexure-11 provide an overview of recent agreements, investments, and joint ventures.

2. **Private Equity and Venture Capital:** Private equity funds and venture capital firms have increasingly began investing in critical mineral projects, especially in early stages. The critical minerals sector offers substantial growth opportunities due to the rising global demand due to the clean energy transition and the relatively limited supply of these minerals. Out of USD 156.6 billion real assets capital raised globally in 2023, $4.2 billion (3.1%) was for the metals and mining sector (PitchBook 2024). Since 2008, it has been the second largest capital raised in absolute terms and share of total annual fund.

   For instance, in 2023, Kinterra Capital raised $565 million for its first fund focused on critical minerals. The fund aims to invest in projects and companies involved in the production, refining, and processing of lithium, cobalt, nickel, and other battery metals (Business Wire 2023). This investment supports the development of new mining projects, particularly in the US, Canada, and Australia, helping to shift EV battery-chemical production away from China.

   Similarly, Appian Capital Advisory closed on over $2 billion for its third fund to make private equity and credit investments in mining (Appian Capital

Advisory LLP, n.d.). The firm has invested in 26 projects, including those producing gold, graphite, nickel, copper, and cobalt.

InfraVia Capital Partners launched a "Critical Metals Fund" with up to €2 billion to invest in critical minerals supply chains across Europe. The fund focuses on early-stage investments in mining projects, processing facilities, and recycling technologies. It manages France's Critical minerals and metals equity fund and aims to achieve the European Union's goals of securing a sustainable and resilient supply of critical minerals (Pacheco 2024).

While VC investments are similarly increasing over the last few years. Deal amounts have been at the highest since 2018 and seem on the uptrend. Bill Gates' Breakthrough Energy Ventures invested in KoBold Metals, an AI-powered minerals exploration company, focused on CETMs. S2G Ventures and Lansdowne Partners invested in TechMet, a PE firm investing in the EV and RE supply chain (Bradbury 2023).

3. **Government Grants, Subsidies and Loans:** Governments offer financial incentives such as grants, subsidies, and preferential loans to promote exploration and production of critical minerals. Government grants and subsidies play a crucial role in promoting the exploration, production, and processing of critical minerals. These financial incentives help reduce the financial risks associated with mining and recycling projects and encourage the development of domestic supply chains.

   For instance, Canada's Strategic Innovation Fund, in 2022 dedicated $1.5 billion for projects in critical mineral manufacturing, processing, and recycling. The fund provides transformative investments in all sectors of the economy. It encourages business to invest in R&D leading to technology transfer and commercialisation of new products, as well as to attract large-scale investments to Canada.

   One of the largest schemes of this kind is the US, Inflation Reduction Act (IRA), passed in 2022. With a goal for reducing carbon emissions by 2030, it provides a combination of tax incentives, grants and loans to bolster domestic deployment of clean energy and clean energy manufacturing, along with its supply chains.

5.4 Factors impacting prices

Pricing in the critical minerals sector is influenced by a complex interplay of factors that contribute to volatility and uncertainty in the market. Here are the key factors impacting pricing:

5.4.1 Geopolitics

Geopolitics plays a crucial role in shaping the availability, pricing, and global dynamics of critical minerals. The concentration of mineral production and processing in specific countries, such as China, makes global supply chains vulnerable to geopolitical tensions. For instance, China's dominance in the processing of minerals like lithium, copper, and REEs allows it to exert significant control over global prices and supply. Any changes in China's policies, such as export restrictions or market flooding, can lead to price volatility and supply disruptions. In response to China's dominance, countries like the US and members of the European Union are forming strategic partnerships and alliances. Also, geopolitical tensions often lead to trade policies and sanctions that directly impact the availability and pricing of critical minerals. For example, sanctions against Russia due to its geopolitical actions have affected nickel supply, while trade barriers and export restrictions from countries like Indonesia and Zimbabwe influence global markets for minerals like copper and lithium. Countries with significant control over mineral production and processing, like China, can influence global markets by adjusting production levels, setting export quotas, or manipulating prices.

Copper: China is set to maintain its dominance in copper smelting, refining, and consumption in the medium term, accounting for 56% of refined copper consumption, 48% of refined copper production, and 43% of smelted copper globally in 2022 (S&P Global 2022a). The US, which relies heavily on Chile and

Canada for refined copper imports, is increasingly focused on securing supply chains and reducing China's influence in key producing regions, particularly Africa. The US's strategy includes the Minerals Security Partnership, increased use of development finance agencies, and enhanced diplomatic efforts in Africa. Notably, a Memorandum of Understanding (MoU) between the US, Zambia, and the DRC aims to strengthen the EV battery value chain in these major African copper producers, challenging China's long-standing dominance (United States Government 2023b). However, the success of this initiative will hinge on private sector involvement and minimising geopolitical tensions.

In the EU, strategic autonomy on critical raw materials, including copper, is being pursued through the European Raw Materials Alliance (ERMA), established in 2020, and the European Critical Raw Materials Act. This legislation sets ambitious targets for 2030. 10% domestic extraction, 40% processing, and 15% recycling. The EU aims to mitigate supply risks by diversifying sources and forming strategic partnerships, a crucial move as China expands its influence in copper production in Latin America and the Balkans, including Serbia and Albania (European Commission 2023).

Lithium: US and EU are trying to reduce China's dominance in the lithium supply chain. In the short term, it is unlikely that the EU and the US can significantly diminish China's dominance in the lithium supply chain, especially in midstream processing. China's advancements suggest it could produce up to one-third of the world's lithium by 2025 (Bloomberg News 2023a). For countries such as US, Bolivia, and Argentina much of the expected expansion relies on the successful scaling of innovative DLE technologies, which remains uncertain.

Manganese: In 2021, South Africa was the largest exporter of manganese (Mn) ore, with exports valued at $2.9 billion, while China was the largest importer. After importing and beneficiating Mn ores, China produces various manganese alloys and other Mn products. China (57%), India (14%), and Ukraine (5%) are the leading producers of manganese alloys (USGS 2023). There are only two refineries outside China that produce battery-grade manganese sulphate: one in Japan and one in Belgium. China, however, dominates this market, producing 97% of the global supply (International Energy Agency 2023b).

Nickel: Nearly half of global nickel production is concentrated in Indonesia. Russia holds 11% of global nickel production and 15% of exports, but the European Union's decreased imports and potential sanctions could disrupt its supply chain. As European buyers turn to sources like the U.S. and Australia, Norilsk Nickel, Russia's leading producer, is considering cutting nickel output by around 10% in 2023 (Bloomberg News 2022b).

Neodymium: In 2021, China consolidated its three largest state-owned entities into the China Rare Earths Group, increasing control over prices and output. Historically, China's mineral export policies have included reducing export quotas and raising tariffs, notably in 2010, causing a surge in REE prices and underscoring its global market influence. Over the past decade, export restrictions on critical minerals have increased five-fold, with China at the forefront. Additionally, China has employed market flooding tactics, directing state-owned companies to drive prices down, undermining Western competition (Godek 2023; Dempsey 2023).

Silicon: To enhance mineral security and reduce dependence on China, the US has established an inter-agency group focused on permitting reform to facilitate domestic production of critical minerals, including silicon. The US has also engaged in partnerships like the Mineral Security Partnership and bilateral agreements to facilitate critical mineral trade, including a specific trade agreement with Japan concerning critical minerals for electric vehicle batteries.

Australia: Australia's Critical Minerals Strategy, initially adopted in 2019 and updated in 2022, aims to position the country as a global leader in critical minerals by 2030. The strategy includes high-purity alumina and silicon in its critical minerals list, recognising their importance in technologies like lithium-ion batteries and semiconductors (Australian Government 2023).

5.4.2 Tariffs, duties and non-tariff barriers

Trade, duties, and non-tariff barriers significantly impact the critical minerals sector by influencing market dynamics, supply chains, and investment flows. Countries like Indonesia and Zimbabwe implement export bans or restrictions to encourage domestic processing and add value locally. Policies like the Inflation Reduction Act in the US, which ties subsidies to the use of domestically sourced or allied critical minerals, can reshape supply chains and trade patterns. Import and export tariffs, such as those imposed by India on manganese, can either protect domestic industries or encourage imports depending on the policy goals. Measures such as restrictions on imports from regions associated with forced labour (e.g., lithium from Xinjiang, China) complicate supply chains, particularly for companies that dependent on materials from those areas. Let's look at these instruments more closely:

Copper: Trade barriers in copper supply chains are primarily aimed at supporting domestic processing capacity. Indonesia, for example, plans to halt copper concentrate exports once Freeport Indonesia and Amman Mineral International complete building new smelters next year (Bloomberg News 2023b). Meanwhile, South Africa imposed a six-month ban on exporting copper scrap to combat infrastructure theft (Creamer 2022). However, increasing demand and tight markets are easing some restrictions. For example, Australia resumed copper ore exports to China in January 2023 after unofficial trade restrictions following diplomatic conflict after the onset of the Covid-19 pandemic (Fitch Solutions 2023).

Lithium: There are a number of rising trade barriers on lithium, covered over three types: local content requirements to prefer lithium sources, outright bans on materials from certain areas, and export restrictions.

With respect to local content requirements, the Inflation Reduction Act's subsidies will require critical minerals in EV batteries to come from specific areas to be eligible for a tax credit. The most stringent measure is that no battery components could come from foreign entities of concern, which includes China. The guidance on how foreign entities of concern will be identified has been released, and could theoretically limit the ability of China's lithium hydroxide to enter the US market directly, or even indirectly when it is used in cathodes produced in aligned countries such as South Korea. While the IRA may have some level of flexibility about processing and use in cathode active materials, this is not yet clear and the coming up of more stringent measures on traceability could affect the structure of the lithium market significantly (CleanEnergy.Gov 2023). Already today, some firms such as Tesla and Ford are making investments into non-Chinese lithium processing facilities, specifically in the US and Australia.

Other trade barriers can include those related to allegations of forced labour in the Chinese province of Xinjiang, which also has lithium production facilities. Lithium supply from Xinjiang in China is set to double by 2028 but global supply chains will not necessarily react positively (Benchmark Source 2023a). This is because the US and EU have regulations that seek to restrict imports from these regions due to allegations of forced labour. This makes things complicated for OEMs like Tesla that are dependent on Chinese cell makers like CATL. Finally, there are also export restrictions. Emerging players like Zimbabwe have implemented a raw lithium export ban to encourage domestic processing of lithium (ESI Africa 2023).

Manganese: Manganese is an important mineral with an input value to various industries. India is a producer of manganese but also a net importer. The net imports indicate that the domestic demand for Manganese is being fulfilled by imports and as such trade implications for this ore become important.

Customs duties, export tariffs, and import barriers serve as policy tools for the administration to promote exports, stimulate demand or supply, or protect domestic industries depending on the situation. For manganese, customs duties are applied but are less protectionist compared to those on finished products. For instance, the Most Favoured Nation (MFN) import duty on manganese is 2.5%, whereas it is 10% for manganese-linked finished products. This facilitation of customs duty helps boost domestic demand in India, although the nature of customs concessions depends on factors like domestic production and trade agreements. The Australia-India Economic Cooperation and Trade Agreement (ECTA) facilitates zero duty on many minerals, including manganese (Australian Government 2021).

India also imposes export tariffs on certain ores and minerals such as iron ore, manganese, and bauxite. Export tariffs are indirect taxes on goods leaving the country. In 2022, an export tariff of Rs 20 per tonne was set for manganese. Investment barriers also affect the trade of mineral ores like manganese. India's inconsistent rankings in the Fraser Institute's Mining Attractiveness Index reflect a pessimistic investment climate in mining. Authorities have at times backtracked and cancelled Reconnaissance Permits (RPs) and First Come First Serve (FCFS) permits, indicating an uncertain regulatory environment. However, there have been positive moves to attract private investment in mining through amendments to the MMDR Act, the Atmanirbhar Bharat policy, and bilateral engagements with producer countries. Overall, trade dynamics are influenced by barriers and facilitation measures, which vary based on mineral demand, regulations, protectionism, investment climate, and other external factors.

Nickel: Like lithium and copper, nickel faces common trade barriers including export restrictions, local content requirements, and potential bans on materials from specific regions. Indonesia implemented a progressive ban on the export of nickel ore from 2009 to 2019, culminating in a complete prohibition in January 2020, mandating domestic processing prior to export (IEA 2023e). Following Indonesia's lead, the Philippines is contemplating similar export restrictions on nickel ore, aiming to advance further in the battery value chain (Chen 2023). Indonesia has also proposed the creation of an organisation, akin to OPEC, to regulate nickel output and prices. However, this proposal faces significant opposition due to the predominantly private ownership of nickel production facilities (Bloomberg News 2022a).

In terms of local content requirements, the US Inflation Reduction Act (IRA) stipulates that critical minerals from specific regions must be used to qualify for tax credits, barring battery components from foreign entities of concern, notably China. As a considerable number of processing plants in Indonesia are owned by Chinese companies, this provision may hinder the entry of China's mixed hydroxide precipitate (MHP) into the US market. Moreover, geopolitical tensions, such as the Russian invasion of Ukraine, have created uncertainties in the global nickel trade. Although no bans have been imposed on Russian imports, many Western countries have voluntarily reduced their imports from Russia, fearing potential sanctions (Guarascio 22AD).

Neodymium: Currently, China dominates REE processing, handling 90% of rare earth processing globally (IEA 2023b) and producing 90% of permanent magnets (Dolf Gielen et al. 2022). Additionally, China stands as the largest importer of unprocessed rare earth ores (IRENA 2023), further consolidating its control over the supply chain.

In 2010, China imposed rare earth export quotas on the global market, citing reasons such as safeguarding its domestic rare earth industry and curbing environmental pollution (Nguyen and Onstad 2023). This sudden restriction led to rare earth shortages and a substantial surge in REE prices, prompting various industries reliant on rare earths to reduce production. Although China lifted these export restrictions in 2015, signalling a willingness to collaborate with other nations, the rare earth market remains unstable due to China's dominance. Driven by environmental concerns, the Chinese government has sought to limit REE mining and has implemented export quotas (Dolf Gielen et al. 2022).

Silicon: The silicon supply chain faces significant trade barriers that challenge the seamless flow of materials and impact industries reliant on silicon metal.

Various countries have implemented protective measures, leading to trade tensions and disruptions.

Trade disputes, such as those between the US and China, have resulted in import tariffs on silicon metal and related products like polysilicon. These tariffs create price distortions and reduce market access for producers in both countries, disrupting the silicon metal market. For instance, in recent years, the United States and China engaged in a trade dispute that resulted in the imposition of import tariffs on silicon metal and its products such as polysilicon from each other (Ya Qin 2012; Allen 2021).

Licensing requirements and technical regulations can impede the movement of silicon metal. Some countries require specific certifications or quality standards for imports, making it challenging for foreign suppliers to enter the local market (US International Trade Commission 2018).

To ensure domestic supply, some countries impose export restrictions on silicon metal, leading to global supply shortages and price volatility. For example, the European Union has imposed antidumping duties on silicon metal imports from China, Russia, and Bosnia and Herzegovina to protect its producers from unfair trade practices (European Commission 2022a).

Overcoming these barriers requires dialogue, transparency, and international cooperation. Establishing fair trade practices and reducing protectionist measures can create a more stable and open trade environment for silicon metal, benefiting global industries that depend on this critical resource. Silicon supply chain faces trade barriers which pose challenges to the seamless flow of trade and materials within the silicon supply chain.

5.4.3 Bankability of contract and agreements

The bankability of contracts for critical minerals is challenged by several factors.These are:

Lack of standardised contracts and limited transparency: The absence of standardised contracts presents significant challenges for both buyers and suppliers in determining appropriate pricing, which in turn hampers the bankability of deals. This issue is particularly pronounced for certain minerals, such as graphite and rare earths, where product standardisation is a major concern. Additionally, the lack of transparency in contracts can further undermine bankability, especially as supply chains face increasingly stringent ESG standards.

Contract renegotiation risks: Countries like Canada and Australia are developing strategic plans and partnerships to secure long-term supplies of critical minerals, offering more attractive opportunities to investors compared to alternatives such as Bolivia and the Democratic Republic of the Congo (DRC). Leveraging a first-mover advantage, China has secured long-term mining and supply contracts with resource-rich countries lacking technical capabilities. Recently, the DRC sought to renegotiate terms of mining contracts with Chinese entities, citing unfavourable and exploitative conditions (Rédaction Africanews 2021). The $6.2 billion deal had granted Chinese investors access to minerals in exchange for infrastructure development in Congo. However, resistance from China and political unrest in the Congo have delayed these negotiations, which could have provided the DRC with a greater share of mine outputs (Bartlett 2023).

These situations show the higher risk of contract renegotiation in emerging markets, often driven by political factors. A similar situation unfolded in Chile in early 2023 when President Gabriel Boric announced the gradual nationalisation of the country's lithium industry. International companies like Albemarle Corp, already operating in Chile, expressed willingness to renegotiate terms through 2043 (Scheyder 2023). While these moves do not directly disrupt supply, they have economic implications, as mineral-rich countries hold a strategic advantage.

The investor-state dispute settlement (ISDS): The investor-state dispute settlement (ISDS) mechanism provides investors with specific benefits and protections under treaties and contracts, helping to mitigate the risks associated with contract renegotiations. ISDS allows companies to seek monetary damages through arbitration proceedings against host states for alleged violations of these protections. Since the Paris Agreement's enactment in 2016, there have been at least 57 ISDS cases related to investments in critical minerals, with nine additional cases where states have been notified of a pending dispute (Songy and Brauch 2024). These disputes predominantly involve investments in traditional base metals like copper, lithium, silver, and iron ore, but there has been a growing number of cases related to nickel, zinc, lead, rare earths, and other critical minerals. From an ESG perspective, ISDS mechanisms can restrict resource-rich nations from amending regulations to better support mining-affected communities and secure fair royalties from mining operations, making it essential to carefully consider these mechanisms in bilateral agreements.

5.4.4 Insufficiently developed Metals Exchange

Traditionally, battery metals like lithium have been traded through bilateral, multiyear agreements, with limited activity on major exchanges like the London Metal Exchange (LME), Chicago Mercantile Exchange (CME), and Shanghai Futures Exchange (SHFE). Although lithium trading has gradually increased, nickel trading has experienced a decline (T.-Y. Kim 2022), emphasising the growing significance of spot pricing and financial tools for managing price uncertainties.

Currently, the trade liquidity of battery metals lags behind that of other bulk materials. For instance, daily trading volumes for lithium and cobalt are less than 1% of their annual production, compared to 10-30% for materials like zinc. This disparity underscores the need to enhance market liquidity and transparency as the battery metals sector continues to grow.

The volatile prices of critical raw minerals, such as lithium and nickel, necessitate the use of derivative trading tools like futures and forward contracts between producers and end-user industries. Futures contracts are essential for price discovery and risk hedging, enabling market participants to make informed decisions regarding production, investments, and resource allocation. These contracts help stabilize and secure the supply of critical minerals, which are vital for industries such as electronics, renewable energy, and defence, especially those relying on long-term supply agreements.

In addition, futures contracts mitigate risks arising from geopolitical instability and supply disruptions, providing companies and governments with a mechanism to hedge against price spikes. Forward contracts offer similar benefits but with added customization, allowing parties to negotiate terms tailored to their specific needs. This flexibility in pricing and terms helps manage price risk effectively and ensures stable supply chains.

Forward contracts play a crucial role in the trading of critical minerals due to their long-term commitment options, risk management capabilities, and flexibility in addressing the unique characteristics of these minerals. They complement futures contracts by offering tailored agreements that meet specific needs while mitigating risks associated with price volatility and supply disruptions. However, despite the presence of these financial instruments, significant loopholes persist on metal exchange platforms, such as the lack of strict regulatory oversight and technological safeguards to ensure the authenticity of traded commodities.

Nickel prices, like those of other critical raw minerals, are highly volatile. This volatility was particularly evident in 2022 when the LME suspended nickel trading on March 8th after prices soared to over $100,000 per tonne, driven by Tsingshan Holding Group Co., the world's top nickel and stainless-steel producer, cancelling billions of dollars in nickel trades. Trading resumed a week later, but the incident raised significant legal concerns. In March 2023, it was discovered that nickel supplied by warehouse firm Access World to commodity traders Trafigura and Stratton was, in fact, stone, prompting an inspection of all LME-licensed warehouses. This scandal led to a significant decline in LME's nickel contracts and storage procedures. By May 2023, the LME initiated consultations to reform its nickel trading market (Reuters 2023b).

This crisis highlighted the vulnerabilities in the critical minerals supply chain, underscoring the urgent need for greater transparency in critical minerals trading. The market turmoil also exposed broader issues within metal trading, particularly the discrepancies between exchange prices and real-world values. Physical delivery delays often result in a premium for short positions. According to Trading Economics, nickel is expected to trade at $19,430.63 per metric tonne by the end of this quarter (Trading Economics, n.d.). The LME requires nickel to meet specific quality, size, and shape standards, including a purity of 99.8%, to be traded on futures contracts (London Metal Exchange, n.d.-b).

To address the challenges on metal exchange platforms, several measures should be proposed or implemented, such as regular inspections of stored commodities and the integration of technologies like block chain to verify the authenticity of stored materials.

5.4.5 Environmental, Social, And Governance (ESG)

Stricter environmental, social, and governance (ESG) requirements in some advanced economies have driven up project costs, rendering these assets less competitive compared to those in countries with lower regulatory standards (International Energy Agency 2024). However, many in the mining industry state that they still do not anticipate receiving a premium even after adopting ESG practices (IEA 2023f). Various reports have observed that ESG practices can influence the prices of critical raw materials in the mining industry through multiple mechanisms in which environmental and social regulations play a crucial role in determining the pricing.

Mining firms must incur higher costs to comply with environmental regulations, which include activities like waste management and emissions reduction. Therefore, these additional expenses can be reflected in the final price of raw materials. Maintaining ethical labour standards and promoting community development can also increase operating expenses within the framework of social regulations. Businesses that disregard these regulations risk fines or suspension of operations, potentially reducing supply and driving up mineral costs.

In the above section concerning price volatility, it has been explained how supply chain disruptions and historic price volatility have made it difficult to obtain the essential minerals needed for the energy transition. Consequently, mining project developers face greater challenges regarding uncertainty in capital costs. This has led to an increasing consumer and corporate demand for sustainably sourced raw materials, enabling companies to charge premium prices for their ESG-compliant reporting. Interestingly, companies with robust ESG practices enjoy a better reputation, which can lead to easier market access and long-term contracts, positively affecting price stability and potentially increasing demand.

Price hedging has become challenging for the mining industry due to various critical factors underlying the reporting of different divisions of ESG. In addition, compared to strong incumbents, diversified refining and processing projects encounter greater challenges due to their limited pricing power, especially for non-integrated assets. Companies that actively engage with local communities and maintain high social standards are more likely to receive and maintain their social license to operate. This minimises disruptions and ensures a steady supply of raw materials, influencing price stability.

By adopting ESG practices, mining companies can more efficiently navigate regulatory environments, attract sustainable investments, meet the growing market demand for ethical products, and maintain stable operations. All of these factors can significantly impact the prices of critical raw materials.

5.4.6 Other factors

1. **Economic Conditions**: Macroeconomic factors such as currency fluctuations, inflation, and global economic trends impact mineral prices. Economic downturns can reduce demand and lower prices, while periods of growth may increase demand and drive prices up.
2. **Technological Advancements**: Innovations in extraction, processing, and recycling technologies can influence supply by making certain minerals easier or more cost-effective to produce. Technological advancements may also create demand for specific minerals, further impacting prices.
3. **Stockpiles and Strategic Reserves**: The management of stockpiles by governments or industry players can stabilise markets. By influencing the availability of these minerals in the market, they play a significant role in influencing price stability, mitigating risks associated with supply disruptions, and shaping the long-term economic landscape of industries reliant on these essential resources.
4. **Government Financing and Subsidies**: Public funding initiatives, subsidies, and investment incentives play a crucial role in supporting the early-stage exploration, extraction, and processing of critical minerals. These financial supports can drive innovation, improve infrastructure, and stabilise prices by encouraging investment in the sector.

6

GEOPOLITICS AND INTERNATIONAL POLICY RESPONSE

6 GEOPOLITICS AND INTERNATIONAL POLICY RESPONSE

The global production of many critical minerals is concentrated in a few countries, while the global demand for these minerals is going to remain strong in many consuming countries. Significant concentration of production and processing, and the ever-changing geopolitical landscape creates risks of potential disruptions in CETM supplies. In this chapter, we understand the global geopolitical scenario and what policies and strategies are being followed by countries to secure resilient supplies.

China's dominance stems from its extensive investment in mining and processing infrastructure, strategic acquisitions of foreign mineral resources, and strong government support for its supply chain. Additionally, China's control over rare earth elements and key minerals provides a competitive edge in global markets. This dominance is further strengthened by its ability to produce and export these materials at scale, reinforcing its strategic position in various high-tech industries. Several nations are trying to diversify supply chains to reduce China's dominance by moving up the value chain through investments in processing and mining or signing up bilateral agreements.

For any nation, an effective international policy creates a framework for securing the supply of minerals, encouraging research and development (R&D), promoting responsible practices and supporting recycling. Accordingly, policies on CETM are being strengthened and made robust. These policies are largely influenced by the increasing competition in clean energy manufacturing, especially in light of China's dominance and the West's renewed push to localise production.

In the United States, for example, the most important policies on critical minerals are part of the Inflation Reduction Act, a piece of legislation that focuses on a much broader buildout of the clean energy industry. Likewise, in Europe, the Critical Raw Materials Act (CRMA) has been paired with the Net Zero Industry Act and is a piece of the larger Green Deal Industrial Plan.

Besides, advanced economies are also finding ways to diversify critical mineral markets through bilateral agreements, multilateral partnerships and frameworks. While mineral-rich countries are trying to leverage their advantages, mineral importing countries are using several strategies to secure supplies. Critical minerals are also beginning to be incorporated into broader multilateral trade and economic frameworks. There is also a trend for countries to specify transparency requirements in imported minerals which are being met by international standards and memberships frameworks.

6.1 Geopolitical Tensions and China's Global Dominance

6.1.1 Disruptions due to Ukraine-Russia Conflict

China has a strong grip on the global critical mineral sector as both a major producer and consumer. It drives more than half of global copper demand and is the fourth-largest copper producer, accounting for 9% of global output (USGS 2023). China is also expanding its smelting capacity to decrease import reliance and is investing in international projects to secure future supplies.

Geopolitical factors have further solidified China's dominance. Russia's invasion of Ukraine has led to a loss of key European markets, making China a major buyer of Russian minerals at potentially discounted rates. With over 50% of Russian copper exports going to Germany, the Netherlands, and Turkey, and discussions of shifting nickel exports to China, Russia's mineral exports are increasingly reliant on Chinese demand (Barich 2022).

Russia holds 11% of global nickel production and 15% of exports, but the European Union's decreased imports and potential sanctions could disrupt its supply chain. As European buyers turn to sources like the U.S. and Australia, Norilsk Nickel, Russia's leading producer, is considering cutting nickel output by around 10% in 2023 (Bloomberg News 2022b).

6.1.2 China's Rise as an Industrial Powerhouse:

China's rise as a dominant force in the critical minerals sector is widely reported to be due to heavy subsidies, government financing, trade and investment partnerships. Critics also accuse it of lowering labour and environmental standards (Nayar 2021, Murphy and Elimä 2021). Additionally, China's successful industrial policies have created a skilled workforce and fostered research and development. This combination of factors has played a crucial role in China's mineral industry success.

Two key factors further explain China's control over critical minerals. First, China's rise occurred during a period of rapid globalisation and de-industrialisation in other major economies. Second, China's processing capacity for critical minerals is closely linked to its high demand from domestic manufacturing industries. For example, China accounts for over half of global copper demand (Statista 2024a) and has seen a sharp rise in rare earth element consumption, while other regions have decreased. By 2022, China also held around 74% of global lithium-ion battery manufacturing capacity (IEA 2023e).

As advanced economies look to re-industrialise and boost clean energy technologies, they will aim to diversify their critical mineral sources for economic and geopolitical reasons. However, China's evolving policies have reinforced its dominance. The country's control over CETMs has been driven by high domestic demand and strategic initiatives like the Belt and Road Initiative. With supportive regulations, public finance, and state-owned enterprises, China has attracted substantial investment, bolstering its CETM processing and downstream manufacturing sectors.

China occasionally uses its market power to achieve broader foreign policy goals, such as recent export restrictions on gallium and germanium (Kharpal 2023). Since China is generally a net importer of mineral concentrates but a net exporter of refined materials, it exerts significant influence in the midstream stage of value chains. This dominance not only benefits China's clean energy industry but also positions it to challenge the clean energy sectors of its geopolitical rivals.

Domestically, China has focused on strengthening its rare earth element (REE) industry. In 2021, China consolidated its REE sector by merging its three largest state-owned entities into the China Rare Earths Group, enhancing its control over prices and output (Htun, n.d.). The country has also tightened regulations on REE mining and processing.

In response, the EU and US are working to reduce China's dominance in the lithium supply chain. The US is boosting domestic production and forming partnerships, while the EU aims to increase its domestic capacity through initiatives like the European Raw Materials Alliance (ERMA) and the European Critical Raw Materials Act. Despite these efforts, China's advancements mean it could still produce up to one-third of the world's lithium by 2025.

6.1.3 China's International Policy

China has been notably active in international mineral policies, with a major development in July 2023 when it announced export restrictions on gallium and germanium. These metals are crucial for semiconductors, advanced electronics, and energy technologies. China controls about 98% of global gallium and 68% of germanium supplies (USGS 2023). The new export licensing system for these minerals is a response to recent semiconductor restrictions imposed by the US, Japan, and the Netherlands (Asenov 2023). This move indicates China's willingness to use mineral export controls as a tool in trade and geopolitical conflicts. China is also considering similar restrictions on rare earth element (REE) magnet technology (Tabeta 2023).

China's history of mineral export policies includes significant actions such as reducing export quotas and increasing tariffs on REEs in 2010, which led to a surge in REE prices and demonstrated China's influence on global markets. In the past decade, export restrictions on critical minerals have increased more than five-fold, with China leading this trend (Godek 2023; Dempsey 2023)

In addition to restrictions, China has used market flooding strategies, particularly in the REE industry. By directing state-owned companies to flood the market, China has driven prices down, making it difficult for Western competitors to compete (Ferreira and Critelli 2022). Similar tactics have been linked to China's growing share in the gallium market, though it's unclear if oversupply was deliberately encouraged (USGS 2023).

6.1.4 China's Overseas Investments

China has made substantial investments in mining assets across Africa and Latin America. From 2020 to 2022, Chinese companies invested $4.3 billion in acquiring lithium assets, surpassing investments from the US, Australia, and Canada combined (Ferreira 2022). Additionally, China has expanded into processing and refining facilities worldwide to secure access to crucial raw materials. For example, BYD plans to build a $290 million lithium cathode plant in Northern Chile (Attwood and Lara 2023).

China's overseas investments have traditionally focused on sourcing raw materials for processing back home. Recently, China has adapted to changing demands from mineral-rich countries to support midstream investments in these countries. Investments in Indonesian nickel refining and discussions with Argentina about battery cathode production illustrate this shift. Chinese battery company Contemporary Amperex Technology Limited (CATL) has also made agreements in Bolivia and the DRC, potentially leading to future value-added projects.

6.2 Strategies by Mineral-Rich Economies

A significant portion of critical mineral production and resources are concentrated in developing economies as follows:

I. Indonesia produces nearly half of global nickel.

II. The DRC produces 68 percent of the world's cobalt.

III. South Africa and Gabon together control 59 percent of manganese production.

IV. The Lithium Triangle—comprising of Argentina, Bolivia, and Chile—account for 53 percent of identified global lithium resources.

Mineral-rich developing economies recognise they have a unique chance to capture revenue, attract substantial investments, and become key players in the new global energy system. However, this opportunity may be fleeting, as advancements in innovation, recycling, and market diversification could diminish the future market power and influence of current producers. These economies have taken a series of measures to capture more value from their mineral production.

6.2.1 Revised regulatory and tax frameworks

Countries are revising their mining regulations to increase revenue and ensure more benefits from their mineral resources. For example:

- **Democratic Republic of the Congo (DRC):** In 2018, the DRC introduced a new mining code that raised royalties and taxes on mineral production. The code also included provisions for the state to benefit during times of high mineral prices and required local economic development and community support (UNCTAD Investment Policy Hub 2018).

- **Chile:** Chile changed its tax and royalty system to prevent the depletion of its natural resources without significant benefits for the country. The Finance Minister emphasised that the goal was to ensure more lasting value from the country's mineral wealth (Cambero 2022).
- **Other Countries:** Mexico, Peru, and Zimbabwe are also considering or have enacted similar changes to their mining taxes and royalties.

Additionally, countries rich in minerals are renegotiating existing mining contracts to secure better terms. The DRC is a key example, particularly with its large contracts involving Chinese investors.

6.2.2 Resource Nationalisation and Protectionism

Many mineral-rich countries are increasing state involvement in mining operations. For example:

- **Chile:** Requires new lithium projects to be public-private partnerships, with the government holding a majority share.
- **Bolivia:** Nationalised its lithium industry in 2008 but has struggled to develop it and is now partnering with a Chinese consortium.
- **Mexico:** Also nationalized its lithium industry.

This trend extends beyond Latin America.

- **Indonesia:** Encourages state-owned companies to participate in mining.
- **Namibia:** Exploring state ownership of mineral resources.

Government interventions are rising globally, including export restrictions and resource nationalism. Since 2009, export restrictions on industrial raw materials have increased fivefold (OECD 2023b). For instance, Canada imposed limits on foreign state-owned investments in its critical minerals sector in 2022 (Hersh and Patel 2022). Chile was also considering the nationalisation of its lithium sector in 2023, impacting global lithium supplies and requiring private companies to work with the state (Villegas and Scheyder 2023).

6.2.3 Moving Up the Value chain

Countries rich in minerals are increasingly focused on moving up the value chain rather than just supplying raw materials. This trend is growing rapidly in South America, Africa, and Southeast Asia.

- **Argentina and Chile:** These countries are encouraging private partnerships to advance into areas like electric vehicle battery production.
- **Indonesia:** This country is taking a more direct approach by banning the export of unprocessed ores to boost its position in the value chain.
- **Namibia and Zimbabwe:** Both have recently followed Indonesia's lead by banning exports of raw minerals.

In addition, Indonesia is investing in downstream value addition through co-location projects. For instance:

- **CATL:** A unit of CATL will partner with Indonesian state-owned companies to build a $6 billion complex that includes nickel mining, processing, battery materials, recycling, and manufacturing.
- **LG Energy Solution:** This consortium plans to invest $9 billion in Indonesia's EV battery value chain, covering nickel smelting, refining, and cathode manufacturing.

Despite these investments, increasing production takes time. For example, high-pressure acid leach (HPAL) nickel projects in Indonesia typically take around five years to reach full production levels. This extended timeline adds uncertainty to when these projects will become operational (International Energy Agency 2023a).

6.2.3 Strategies by Australia and Canada

Australia is a major player in critical minerals, contributing 49% of global lithium and 12% of global manganese production (USGS 2023). Canada also has significant reserves of CETMs. The country is taking up several strategic initiatives to fostering innovation, sustainability, and resilience in its critical mineral supply chain. Australia and Canada are positioning themselves as key players in the critical mineral supply chain due to their vast resources and strong ties with Western allies. Both countries aim to increase their market share and reduce China's dominance in the sector.

Australia:

- **Strategy:** Focuses on enhancing mineral processing capabilities and developing strong environmental, social, and governance (ESG) standards. It aims to build sovereign capabilities in processing and attract international investment.
- **Efforts:** Australia's 2023-2030 Critical Minerals Strategy emphasises increasing processing capacity and ESG leadership. It seeks to attract capital and intellectual property to develop its processing sector (Australian Government 2023).
- **Challenges:** Overcoming barriers to commercial production and competing with established Chinese expertise. Some projects are in the pilot stage and face delays and cost overruns.

Canada:

- **Strategy:** Aims to boost critical mineral processing and manufacturing, capturing value by exporting processed materials and expanding domestic refining.
- **Efforts:** Canada's Critical Minerals Strategy focuses on increasing exports to allies and expanding processing and manufacturing. It has attracted investments from major companies for battery production.
- **Challenges:** Similar to Australia, Canada faces technical and financial hurdles and has imposed restrictions on Chinese investments for national security reasons (Cecco 2022).

Both Countries:

- **Objective:** Reduce China's market power by moving up the value chain, from raw material export to processing and manufacturing.
- **Approach:** Prefer positive incentives over coercive measures. They are investing in processing and refining and focusing on ESG standards to attract investment and gain market advantages.
- **Differences:** Canada has taken a firmer stance against Chinese investments compared to Australia, which remains cautious due to its significant trade dependency on China.

In summary, Australia and Canada are working to increase their roles in the critical mineral supply chain, focusing on processing and manufacturing while navigating challenges related to competition and investment. Their efforts are significant but face uncertainties as many projects are still in early stages of development.

6.2.4 Government-led subsidies, tax credits, and grants

Countries worldwide are recognising the need for financial collaboration to ensure responsible and reliable critical mineral supply chains. To support this, governments are partnering with other nations and businesses. Since 2021, countries like the United States, Australia, Canada, and the European Union have introduced policies offering subsidies, tax credits, and grants to attract both local and foreign investments in the critical minerals sector. These countries are investing heavily in their critical minerals sectors through various funding programs and strategic initiatives, aiming to enhance processing capabilities, attract international investment, and secure their positions in the global market.

Australia: In 2023, Australia launched its Critical Mineral Strategy 2023-2030, which includes several key initiatives. The Critical Minerals Development Program provides about $35 million in funding for early- and mid-stage mineral development projects. The Critical Minerals International Partnership offers $40 million in grants for strategic partnerships with other countries and an additional $6.7 million to enhance international engagement (Australian Government, n.d.-a). The Critical Minerals Facility (CMF) is a $2 billion loan facility supporting mining and refining projects where private finance is limited (IEA 2023a). Notable funded projects include an $815 million loan to Iluka Resources for the Eneabba Rare Earths Refinery, a $125 million loan to Renascor Resources for the Siviour Graphite project, and a $40 million loan to EcoGraf for graphite production (Iluka, n.d.; Renascor Resources, n.d.). Australia's strong critical mineral presence, political stability, and robust policies make it an attractive partner. For example, South Korea signed a Memorandum of Understanding with Australia in 2021, leading to collaboration between Korean and Australian companies in various projects (Australian Government, n.d.-b).

Canada: In December 2022, Canada unveiled its Critical Mineral Strategy, featuring several pivotal components aimed at bolstering its critical mineral sector. Key initiatives include a 30% Exploration Tax Credit designed to stimulate exploration activities for critical minerals, alongside a commitment of $47.7 million towards upstream research and development conducted in Canadian laboratories (Government of Canada 2022b). Canada's strategy leverages existing support mechanisms such as the Strategic Innovation Fund (SIF), which received an additional $1.5 billion in 2022 to advance projects in advanced manufacturing and recycling. Noteworthy among these investments is SIF's $27 million contribution to E3 Lithium for enhancing electric vehicle (EV) battery production capabilities (Government of Canada 2022a).

Moreover, Canada's Mines to Mobility Initiative, launched in 2019, has successfully attracted over $7 billion in investments, particularly from major automotive manufacturers like Ford and General Motors, to expand EV and hybrid vehicle production within the country. To further incentivise investments in critical minerals, Canada has implemented the Clean Technology Manufacturing Tax Credit, which supports initiatives across extraction, recycling, and processing sectors (Government of Canada 2023a). Additionally, the Critical Minerals Research, Development, and Demonstration (CMRDD) Program focuses on funding pilot and demonstration projects aimed at advancing technologies for minerals such as nickel, lithium, and rare earth elements (Natural Resources Canada, n.d.).

These strategic initiatives underscore Canada's commitment to fostering innovation, sustainability, and resilience in its critical mineral supply chain, positioning the country as a key player in the global transition towards cleaner energy technologies.

6.3 Strategies by Mineral importing countries

Countries are increasingly focused on securing responsible and reliable supply chains and reducing reliance on a few key producers to manage market volatility. They are also working on recycling and developing alternative materials to lessen the impact of supply disruptions.

Advanced economies like the United States, United Kingdom, European Union, Japan, and South Korea share similar goals. They aim to attract clean energy technology manufacturing to both decarbonise their economies and benefit economically from the energy transition. However, these countries are heavily dependent on imports for critical minerals, particularly from China. This reliance is becoming problematic due to rising trade and political tensions.

These economies face a common challenge with critical minerals and have set similar policy objectives to address it. They are all working to create more resilient supply chains, though their approaches may differ. Domestically, they use tools such as subsidies, domestic content requirements, grants, loans, and simplified permitting processes. Internationally, they focus on increasing finance, forming bilateral agreements, and participating in multilateral initiatives.

6.3.1 Policies

Several governments have announced dedicated critical mineral policies and strategies with three main objectives: ensuring supply reliability and resiliency, promoting exploration, production, and innovation, and encouraging sustainable and responsible practices.

The IEA's critical minerals policy tracker provides an exhaustive overview of different CETM policies, covering 35 countries and 450 polices (IEA 2022a). Some of the key elements of different policies in industrialised countries are highlighted below:

- **Sourcing Requirements:** This policy instrument includes procurement of raw and processed minerals either domestically or with allied countries, thereby spurring the growth of domestic exploration and mineral processing.
- **Tax credits:** A tax credit is typically provided as an incentive to companies to invest in exploration or mineral processing, such as under the US's IRA. This could have eligibility criteria, such as a certain project size or other conditions.
- **Grants:** A grant is a policy tool to provide direct funding for critical mineral projects, usually with no repayment obligations.
- **Loan assistance:** Loan assistance is provided as financial assistance to projects, typically with preferential repayment terms compared to regular finance.
- **Streamlined permitting**: Another central piece of critical mineral policy in industrialised nations is streamlined permitting requirements, through either fast-tracked clearances and/or reduced red tape. The US and EU have targeted permitting as key areas of policy action, but it is questionable to what extent this can practically occur given political considerations and environmental regulations.

Many governments are focusing on increasing federal funding for critical mineral projects through a mix of grants and loan assistance. Notable examples include the Defence Production Act and Infrastructure Investment and Jobs Act in the United States, the Automotive Transformation Fund in the United Kingdom, the 2030 Investment Plan in France, the newly planned Critical Materials Fund in Germany, and the National Strategic Energy Plan in Japan (IEA 2023c). These initiatives aim to support and enhance critical mineral production and processing capabilities. Additionally, countries can negotiate grants or loans on a project-specific basis as needed.

Table 9: Domestic critical mineral policies instituted by key industrialized countries

Country	Sourcing requirements	Tax credit	Grants	Loan assistance	Streamlined permitting
All EU countries	Prospective				Prospective
France	Prospective		Yes	Yes	Prospective
Germany	Prospective		Prospective	Prospective	Prospective
Japan			Yes	Yes	
South Korea		Prospective			
United Kingdom			Yes	Yes	
United States	Yes	Yes	Yes	Yes	Yes

Subsidies, although less commonly implemented through legislation, are also used, with the United States being a notable exception. The Inflation Reduction Act (IRA) in the U.S. offers critical mineral producers the choice between a 45X production tax credit and a 48C investment tax credit (Congress.gov 2022). Trade measures and domestic content requirements are rapidly evolving areas that may significantly impact the critical mineral landscape. For instance, the IRA's Section 30D links eligibility for up to $7,500 in tax credits for electric vehicles to the proportion of critical minerals and battery components sourced domestically or from countries with Free Trade Agreements with the U.S (Congress.gov 2022). This provision could affect mineral and component prices based on their origin. Although this has raised concerns among some U.S. allies about potential market access and competitiveness, the broad definition of Free Trade Agreements allows for further bilateral negotiations. Japan has already signed a critical mineral agreement with the U.S., enabling its products to qualify for Section 30D benefits, and similar negotiations are underway with the United Kingdom and the European Union (M. Kim, Smith, and Koo 2023). India, which is not currently a U.S. free trade partner, does not benefit from Section 30D but could potentially negotiate entry in the future.

Europe's Critical Raw Materials Act (CRMA) introduces domestic targets for critical mineral extraction (10%), processing (40%), and recycling (15%) by 2030, relative to the EU's annual consumption. It also aims to limit reliance on any single country for more than 65% of imports of any mineral. Unlike the IRA, the CRMA does not yet offer financial incentives tied to these targets, which may limit its immediate market impact.

A central aspect of critical mineral policy in advanced economies, particularly under Europe's CRMA, is streamlining mineral permitting processes. Other countries, including the United States, Australia, and Canada, are also focusing on improving permitting, mapping, workforce development, and circularity. While the impact of these efforts is uncertain due to political and environmental regulations, streamlined permitting remains a major component of critical mineral strategies across these regions.

6.3.2 Bilateral agreements

To counter China's dominance in the critical minerals market, advanced economies are forming international agreements like Free Trade Partnerships and Memoranda of Understanding (MoUs). These economies know they can't independently meet their critical mineral needs, so they are rapidly increasing bilateral agreements with mineral-rich countries. For example, there are agreements between the U.S. and Canada, the EU and Canada, as well as various agreements involving Australia with the U.S., U.K., India, South Korea, Japan, France, and Germany.

Additionally, advanced economies are now also signing agreements with developing countries rich in minerals. The U.S. has recently signed MoUs with the Democratic Republic of Congo (DRC), Mongolia, and Zambia (United States Government 2023a; 2023b). The EU has agreements with Argentina and Namibia (Reuters 2023a; NBC 2023), and Japan signed an MoU with the DRC in late 2022 (Kyodo News 2022)**.** These MoUs reflect a proactive approach by advanced economies to secure mineral supplies and prepare for future competition.

With the rise of electric vehicles (EVs), driven by policies like the U.S. Inflation Reduction Act (IRA), many American EV manufacturers are investing in Indonesian nickel projects to secure their nickel supply for batteries. For example, Tesla has a $5 billion deal with nickel refineries in Indonesia, and Ford has a $4.5 billion joint venture for nickel processing. Indonesia is also working on a limited free trade agreement with the U.S. to help its businesses benefit from U.S. tax credits available through the IRA, similar to recent agreements with Japan and ongoing negotiations with the EU.

6.3.3 Plurilateral Partnerships and Frameworks

Plurilateral partnerships for critical minerals are gaining traction as global economies recognise the importance of securing supply chains essential for clean energy technologies. These efforts are driven by a combination of economic, security, and geopolitical concerns as countries seek to secure their supply chains for the transition to a low-carbon economy. As demand surges, countries are increasingly turning to collaborative efforts to stabilise their supply chains and reduce reliance on a few dominant producers like China, which controls significant refining capacity. While plurilateralism in the critical minerals space is still in its infancy and burdened with its own challenges, partnerships are essential for diversifying supply chains, mitigating risks, and fostering a more resilient global market for critical minerals.

Some examples of plurilateral frameworks are:

European Raw Materials Alliance (ERMA): It was established as part of the EU's action plan on critical raw materials to secure sustainable access to critical raw materials for Europe. It involving various stakeholders including Member States and regions to develop resilient value chains.

Quadrilateral Security Dialogue (Quad): Comprising the US, Japan, Australia, and India, the Quad is a diplomatic partnership that focuses on the region's priorities regarding critical and emerging technologies and climate action among others. It has been increasingly focusing on securing a stable supply of critical minerals in the Indo-Pacific region.

Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP): It is a free trade agreement between 11 countries in the Asia-Pacific region aimed at promoting economic integration and reducing trade barriers among its members.

Minerals Security Partnership (MSP): It is a collaboration of 14 countries and the EU that aims to accelerate the development of diverse and sustainable critical energy minerals supply chains. It works with host governments and industries to facilitate targeted financial and diplomatic support for strategic projects along the value chain.

International Energy Agency (IEA) Critical Minerals Working Group: It is a collaborative initiative established by IEA to promote collaboration and data transparency on critical minerals necessary for clean energy transitions.

Types of Plurilateral initiatives:

These fall into two general categories:

1. **Mineral-specific partnerships** - These are collaborations focused on specific critical minerals essential for various industries.
2. **Broader partnerships** - These initiatives are wider in scope and address broader economic, environmental, or technological issues, with critical minerals being a significant point of discussion which include dialogue on critical minerals.

Table 10: Examples of different forms of plurilateral critical mineral agreements

Name of agreement	Type of agreement
Minerals Security Partnership (MSP)	Mineral-specific
Energy Resource Governance Initiative (ERGI)	Mineral-specific
Indo-Pacific Economic Framework for Prosperity (IPEF)	Broad partnership
Americas Partnership for Economic Prosperity (APEP)	Broad partnership
Quadrilateral Security Dialogue (Quad)	Broad partnership

6.3.4 Overseas investments

The United States is working to boost the Export-Import Bank's (EXIM) role in mining projects, while the United Kingdom and European Union are seeking more international investment (Export-Import Bank of the United States 2022). Japan supports overseas investments through the Oil, Gas, and Metals National Corporation (JOGMEC) and the Bank for International Cooperation (JPIC), and South Korea is providing $5.3 billion in financing to support South Korean battery investments in North America (Yang 2023).

The success of these strategies to build more resilient critical mineral supply chains is still uncertain. Their effectiveness will depend on various factors, including market conditions, regulatory environments, geopolitical relations, and technological developments.

United States: The United States has implemented some of the most comprehensive policies for critical minerals among importing countries. The Inflation Reduction Act (IRA) of 2022 is a key piece of legislation aimed at boosting clean energy manufacturing in the US. It offers significant incentives through investment and production tax credits, provided that companies use local inputs. Since natural resources within the US are limited, the government is encouraging trade with countries that have free trade agreements (FTAs) with the US.

To qualify for electric vehicle (EV) tax credits, companies must source a specified percentage of critical minerals from the US and FTA countries—40% by 2023, increasing to 80% by 2026 and beyond. Additionally, battery components must be manufactured in the US. This policy has led both domestic manufacturers like Tesla and General Motors, who already meet these requirements, and international OEMs such as Volkswagen and Honda to reconsider their manufacturing strategies. For example, Honda has partnered with LG Chem to build cell production facilities in the US. Vale Canada and General Motors have collaborated to secure nickel-sulphate supply with support from the Canadian government. Australia is also a preferred partner, and in 2022 Tesla formed an agreement with Liontown Resources an Australian-based battery mineral to secure supply of spodumene concentrate (Liontown 2022).

In addition to the IRA, the US supports critical mineral projects through the Development Finance Corporation (DFC), which has invested in TechMet, a company involved in mining and processing metals used in energy products (US IDFC, n.d.).

The Mineral Security Partnership (MSP), launched in 2022 and led by the US, is a major international initiative focused on critical minerals. The MSP aims to develop diverse and sustainable supply chains for critical energy minerals through financial and diplomatic support for strategic projects. It also promotes high environmental, social, and governance standards and supports economic development in host countries. The MSP partner countries include advanced economies such as Australia, Canada, Norway, Finland, France, Germany, Japan, Italy, South Korea, Sweden, the United Kingdom, the European Union, and India. India joined the MSP in June 2023, enhancing its ability to secure critical mineral supply chains and collaborate on sustainable mining practices and technologies. The MSP is considering 15 international projects (some located outside partner countries) for investment from partner countries' credit agencies, development finance corporations, and the private sector (Mooney 2023).

European Union : Europe's Critical Raw Materials Act (CRMA) sets ambitious domestic targets for critical minerals, aiming to achieve 10% for extraction, 40% for processing, and 15% for recycling by 2030, based on the EU's annual consumption. The CRMA also aims to reduce reliance on any single country for more than 65% of imports of a single mineral. Unlike the US Inflation Reduction Act (IRA), the CRMA does not yet offer specific tax credits or incentives tied to these targets, which might limit its immediate market impact until financial incentives are introduced (European Commission 2023).

The CRMA reflects a broader trend toward responsibly sourced materials. The European Union is leading efforts in mineral traceability through initiatives like the Battery Passport and the Directive on Corporate Sustainability Due Diligence (European Commission 2022b; Everledger, n.d.). Industry schemes, such as those by the London Metal Exchange and the Initiative for Responsible Mining Assurance, are increasing pressure on traceability and ethical sourcing. Automakers, motivated by reputational concerns and human rights issues, are also pushing for more responsible practices (Castillo and Purdy 2022).

In addition to these domestic efforts, Europe is making significant investments in overseas mining. Germany has established a state fund of approximately USD 2.2 billion to support both domestic and international mining projects crucial for the green energy transition. This fund aims to strengthen supply chains and boost domestic manufacturing. The EU is also planning to launch a Raw Materials Club under the CRMA to build strong partnerships with both resource-rich countries and importing nations, aiming to secure and enhance critical mineral supply chains (European Commission, n.d.)

6.3.5 Government-led subsidies, tax credits, and grants

United States: The United States Infrastructure Investment and Jobs Act, passed in 2021, includes a grant program with over USD 7 billion in funding (White House 2023). Half of this funding supports the domestic production of key materials for the electric vehicle (EV) supply chain, such as nickel, lithium, cobalt, and rare earth elements (REEs). The other half is allocated to battery production and recycling. The Act also provides a USD 7,500 tax credit for purchasing clean vehicles, which is contingent on a significant portion of essential minerals being sourced from the United States or from countries with free trade agreements with the US, and the majority of battery components being manufactured in North America. Since its enactment, battery supply chain projects have drawn over USD 45 billion in investments, covering everything from mineral extraction to battery manufacturing. Additionally, tax credits under the Inflation Reduction Act encourage downstream participants to source from allied regions, which helps mitigate investment risks in diverse refinement projects.

France: France's 2030 investment initiative includes EUR 500 million in public support for critical mineral ventures, with half of the investment allocated as loans and grants, and the other half invested in a dedicated public-private equity investment fund (IEA 2022b).

European Union: Research and development efforts in the critical minerals sector have received funding. For instance, the European Union's Horizon Europe program allocates funds for research and innovation in strategic value chains, including projects related to raw materials (European Commission 2023).

6.4 Strategies by Multilateral Organisations

Multilateral organisations such as the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), Organisation for Economic Co-operation and Development (OECD), and the World Bank are expanding their work on critical minerals. This is being done to support global energy transitions, enhance supply chain resilience, and promote sustainable development through research, policy frameworks, and financial assistance. The OECD organised a week-long forum on critical minerals recently and the IEA has been ramping up its critical minerals capacity and held a Critical Minerals Summit in September 2023. Each organisation plays a slightly different role in the context of critical minerals. OECD, likewise, has focused on deep-dive reports and supply chain transparency. The IEA is developing its capacity to serve as the premier source of data and market tracking, as it historically has done with oil and gas. IRENA has focused more on deep-dive reports, but also recently formed the Collaborative Framework on Critical Materials for the Energy Transition which seeks to foster dialogue and coordinate activities between members. The World Bank focus is slightly different than other multilateral organisations and centres more around implementation. The World Bank's Global Energy and Extractives Practice and its Climate-Smart Mining Initiative seek to ensure that "resource-rich developing countries benefit from the increasing demand for minerals and metals, while ensuring the mining sector is managed in a way that minimises the environmental and climate footprint" (World Bank Group, n.d.-a).

6.5 Global Policies on Recycling

Recycling is a crucial element in global CETM policies. These policies collectively underscore the importance of recycling in ensuring a sustainable and resilient supply of critical raw materials. Here are some key points from various international policies:

European Union: The Critical Raw Minerals Act aims to cover the entire supply chain, including recycling. It promotes quality strategic raw materials and a cohesive implementation of EU regulations. By establishing a market for secondary raw materials, it supports a circular economy.

United States: The Critical Minerals and U.S. Public Policy encourages recycling end-life products to reduce dependence on primary sources. The government, alongside institutions like the Department of Energy (DOE) and MIT, prioritises R&D investments to enhance recycling technologies. Despite advancements, recycling may only meet a fraction of rising demand, highlighting the need for continued research.

Chile: The National Mineral Policy advocates for mining projects with a circular approach. By 2030, the policy aims to recycle 50% of construction and demolition waste and mandates tire recycling targets. These initiatives aim to optimise resource use and promote sustainable development.

Finland: The National Battery Strategy recognises that recycling alone won't meet the escalating demand for materials like lithium and cobalt. Finland is a global leader in recycling and continues to develop advanced recycling technologies to address this challenge.

United Kingdom: The UK's Critical Minerals Strategy emphasizes maximising the production of critical minerals through mining, refining, manufacturing, and recycling. Notable initiatives include supporting Britishvolt's gigafactory, which aims to create thousands of jobs and promote battery recycling in partnership with Glencore (Government of UK 2023). This holistic approach aims to reduce reliance on virgin materials and minimise environmental impact.

6.6 Global Policies on ESG

ESG Investing: ESG investing began in the 1960s with socially responsible investing (SRI). By the early 2000s, it evolved to consider social, ethical, and environmental impacts alongside financial gains. The United Nations' 2004 report "Who Cares Wins" highlighted that ESG-committed companies tend to thrive in the long term. In 2006, the UN launched the Principles for Responsible Investment (PRI), encouraging investors to integrate ESG factors into their decisions. Today, six principles address environmental, social, and corporate issues. In 2013, the Global Reporting Initiative (GRI) released the G4 Sustainability Reporting Guidelines.

The OECD indicates that ESG investing has grown substantially, with ESG fund assets surpassing $30 trillion by 2022, driven by increased environmental and social awareness, investor demand for sustainable options, and regulatory changes (OECD 2020).

Voluntary international membership and standard frameworks: Robust multilateral engagement on critical minerals involves voluntary international memberships and standard frameworks like the Extractives Industry Transparency Initiative (EITI) and the Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development (IGF). These initiatives focus on improving transparency and promoting sustainable development in the mining sector. Moreover, it provides guidance to countries on crafting policies, including those related to critical minerals. In 2024, the IGF issued a handbook to assist nations in identifying strategic minerals and developing tailored policies (Intergovernmental Forum 2024). The Corporate Sustainability Due Diligence Directive (CSDDD) is a proposed European Union (EU) directive designed to enhance corporate accountability and transparency.

India's participation in multilateral networks, such as the MSP, the Quad, and the IGF, is crucial for its critical mineral strategy. These networks enable collaboration with like-minded countries, enhancing the resilience and sustainability of India's critical minerals supply chain. The technical expertise from organisations like the IGF helps India adopt best practices and improve its mining sector's credibility and sustainability.

Voluntary Standard Initiatives for corporates: Adopting sustainable mining practices can improve operational efficiency, reduce costs, and enhance reputations among stakeholders. Engaging with local communities and addressing their needs helps reduce the risk of social unrest and regulatory backlash. Transparent and ethical governance practices minimise the risk of legal issues and reputational damage.

Globally, significant measures address concerns in CETM mining. For instance, the EU's Critical Raw Material Act aims to ensure long-term access to a responsible and reliable supply of CETMs. Adhering to accepted standards can mitigate the negative impacts of mining on society and the environment.

Initiatives like the World Bank's Responsible Minerals Initiative (RMI) and the Responsible Gold Initiative (RGI) address social and environmental issues, including child labour in mining. The International Council on Mining and Metals (ICMM) has also introduced principles for responsible mineral supply chains.

The future of the mining industry will be shaped by various disruptive themes, with ESG being a significant factor. Incorporating ESG considerations into CETM mining in India will help manage risks and create long-term value. Several Indian companies have signed up to the PRI, promoting responsible investment.

Traceability Initiatives: The European Union promotes mineral traceability through initiatives like the Battery Passport and the Directive on Corporate Sustainability Due Diligence. Industry schemes such as the London Metal Exchange's requirements and the Initiative for Responsible Mining Assurance increase pressure around traceability and mineral sourcing. This momentum is supported by reputational risks and initiatives from original equipment manufacturers, especially automakers, to avoid ties to forced labour and other human rights issues.

Free, Prior, and Informed Consent (FPIC): The principle of Free, Prior, and Informed Consent (FPIC) establishes the right of Indigenous Peoples to be fully informed and actively engaged in decision-making processes, allowing them to give or withhold consent and negotiate the terms of projects impacting their communities or territories (University of British Columbia, 2021). In 2007, the United Nations advocated for the universal adoption of FPIC, urging that Indigenous communities' consent be sought before initiating any project. This principle is reinforced by the earlier adoption of the International Labour Organization's Convention No. 169 in 1989, a legally binding international instrument affirming the rights of Indigenous and tribal peoples (Earthworks, n.d.). Additionally, voluntary standards such as those from the International Council for Metals and Mining (ICMM) and the Initiative for Responsible Mining Assurance (IRMA) increasingly emphasize FPIC, requiring member companies to incorporate it as a core component of their operating standards.

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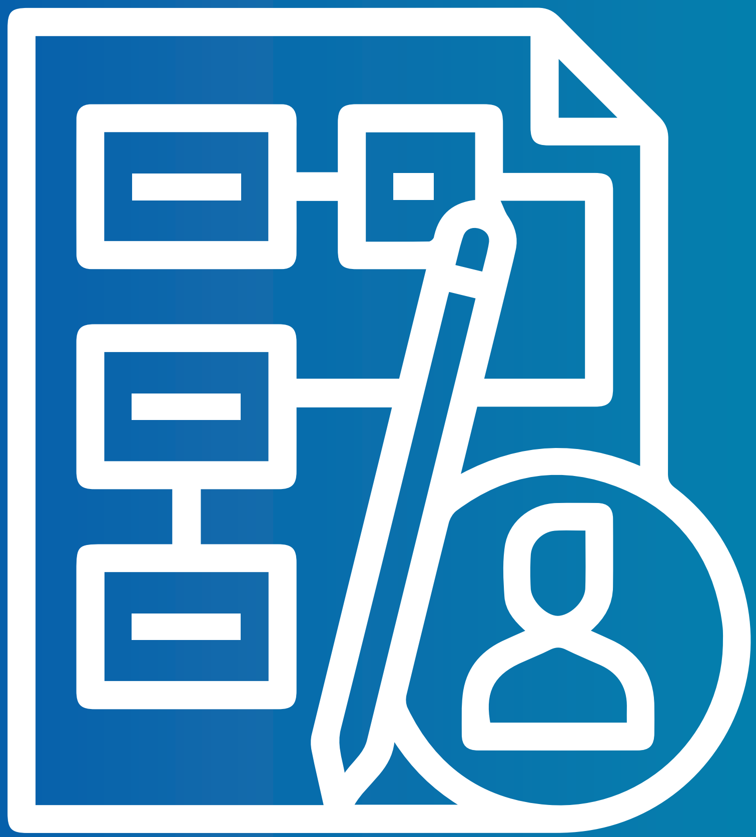

INDIA: CURRENT SCENARIO, POLICY, INITIATIVES, CHALLENGES AND WAY FORWARD

7 INDIA: CURRENT SCENARIO, POLICY, INITIATIVES, CHALLENGES AND WAY FORWARD

India has diverse geological-tectonic domains, promising varied mineral potential. The country is rich in mineral resources such as coal, iron ore, bauxite, and precious metals. With a rich mining legacy dating back to prehistoric times, India continues to produce a range of minerals including iron ore, copper, zinc, lead, gold, silver, diamonds, and precious gemstones. This legacy, coupled with post-independence industrial growth, has fuelled India's rapid development.

Being part of the Gondwana region, India shares geological similarities with mineral-rich areas like Western Australia, South America, and South Africa. India also has a vibrant history of mining. Terracotta bricks, bronze workings, and precious metal jewellery trace back to the Indus Valley Civilisation as well as landmarks like the Iron Pillar of Delhi (5th century CE). Throughout history, mining has stood as the cornerstone of industrial progress, furnishing essential raw materials crucial for power generation, agricultural activities, infrastructure development, and manufacturing.

India has been making several moves through its policies and international alliances. The Mines and Minerals (Development and Regulation) Act, (MMDR) 1957 has been amended with the focus of encouraging more participation and investment in the sector. India's National Mineral Policy (NMP), 2019, promoted sustainable mining practices, enhanced exploration efforts, and incentivising private investment. However, legislative changes have not been successful in attracting investments from leading domestic and foreign private companies. The MMDR Act, 1957, was amended in 2015 and the auctions system was introduced as the only means of allocating mineral concessions. The auctions system has not been conducive for green field exploration, therefore, investments in mineral exploration have significantly reduced since 2015. Further delays in issuing post-lease clearances have also led to inefficient use of mineral resources.

The NMP, 2019, had set out important parameters to be considered by policymakers. However, the policy lacks effective implementation strategies, robust enforcement mechanisms, and sufficient measures to address various issues including environmental and social sustainability concerns in the mining sector. India must follow robust ESG standards and strengthen recycling efforts, not only to be sustainable but also to gain a foothold in the global mineral market.

India is also seeking partnerships with countries like Australia and Argentina, known for their abundant critical mineral resources. In 2023, India joined a multilateral framework led by US called the Mineral Security Partnership (MSP). It has also established Khanij Bidesh India Limited (KABIL), a joint venture under the central government to identify, acquire, develop, mine, and process strategic minerals abroad. KABIL has made several efforts to work with governments in major mining jurisdictions in Australia, Argentina and Chile to collaborate on critical mineral projects. KABIL has only focused on G2G collaboration which required adhering more bureaucratic and procedural norms. Overseas investments in mineral assents also requires partnering with private companies as they can offer large capital investments and expertise. Globally, collaborations in overseas projects are led by private companies with very few PSUs investing in the same.

In geopolitical efforts, India's positioning as a counterweight to China for both developed and developing countries could serve as a cornerstone of its critical minerals and foreign policy strategy. However, alignment may be more complex in other areas, such as evaluating whether it is in India's interest to engage with Russia on critical minerals. Although drawing definitive conclusions on these issues is challenging, the overarching message for policymakers is the importance of harmonising India's critical minerals strategy with its broader foreign policy objectives.

This chapter provides details on the current value chain status in India, the policy framework, its geopolitical efforts including partnerships and positioning, as well as its future directions in securing critical minerals for sustainable development.

7.1 Policy Developments in Upstream

Only 10% of India's Obvious Geological Potential (OGP) has been explored. India has not yet fully capitalised on its mineral assets due to limited exploration activities. This under-exploration limits the discovery and subsequent development of critical mineral resources. To address this, the government has been implementing policies and initiatives to encourage investment and technological advancements in the mining sector. These efforts include liberalising the regulatory framework, promoting private sector participation, and enhancing collaboration with international experts. Effective mineral exploration can lead to the discovery of new deposits, ensuring a stable supply of raw materials necessary for the country's infrastructure development and technological advancements.

Today, India's mining landscape encompasses a diverse array of 88 non-fuel minerals, yielding a production value exceeding ₹1 lakh crore (US $13 billion) during 2022-23. This sector is estimated to contribute approximately 2.85% to the nation's Gross Value Added (GVA) and through its downstream economic linkages provides both direct and indirect employment as well as value creation. For instance, a ₹1 lakh investment in the non-fuel mining sector has the potential to stimulate a remarkable ₹50,822 increase in labour income (Chadha, Sivamani, and Verma 2023).

Mining falls within both the Central List and State List of the Indian Constitution, granting both the Union (Central) and State governments authority to regulate the sector. The Union (Central) government is responsible for formulating legislation and policies governing mining, while the state governments execute these policies and oversee industry regulation. The Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act), enacted by the Union government, serves as the principal legislation governing the mining sector in India.

India's untapped geological potential necessitates extensive mineral exploration and addressing challenges in allocation of mineral assets. Mineral development is crucial for India's economic growth and reduce import dependency. Critical minerals are also important for meeting India's energy transition targets as they are important raw materials for manufacturing of various green technologies.

Box-1: Mineral classification and managing inventories

Minerals may also be classified into broad categories of 'surficial' or 'deep-seated' commodities. The former refers to entities such as iron ore, coal, manganese, bauxite, and limestone found near the surface or at shallow depths. The deep-seated minerals are typically more concealed, including gold, lead, zinc, copper, nickel, platinum group metals (PGMs), diamond, and rare earth elements (Federation of Indian Metal Industries 2018).

The Indian National Mineral Inventory offers a comprehensive assessment of mineral deposits, gathering data from exploration, development, and exploitation agencies. This detailed inventory

includes information on location, infrastructure, geology, exploration methods, physicochemical analysis, reserve estimates, estimation parameters, and end-use grade (Indian Bureau of Mines 2015).

This inventory must be aligned with the United Nations Framework Classification (UNFC) that employs a numeric codification system based on economic viability, feasibility studies, and geological knowledge of deposits (Indian Bureau of Mines 2015). The UNFC's three-digit system categorises quantities, with economic viability and feasibility taking values of 1, 2, or 3, and geological assessment ranging from 1 to 4. Thus, the highest category in UNFC is 111, while the lowest class is 334. By aligning with this classification, India's mineral inventory will use a standardised numeric codification system. This alignment ensures consistency and comparability in the assessment and reporting of mineral resources.

Key Developments: The National Mineral Policy (NMP) was first launched in 1993. It aimed to promote privatisation and Foreign Direct Investment (FDI) in mining, including exploration. It has since undergone revisions and updates to address evolving challenges and opportunities in the mineral sector. The most recent version, the National Mineral Policy 2019, builds upon earlier versions and aims to foster sustainable mining practices, attract investment, and promote inclusive growth in the mining industry.

The 1994 amendment to the MMDR Act expanded the First Come, First Serve (FCFS) method for allocating mineral concessions, allowing any registered Indian company to apply for Prospecting Licenses (PL) or Mining Leases (ML) and attracting investment from international mining firms. Subsequent amendments in 1999 enabled private enterprises to apply for Reconnaissance Permits (RP), granting holders preferential rights to obtain PLs or MLs. In 2015, the MMDR Act only allowed mineral concessions to be granted through the auctions system and exploration permits were only being issued to public sector companies.

Despite efforts to encourage private investment and bring advanced technology to exploration and mining, the sector continues to face substantial obstacles. The Working Group on Mineral Exploration and Development for the Twelfth Five-Year Plan outlined several key recommendations to enhance private sector participation (Ministry of Mines, 2011). These included reducing procedural delays in obtaining Reconnaissance Permits (RPs) and Prospecting Licenses (PLs), improving transparency in the mineral concession process, and facilitating a seamless transition from RP/PL to Mining Lease (ML). The report also emphasised that auctioning pre-explored RP/PL blocks or reserving them solely for state-owned enterprises would significantly discourage private sector investment. The Mid-Term Appraisal of the Tenth Five-Year Plan identified procedural delays in processing mineral concession applications and inadequate infrastructure in mining regions as major obstacles to achieving desired outcomes.

1. India's National Mineral Policy (NMP) 2019

India's National Mineral Policy (NMP) 2019 is designed to facilitate the sustainable and scientific development of the country's mineral resources while ensuring environmental protection, economic growth, and social development. The key tenets of this policy include:

Sustainable Mining: Emphasis on scientific mining practices to ensure the sustainable extraction of minerals. This includes adopting modern technology and practices to minimise environmental impact.

Transparency and Accountability: Ensuring transparency in the allocation of mineral concessions and operations, reducing corruption, and fostering accountability.

Value Addition: Encouraging the processing and value addition of minerals within the country to increase employment and economic benefits.

Exploration and Auctioning: Strengthening the exploration of mineral resources using advanced technologies and promoting auction-based allocation of mining leases to ensure fair competition and optimal resource utilisation.

Research and Development: Promoting research and development in mineral exploration, mining technologies, and environmental management to enhance efficiency and sustainability.

Ease of Doing Business: Simplifying regulatory frameworks to attract investments and make it easier for businesses to operate within the mineral sector.

Inter-Generational Equity: Ensuring that the benefits of mining are shared with future generations, balancing the need for economic development with the preservation of resources for the future.

Infrastructure Development: Facilitating infrastructure development in mining areas, including roads, power, and water supply, to support mining operations and associated communities.

Environmental and Social Responsibility: Mandating that mining companies undertake measures for environmental protection and social development, including rehabilitation and resettlement of affected communities.

Human Resource Development: Developing skilled human resources for the mining sector through training and education, improving productivity, and ensuring safety and welfare of the workforce.

Regulatory Reforms: Implementing regulatory reforms to enhance the efficiency and effectiveness of the mining sector, reducing bureaucratic delays and improving governance.

2. **Mines and Minerals (Development and Regulation) Act, 1957**

The Indian mineral ecosystem is governed by various rules, regulations, and executive orders that essentially flow from the Mines and Minerals (Development and Regulation) Act, 1957, commonly known as the MMDR Act. Over the years, the MMDR Act has evolved with significant amendments in 1996, 2015, and recently in 2023. The MMDR Act and subordinate legislations focus primarily on exploration, mining auction and allocation, mineral development and regulations, transfer of lease, tax, royalties, and other concessions (trust and foundation). National Mineral Policy 2019 is also an important guiding document for the Ministry of Mines for the growth of the mineral ecosystem in India. The MMDR Act through various amendments has implemented some tenets of national policy. The main tenets of the MMDR Act include:

Regulation and Development: Establishing a legal framework for the regulation and development of mines and minerals under the control of the Union.

Grant of Mineral Concessions: Outlining the procedures for the grant of reconnaissance permits, prospecting licenses, mining leases, composite and exploration licenses. This includes auction-based allocation to ensure transparency and competitiveness.

District Mineral Foundation (DMF): Establishing DMFs to work for the interest and benefit of persons and areas affected by mining operations, funded by contributions from mining leaseholders.

National Mineral Exploration Trust (NMET): Creating the NMET to facilitate exploration activities, with a focus on enhancing mineral resources through scientific and technological advancements.

Sustainable Mining: Promoting sustainable and responsible mining practices to ensure environmental protection, including the implementation of mine closure plans and environmental safeguards.

Revenue and Royalties: Defining the structure for the collection of royalties, dead rent, and other fees from mining operations to generate revenue for the state and central governments.

Penalties and Compliance: Establishing penalties for illegal mining activities, non-compliance with statutory requirements, and unauthorised exploitation of mineral resources.

Role of State Governments: Empowering state governments to make rules regarding minor minerals and to issue licenses and leases for mining operations within their jurisdictions.

Simplified Procedures: Streamlining the processes for granting mineral concessions and ensuring a conducive environment for investment in the mining sector.

Auction Mechanism: Introducing an auction mechanism for the allocation of mining leases and composite licenses (prospecting license-cum-mining lease) to ensure transparency and fair competition.

To address concerns regarding resource allocation, the MMDR Act was amended in 2015, transitioning from a First Come, First Serve (FCFS) system to granting mineral concessions through auctions. Subsequent revisions in 2019 and 2021 aimed to further streamline regulations. Consequently, private mining companies can now acquire mineral concessions exclusively through auction processes, either in the form of Mining Leases (MLs) or Composite Licences (CLs), which are granted for areas with insufficient evidence of mineral presence.

The auction process commences with the state government issuing notifications for areas eligible for composite licences or mining leases based on mineral content evidence. Subsequently, the process unfolds through an online platform in a two-stage manner. The first stage assesses the technical qualifications of bidders and establishes the floor price for the second stage. Eligible bidders participate by quoting a percentage of the mineral value they anticipate extracting from the operational mine. This percentage serves as the auction premium paid to the state government, in addition to existing royalties and taxes (Chadha and Sivamani 2021).

Since 2015, 286 mining leases (ML) and composite licenses (CL) have been auctioned till the first quarter of 2023 (Ministry of Mines). In 2021, the MMDR Act, 1957 was amended to allow for CLs for certain minerals to be auctioned event at the early stages of exploration like G3 and G2. This increased the number of CLs being auctioned. The government has also passed amendments to the MMDR Act to incorporate exploration licenses (EL) and de-listing of various strategic and critical minerals for more private participation.

3. Supreme Court on Mining Concessions in India

In September 2012, the central government filed a Presidential Reference to the Supreme Court to clarify the permissible methods of allocating natural resources (Natural Resources Allocation, In Re, (2012) 10 SCC 1). The Court noted that while auctions might optimise revenue, they might not necessarily align with the constitutional goal of "common good" under Article 39(b) of the Indian Constitution. Emphasising that "common good" should be the guiding principle for natural resource allocation, the court declined to endorse any specific method for resource disposal, citing it as a matter of economic policy beyond its jurisdiction.

Acknowledging that auctions are not the sole method for distributing natural resources, the court stressed that any allocation process must adhere to principles of fairness, reasonableness, transparency, non-discrimination, and impartiality to foster healthy competition and equitable treatment. Recognizing the substantial capital involved in resource exploration and mining contracts, the court highlighted the reluctance of exploration companies to undertake high costs without assurance of resource utilisation, particularly if they are required to compete later in an open auction for the same resources. The court also observed that beyond legal concerns, making auctions mandatory for mineral concessions is also contrary to economic logic.

4. Incentivising Mineral Exploration:

The National Mineral Exploration Policy, 2016 (NMEP), aimed to increase private sector involvement in exploration by leveraging their technical expertise, technological prowess, and financial resources. To incentivise exploration efforts, the NMEP allowed private agencies to receive a share of revenue from royalty or auction premia when an explored block is auctioned for mining. Building upon the NMEP, the Ministry of Mines (MoM) initiated various policies such as the National Mineral Exploration Trust (NMET) and the Exploration License (EL)

The 2021 Amendments to Sections 4 and 9C of the MMDR Act, 2015, introduced provisions enabling Notified Exploration Agencies (NEAs) to receive funding through the National Mineral Exploration Trust (NMET). To qualify for notification under Section 4, any exploration agency must be accredited by the National Accreditation Board for Education and Training of the Quality Council of India (QCI-NABET). This accreditation scheme outlines specific procedures and criteria for the exploration companies. Currently, the Ministry of Mines (MoM) has listed 40 NEAs, comprising 15 private and 25 government agencies. However, majority of NMET funds have supported government agencies like the GSI and state mineral development corporations. Private agencies have not been incentivised through NMET.

In 2023, Exploration Licences (ELs) were introduced targeting exploration of deep-seated and critical minerals, which were be specified in the MMDR Act. Under the framework, ELs for reconnaissance and prospecting can be granted through auctions for areas suggested by any individual to the State Government. Eligible explorers would bid for their desired percentage share of the auction premium payable by a Mining Lease (ML) holder to the state government upon successful discovery and subsequent auction. The EL auction would be awarded to the bidder offering the lowest bid. State governments are required to auction off successfully explored areas within one year from the submission of the Geological Report. EL holders are also eligible to receive financial support through the NMET fund. However, ELs may not be able to incentivise mineral exploration as returns on investment would only be received in the future once the explored block is successfully auctioned. An EL holder would have to wait several years as operational and clearance delays have increased the time-cost in commencing mineral production.

5. Establishment of a Critical Minerals List

In June 2023, the Ministry of Mines in India proactively identified and shortlisted 30 critical raw minerals necessary for the country's economic and low-carbon transition. This step demonstrates India's commitment to strategic resource planning and aligning mineral resources with its developmental. This list serves as a strategic foundation for focused policy development and investment in securing these minerals.

The set of 30 critical minerals was identified by the Ministry of Mines based on a comprehensive three-stage assessment process. This assessment considered key parameters such as the resource/reserve position in the country, production levels, import dependency, relevance for future technologies and clean energy, the need for fertilizer minerals in an agrarian economy, and other critical factors. The identified minerals are Antimony, Beryllium, Bismuth, Cobalt, Gallium, Germanium, Graphite, Hafnium, Indium, Lithium, Molybdenum, Niobium, Nickel, Platinum Group Elements (PGE), Phosphorous, Potash, Rare Earth Elements (REE), Rhenium, Silicon, Strontium, Tantalum, Tellurium, Tin, Titanium, Tungsten, Vanadium, Zirconium, Selenium, and Cadmium (Ministry of Mines 2023).

6. Auctioning of Critical Mineral Blocks

In a move to encourage private sector participation and responsible resource extraction, the government of India launched the auctioning of mineral blocks in 2023. From November 2023 to March 2024 the Ministry of Mines has carried out 4 tranches of critical mineral auctions. 20 critical mineral blocks were auctioned in November 2023, followed by 18 blocks more in February 2024 and 11 new blocks in June 2024. This initiative aligns with global efforts to engage the private sector in sustainable mineral resource development. The auction of critical mineral blocks in India was open to both domestic and foreign parties.

This initiative aimed to attract a diverse range of investors to encourage competition, foster responsible resource extraction, and integrate advanced technologies and practices from around the world. However, there have been several challenges in successfully auctioning these blocks as domestic mining companies do not have the relevant expertise in mining of deep-seated minerals. Annexure-12 shows the annulment of majority of critical mineral blocks that have been auctioned under the first three tranches.

7. Offshore Areas Mineral (Development and Regulation) Act, 2002

The Offshore Areas Mineral (Development and Regulation) Act (OAMDR) 2002 regulates the exploration and mining of minerals in offshore areas, which include the seabed and subsoil of the territorial waters, the continental shelf, the exclusive economic zone, and other maritime zones of India.

The OAMDR Act provides a framework for granting mineral concessions, ensuring environmental protection, and promoting sustainable development of mineral resources in offshore areas. It aims to facilitate systematic and scientific exploration of offshore mineral resources, attract investment, and ensure that activities are conducted in a manner that minimizes environmental impact. The Act also outlines the roles and responsibilities of various regulatory bodies and sets guidelines for the sustainable and equitable development of offshore mineral resources.

An Exploration License (EL) is a permit granted to explore and assess the mineral potential of a designated area. In India, ELs are granted under the Offshore Areas Mineral (Development and Regulation) Act (OAMDR) of 2002. This Act regulates the exploration and mining of minerals in offshore areas, ensuring that such activities are conducted systematically and sustainably.

8. Amendment of MMDR and OAMDR Acts (2023)

In a landmark move, the Mines and Minerals (Development and Regulation) Act (MMDR) and the Offshore Areas Mineral (Development and Regulation) Act (OAMDR) were amended in 2023. These amendments were made to streamline the mining process, enhance the exploration and commercial production of these critical minerals, and reduce India's dependency on imports. These amendments paved the way for the commercial mining of six critical minerals — lithium, beryllium, niobium, tantalum, titanium, and zirconium. These minerals were delisted from the list of atomic minerals specified in Part-B of the First Schedule to the Act. These minerals have various applications in the space industry, electronics, communications, energy sector, and electric batteries and are critical for India's net-zero emission commitment.

As part of the amendments, twenty-four minerals in Part D of the First Schedule as Critical and Strategic Minerals. Section 11(D) was inserted in the Act, conferring the power of auctioning Critical and Strategic mineral blocks to the Central Government to grant mineral concessions for minerals specified in Part D of the First Schedule (Ministry of Law and Justice 2023a). The Offshore Areas Mineral (Development and Regulation) Amendment Act, 2023, provides for a) Production leases to be granted only through auction by competitive bidding b) Introduction of a composite licence, a two-stage operating right granted for exploration followed by production operations, to be awarded only through auction by competitive bidding (Ministry of Law and Justice 2023b).

The introduction of a two-stage operating right granted for exploration followed by production operation signifies a comprehensive and structured approach to mineral resource development. This signifies a strategic and methodical approach to mineral resource development. However, this has not enhanced the overall efficiency, sustainability, and economic viability of mining projects. The use of auctions as a means of allocating mineral resources has not resulted in favourable outcomes for critical mineral projects. Several improvements in the current system are required to address the concerns that led to the annulment of various critical mineral block auctions.

9. **Launch of National Geoscience Data Repository (NGDR)**

   Recognising the importance of data transparency in informed decision-making, India launched the National Geoscience Data Repository (NGDR). This repository serves as a valuable resource for geological data, promoting accessibility and aiding in the exploration and exploitation of critical minerals with a focus on sustainable practices

7.2 Policies and Incentives for Downstream Manufacturing

The Atmanirbhar Bharat, 2020 deeply impacts the CETM sector by promoting self-sufficiency through increased domestic exploration, mining, and processing. It emphasizes the development of indigenous technologies, investment in R&D, and the creation of strategic reserves to reduce import dependency. The policy simplifies regulatory frameworks and offers financial incentives to attract private investment while fostering sustainable and responsible mining practices. It also enhances infrastructure for logistics and processing, encourages recycling and recovery technologies, and leverages international collaborations and partnerships to secure a reliable and responsible supply chain for CETMs, crucial for sectors like renewable energy, electronics, and advanced manufacturing.

Domestic Incentives: The Indian government has implemented several schemes to incentivise domestic manufacturing of low-carbon technologies (LCTs).

PLI schemes: The Production Linked Incentive (PLI) scheme offers reimbursement mechanisms for original equipment manufacturers (OEMs) based on product sales. To qualify for various PLI schemes, OEMs must meet specific criteria promoting domestic production. In October 2022, India launched the second phase of the High-Efficiency Solar PV Modules PLI scheme, aiming for a domestic manufacturing capacity of 48 GW by 2026 (Press Information Bureau 2023a). The government plans to provide $2.4 billion in incentives to boost domestic production of polysilicon, ingots, wafers, cells, and modules (IEA 2023g). Additionally, import duties on PV modules and cells have been increased to further support domestic manufacturers.

FAME II: The government has also introduced initiatives to promote domestic consumption and manufacturing of electric vehicles (EVs) (Press Information Bureau 2023c). The Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME II) provides demand and production incentives for consumers and manufacturers. Launched in April 2019 with a budget of ₹10,000 crore, FAME II aims to increase EV use in public and commercial transport sectors. Two other PLI schemes support domestic manufacturing of EVs and related components: the PLI for the automobile and auto component industry and the PLI for Advanced Chemistry Cells (ACC). The automotive industry scheme had an initial budget of ₹25,938 crore, attracting ₹74,850 crore in investments from approved OEMs for EVs and components. In March 2022, the government approved incentives worth ₹18,100 crore under the ACC PLI scheme for domestic battery cell production, with leading investors like Ola, and Reliance participating (Press Information Bureau 2022).

Budget 2024: The government has recently exempted custom duties on capital goods and machinery for lithium-ion cell manufacturing, indicating a potential increase in demand for refined lithium products. To support the development of a domestic lithium refining industry, the government is considering various incentives, including assistance with land acquisition, permit facilitation, and capital cost reductions.

7.3 Trade and Regulation

Customs duties, export tariffs, and import barriers are policy instruments used by governments to encourage exports, influence demand or supply, or safeguard local industries as needed. In the case of manganese, while customs duties are in place, they are less restrictive compared to those on finished products. For example, the Most Favoured Nation (MFN) import duty on manganese stands at 2.5%, contrasted with 10% for manganese-related finished goods. This lower duty on manganese helps to increase domestic consumption in India, although the specifics of customs concessions are contingent upon factors such as domestic production and trade agreements. By maintaining lower customs duties on raw materials (e.g., 2.5% for manganese) compared to finished products (e.g., 10% for manganese-related goods), India promotes domestic consumption and supports local industries that rely on these inputs.

The Australia-India Economic Cooperation and Trade Agreement (ECTA) further supports this by allowing for duty-free import of various minerals, including manganese. This helps India achieve a more reliable and cost-effective supply of essential raw materials.

India also levies export tariffs on select ores and minerals, including iron ore, manganese, and bauxite. These tariffs are taxes on goods exported from the country. In 2022, manganese was subject to an export tariff of Rs 20 per tonne. Investment barriers also play a role in the trade of mineral ores like manganese. Export tariffs, are used to manage the outflow of valuable minerals, aiming to conserve resources for domestic use or to increase domestic value addition. This approach helps ensure that India retains a portion of its mineral resources for its own industries, potentially fostering local processing and manufacturing.

However, challenges like fluctuating positions in the Fraser Institute's Mining Attractiveness Index and regulatory uncertainties, such as the reversal of permits, reflect the ongoing difficulties in attracting and retaining investment in the mining sector. Instances of the government reversing or cancelling Reconnaissance Permits (RPs) and First Come First Serve (FCFS) permits highlight the regulatory uncertainty.

7.4 India's policies on ESG

Environmental and Social Regulations: India has established laws and policies to ensure environmentally sustainable and socially responsible mining. Regulatory bodies include the Ministry of Environment, Forest and Climate Change (MoEFCC), Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs), and the Indian Bureau of Mines (IBM). Mining and mineral processing operations must obtain Environmental Clearance (EC) after conducting Environmental Impact Assessments (EIA). The Environment (Protection) Act, 1986, mandates EIAs and public consultations for mining projects. Forest Clearance (FC) and Wildlife Clearance (WC) are required under the Forest (Conservation) Act, 1980, and the Wildlife (Protection) Act, 1972. Compliance with pollution control standards is mandatory under the Air (Prevention and Control of Pollution) Act, 1981, and the Water (Prevention and Control of Pollution) Act, 1974, with companies needing Consent to Operate (CTO) from the SPCBs.

Labour and Amendments: In 2021, 1.33 million labourers were employed in the mining sector (Statista, n.d.). Amendments to the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act) include provisions for sustainable mineral development, environmental protection, and the establishment of the District Mineral Foundation (DMF). The DMF uses mining company funds for the welfare of affected communities, including health, education, and infrastructure.

Regulatory Enforcement and Responsible Mining: The government has enhanced tracking and enforcement of mining regulations. The National Mineral Policy emphasises sustainable mining practices that protect the environment and miners' rights. The Securities and Exchange Board of India (SEBI) now regulates ESG rating firms, enhancing transparency and accountability (SEBI, n.d.). The Ministry of Mines implements the Sustainable Development Framework (SDF) to oversee inclusive growth while safeguarding social, economic, and environmental interests. The IBM enforces the Star

Rating system under Rule 35 of the Mineral Conservation and Development Rules, 2017, to assess the environmental impact of mining operations. India aligns its mining practices with international standards, such as the Extractive Industries Transparency Initiative (EITI), to improve transparency and sustainability.

Challenges and Stricter Standards: Stricter ESG standards are making it harder to secure a social license for new mining projects globally. Restrictions exist on operations near protected areas and natural reserves, with expanding consultation requirements, especially on indigenous lands. In India, the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA), ensures forest-dwelling communities are involved in decisions about mining on their land. The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation, and Resettlement Act, 2013 (LARR Act), provides for fair compensation and resettlement for those displaced by mining activities.

7.5 India's recycling policies

India has implemented two significant regulations, the Battery Waste Management Rules, 2022, and the E-Waste Management Rules, 2022, to govern various battery types, including those used in automotive, electric vehicles, industrial, and portable applications. These rules introduce extended producer responsibility (EPR) targets and centralized provisions, aiming to align with the growing shift towards circular economies and to mitigate pollution from battery waste. Despite these regulations, India still lacks a nationwide battery recycling program managed by authorised agencies. Approximately 90% of used batteries—primarily lead-acid, rather than lithium-ion—are handled by the unorganised sector or end up in landfills, posing significant environmental and health hazards.

The country also faces challenges in collecting accurate data on electronic waste recycling, which hampers effective policy implementation. Although agencies like the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) are making strides in improving data collection, there is a need to harmonize procedures across different sources to ensure reliable data and successful policy enforcement.

Additionally, the recycling sector holds substantial employment potential. Batteries account for a significant portion of hazardous waste in India, and understanding employment dynamics in hazardous waste collection, treatment, and material recovery can provide valuable insights into the battery recycling sector. According to the latest Periodic Labour Force Survey (PLFS) for 2021-22, the material recovery sector employs 42% of workers in the waste sector, followed by waste collection. However, the waste treatment sector employs the fewest workers. With the anticipated increase in spent batteries, the small workforce in hazardous waste treatment reveals a critical gap that needs to be addressed.

The informal sector plays a crucial role in waste management. PLFS data indicate that approximately 72.3% of total employment is in informal enterprises, a trend that extends to two-thirds of industry divisions, resulting in inadequate waste handling and associated environmental risks. By leveraging the informal sector's efficiency in waste collection, there is potential to enhance the deployment of recycling technology and promote sustainability. Data on e-waste recyclers authorised by SPCBs/PCCs under the E-Waste (Management) Rules, 2026, show that Uttar Pradesh leads in e-waste recycling capacity, followed by Gujarat and Haryana. The material recovery sector operates in 12 states, with the highest employment in Tamil Nadu, followed by Karnataka and West Bengal.

Details of the two policies governing the Indian recycling sector are:

The Battery Waste Management Rules, 2022: The Battery Waste Management Rules, 2022 issued by the Ministry of Environment, Forestry and Climate Change (MOEFCC) in India seek to ensure responsible management of used batteries through the establishment of an Extended Producer

Responsibility (EPR) system. Under the EPR system, battery manufacturers and importers are responsible for the collection, recycling, and refurbishing of used batteries. This includes batteries of all shapes, sizes, weights, chemistries, compositions of materials, and uses.

The rules prohibit the disposal of used batteries in landfills and incinerators, mandating their collection for recycling or refurbishment instead. Producers can undertake these activities independently or delegate them to authorized entities. Moreover, the rules introduce an online portal facilitating the exchange of Extended Producer Responsibility (EPR) certificates between producers and recyclers/refurbishers. This measure aims to enhance the efficiency and effectiveness of the EPR system implementation. The producers, in addition to the collection and recycling targets have minimum requirement for the use of recycled materials in the new batteries. Additionally, manufacturers are prohibited from using heavy metals beyond specified limits in new batteries.

Complementing the Extended Producer Responsibility (EPR) system, the rules stipulate environmental compensation to be paid if EPR goals, obligations, and responsibilities are not fulfilled, aligning with the Polluter Pays Principle.

The rules represent a significant stride in ensuring the responsible management of used batteries in India. They are poised to mitigate the environmental repercussions of battery waste while fostering the recycling and reuse of batteries.

The E-Waste Management Rules, 2022: The E-Waste (Management) Rules, 2022, usher a fresh Extended Producer Responsibility (EPR) framework for e-waste recycling in India, marking a significant stride in e-waste management. These regulations are poised to curtail environmentally harmful disposal practices and foster the recycling and reuse of e-waste.

Under the new rules, manufacturers, producers, refurbishers, dismantlers, and recyclers of e-waste must register on a portal administered by the Central Pollution Control Board (CPCB) to operate legally. Transactions with unregistered entities are prohibited to ensure regulatory compliance and accountability. The E-Waste Management Rules include a provision for reducing hazardous chemicals in the manufacture of Electrical and Electronic Equipment (EEE). It requires that every manufacturer of EEE and their components ensure that their goods do not include lead, mercury, or other dangerous compounds in concentrations more than the maximum permitted.

Producers of notified EEE (Electric and Electronic Equipment) have been allocated annual e-waste recycling targets based on the generation from previously sold EEE or, where applicable, based on EEE sales. The targets are 60% for the years 2023-2024 and 2024-2025, 70% for the years 2025-2026 and 2026-2027, and 80% for the years 2027-2028 and 2028-2029.

The new rules also include provisions for the management of solar PV modules/ panels/cells, the generation and transaction of EPR certificates, environment compensation, verification and audit, and the constitution of a Steering Committee to oversee the overall implementation of the rules.

The E-Waste (Management) Rules also include provisions for worker recognition and registration, skill development, monitoring, and protecting worker safety and health. However, it is notable that none of these rules specifically address the mainstreaming of the informal sector, particularly those involved in e-waste collection. This informal sector plays a crucial role in the e-waste recycling system. To enhance the effectiveness of worker recognition under the e-waste rules, it is essential to include considerations for this segment, acknowledging their contributions and integrating them into formalised workforce.

7.6 India's strategic efforts to secure CETM supply

India has strategically aligned its foreign policy and strategic initiatives to secure CETMs essential for its economic and technological development.

India's foreign policy for CETMs is a comprehensive strategy involving bilateral agreements, multilateral partnerships, ESG compliance, and strategic geopolitical alignments to secure a responsible and reliable supply of critical minerals.

7.6.1 Mineral Security Partnership (MSP)

India joined the MSP in June 2023, led by the United States, to collaborate with other advanced economies in securing critical mineral supplies. Potential benefits could include new flows of investment into India's critical mineral industry. They could also include cooperation on R&D and information sharing among partners. Indian overseas mineral investments could conceivably benefit from participating in MSP-pooled financing in strategic projects that have been strongly vetted (Goel et al. 2023).

More broadly, India's partnership in the MSP signals its willingness to align with the US and its allies' political bloc, and the willingness of that political bloc to partner with India. Such an alignment will provide India with an important network of global allies in the increasingly geopolitical landscape of critical minerals. This may prove essential moving forward, as India will have access to a broader pool of technical, financial, market, and scientific resources. But MSP partnership also comes with strings attached. Most notably, the MSP is very much a principle-oriented partnership, and it will be expected that India abides by the MSP Principles both in its domestic mining industry and overseas activity (US Department of State, n.d.). Such compliance implies India will be made to gradually align with the ESG-oriented approach of current MSP partners (Goel et al. 2023).

In June 2023, India became the newest partner (14th member country) in the Minerals Security Partnership (MSP), to accelerate the development of diverse and sustainable critical energy minerals supply chains globally while agreeing to the principles of the MSP, including environmental, social, and governance standards.

7.6.2 Bilateral Agreements

India, recognising the importance of international collaboration, entered into bilateral agreements with key countries such as Australia and Japan to secure access to critical raw materials. With Australia, it has entered an MoU to increase trade and investment in critical minerals, secure Indian supply through investment in Australia's mining industry, diversify global mineral supply chains, and enhance R&D and scientific cooperation. India and Japan have established a bilateral agreement focused on critical minerals through the "Japan-India Minerals and Metals Partnership". This agreement aims to enhance cooperation and ensure the secure supply of critical minerals essential for both countries' industrial and technological needs.

Table 11: India's international action on critical minerals

Country	Status	Detail
Australia	Negotiated (2020)	Trade, cooperation, and investment on critical minerals
Japan	Negotiated (2012)	Trade and investment on rare earth elements
Minerals Security Partnership	Negotiated (2023)	Trade, cooperation, and investment on critical minerals
Argentina	Negotiated (2020), future MoU in progress	Lithium exploration and investment
Brazil	In progress	Exploration and investment in lithium, copper, and nickel
Chile	In progress	Exploration and investment in lithium, copper, and nickel

India and Australia: Australia, a mineral-rich country, was the world's largest producer of lithium in 2021 (53% of global production) and ranked in the top five producers of antimony, cobalt, and manganese ore. India and Australia have signed a Memorandum of Understanding (MoU) on critical minerals in June 2020 that laid out mutual objectives to increase trade and investment, secure Indian critical mineral supply through investment in Australia's mining industry, diversify global mineral supply chains, and enhance R&D and scientific cooperation (Ministry of Mines, n.d.). The MoU's emphasis on securing Indian supply through investment in Australia is noteworthy.

From an Indian perspective, Australia stands out as a strategic partner given its abundance of mineral resources, experience in mining and processing, and existing trade relations with India. For Australia, partnership with India helps achieve strategic objectives of attracting international investment and accessing new sources of demand outside of China. India's Make in India and self-reliant India policies provide Australia with confidence in the Indian market's future growth in mineral demand. The MoU has paved the way for other significant agreements and future steps. In 2023, it was revealed that five projects—two focused on lithium and three on cobalt—are under consideration for due diligence and potential investment by both nations (The Hon Madeleine King MP 2023).

Additionally, the Australia-India Economic Cooperation and Trade Agreement (ECTA) includes crucial provisions for critical minerals, notably the elimination of tariffs on a variety of essential minerals (Department of Foreign Affairs and Trade, n.d.). This tariff removal is expected to boost Indian imports of Australian critical minerals and further encourage Indian investments in Australian critical mineral projects, as offtake agreements will become more profitable with the lower tariffs.

The Comprehensive Economic Cooperation Agreement (CECA) between Australia and India came into force in December 2022, establishing a strategic framework to foster collaboration in exploration, mining, extraction, and processing technologies for critical minerals (Ministry of Commerce and Industry 2022). The New Delhi Leaders' Declaration at the G20 Summit emphasized the critical role of these minerals in supporting the global energy transition, incorporating this priority into the declaration (G20 India 2023a). The declaration also acknowledged the High-Level Voluntary Principles for collaboration on Critical Minerals for Energy Transition, proposed by the Government of India, signalling a cooperative approach to meeting critical mineral demands essential to sustainable energy goals (G20 India 2023b).

7.6.3 Setting up of KABIL

Khanij Bidesh India Limited (KABIL), established in August 2019, is a joint venture between National Aluminium Company Limited (NALCO), Hindustan Copper Limited (HCL), and Mineral Exploration Corporation Limited (MECL). Its main objective is to identify, acquire, explore, develop, mine, and process strategic minerals abroad to meet both commercial and domestic demands. Despite India's moderate success in securing oil and gas equity assets for energy security, the experience from those endeavours could benefit the country's pursuit of mineral security.

KABIL has been instrumental in securing lithium supply for India, diversifying mineral sources, strengthening bilateral relations, and expanding into Africa. Particularly active in Argentina, KABIL is developing lithium block acquisitions there (Law 2023). Its goal is to "identify, acquire, develop, process, and make commercial use" of critical minerals like cobalt, copper, lithium, and nickel. Outside Argentina, KABIL seeks similar engagements in Brazil and Chile, considering acquisitions or partnerships and long-term asset leasing. These efforts aim to provide India with preferential access to off-take and strengthen relations with strategic developing economies.

KABIL's potential to expand its portfolio into Africa aligns with India's decade-long focus on strengthening ties with Africa in areas like maritime security, health, and trade (Pant and Mishra 2021). Increased India-Africa cooperation could extend to minerals and the broader energy transition. Africa's rich mineral resources and desire to diversify investments away from China support India's vision to procure critical minerals and offer a development model different from China's.

Recent activities of KABIL include:

1. **Australia**:
   - Under an MoU signed between KABIL and the Critical Mineral Office (CMO) of the Department of Industry, Science and Resources (DISR), Australia, in March 2022, both parties agreed to joint due diligence and investment in lithium and cobalt mineral assets.
   - PwC Australia was appointed as a consultant in January 2023 to start due diligence activities for selecting suitable projects for investment.
   - Five projects (two lithium and three cobalt) were shortlisted in March 2023, and detailed due diligence has since commenced, with both sides actively engaging to expedite the process.
2. **Argentina**:
   - Following an MoU with CAMYEN, a state-owned enterprise of Catamarca province, signed in December 2020, KABIL formalised an agreement in February 2023 to explore and develop five lithium blocks in Catamarca Province.
   - In June 2023, KABIL's Board approved the "Draft Exploration and Development Agreement" with CAMYEN and a proposal to open a branch office in Catamarca. The Ministry of Mines has approved the agreement.
3. **Chile**:
   - In May 2023, KABIL signed a Non-Disclosure Agreement (NDA) with ENAMI, a state-owned mining company, to evaluate potential business opportunities in lithium exploration, extraction, processing, and commercialisation.

8

CHALLENGES AND OPPORTUNITIES FOR INDIA

8 CHALLENGES, OPPORTUNITIES AND RECOMMENDATION

In light of India's growing energy needs and the global shift towards clean energy technologies, ensuring a responsible and reliable supply of CETMs has become a national imperative.

In this last chapter, we outline India's current value chain status, its policy developments, strategic initiatives and also some challenges.

8.1 India's Policy, Implementation and Capacity Gaps

8.1.1 Exploration and Mining

- While the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act) provides a legal framework, there is a need for more specific policies and incentives to encourage the exploration and mining of critical minerals. This includes streamlining the auction process for critical minerals by encouraging participation from major mining companies that have the technical expertise mining critical and deep-seated minerals.
- The new Exploration License (EL) system has weak incentives for junior mining companies as there is no mining rights conferred on the EL holder. The returns on investment are contingent upon the state successfully auctioning the explored block and the commencement of mineral production. Exploration is a high-risk and capital-intensive process requiring assured returns in the future. The government should reexamine the scope of ELs to address this gap.
- The exploration and mining of critical minerals require advanced technology. This includes geophysical and geochemical surveying, remote sensing, and data analytics to identify and develop mineral resources more efficiently. The technologies are capital intensive and require constant upgradation. Globally, private mining companies have the capacity and expertise to support such technological advancement. Technological collaboration and knowledge sharing between government and private sector is crucial for resource efficiency.
- Lastly, engaging in international partnerships and agreements can help India access technology, investment and expertise from more developed mining sectors. Collaborations with countries like Australia, Canada, and the United States can be particularly beneficial.

8.1.2 Processing and Refining

- Despite having significant mineral resources, India's capabilities in processing and refining these minerals remain underdeveloped. It is critical that India develops capacity and infrastructure in these areas.
- Indian facilities often lack the sophisticated technologies required for high-purity extraction and refining of critical minerals, which are crucial for high-tech applications. Collaboration with international technology providers, academic institutions, and research organisations can facilitate the transfer of cutting-edge technologies and innovations.
- There is also a strong need to build and upgrade processing and refining facilities within India. This includes establishing pilot plants, research and development centres, and large-scale processing units to handle critical minerals. Government incentives, such as subsidies, tax breaks, and low-interest loans, can help attract private investment. Encouraging PPPs can accelerate the development of processing and refining capabilities. These

partnerships can leverage the strengths of both the public and private sectors, combining government support with private sector efficiency and innovation. Collaborations with nations like Australia, Canada, and the United States can facilitate technology transfer, joint ventures, and investment in processing infrastructure.

- Besides, the regulatory framework and financial incentives for establishing processing and refining facilities are not sufficiently developed. High capital costs, regulatory complexities, and a lack of targeted financial support deter investments in this sector.
- Another hurdle is lack of skilled work force. Establishing training programs, vocational courses, and collaborations with educational institutions can enhance the skills and expertise required for advanced mineral processing. Besides, implementing sustainable mining and processing practices is crucial for minimising environmental impact. This includes adopting cleaner technologies, recycling waste materials, and adhering to stringent environmental regulations. Promoting green mining practices and ensuring compliance with international environmental standards will be vital.

8.1.3 LCT Manufacturing

- India's transition to a low-carbon economy hinges significantly on the development and manufacturing of low carbon technologies (LCTs). These technologies include renewable energy systems, electric vehicles (EVs), energy storage solutions, and energy-efficient appliances. India has set ambitious targets for renewable energy capacity, aiming to achieve 500 GW by 2030. The demand for EVs is also rising, driven by government initiatives and incentives. However, the domestic manufacturing capacity for LCTs is still in its nascent stage.
- The supply chain for critical components used in LCTs, such as lithium-ion batteries, solar cells, and wind turbine parts, is underdeveloped. India relies heavily on imports for these critical components, making the supply chain vulnerable to international market fluctuations and trade policies.
- The technology required for manufacturing advanced LCTs is often lacking. Many Indian manufacturers depend on outdated technologies, resulting in lower efficiency and higher costs compared to global standards. High capital investment is required for setting up manufacturing facilities for LCTs. Access to finance is a significant barrier, especially for small and medium-sized enterprises (SMEs) in the sector (Singhaphandu and Pannakkong 2024).
- The government can play a pivotal role by providing subsidies, tax breaks, and incentives to manufacturers of low carbon technologies. Policies like the Production-Linked Incentive (PLI) scheme for high-efficiency solar PV modules and advanced chemistry cell batteries are steps in the right direction (Chadha, Sivamani, and Bansal 2023b).
- Developing a robust domestic manufacturing ecosystem is crucial. This includes setting up dedicated manufacturing zones, providing infrastructure support, and fostering clusters of related industries to create synergies and reduce costs.
- Investing in R&D to innovate and develop indigenous technologies is essential. Government funding, private sector investment, and public-private partnerships can drive innovation in LCTs. Establishing centres of excellence and innovation hubs can facilitate this process.
- Building a skilled workforce is vital for the LCT manufacturing sector. Vocational training programs, partnerships with educational institutions, and on-the-job training initiatives can help bridge the skill gap. Collaborating with global leaders in LCTs can help India access advanced technologies and best practices. Joint ventures, technology transfer agreements, and strategic partnerships with countries like Germany, Japan, and the United States can accelerate the growth of domestic manufacturing capabilities.
- Developing integrated and resilient supply chains for critical components is crucial. Encouraging local production of components like lithium-ion batteries, solar cells, and wind turbine parts can reduce dependency on imports and enhance supply chain security. Besides, creating a stable and

growing market for LCTs is essential. Government procurement programs, incentives for end-users, and awareness campaigns can stimulate demand. For example, subsidies for EV purchases, rooftop solar installations, and energy-efficient appliances can boost market growth.

- While the PLI schemes incentivise production at various supply chain levels and favour large manufacturing firms, they have not achieved the expected growth in domestic manufacturing capacity. Benefits under the PLI scheme can be claimed even if many components are imported and the final product is assembled in India. Many PLI schemes focus on the finished product rather than the technology and raw materials used in manufacturing. To build resilient supply chains, incentive schemes should also target different supply chain stages, starting from mineral procurement and processing.

8.1.4 Recycling

Inadequate waste collection and segregation infrastructure hampers effective recycling, as e-waste is often handled by informal collectors without proper training or safety measures. This informal waste collection system not only struggles with these challenges but also inadvertently supplies waste to illegal recyclers. Therefore, it is crucial to mainstream the informal collection system to enhance both safety and efficiency in e-waste management.

- Authorised recycling facilities are limited and typically located in major cities, making it difficult for those in rural areas to recycle. Most of the e-waste is funnelled to illegal recyclers, who are able to offer better prices for the materials, further complicating the recycling landscape.
- The informal sector, which processes a significant portion of e-waste, often lacks advanced recycling technologies, presenting a challenge in integrating these informal players into the formal system. To address this, illegal recycling units need to be identified and closed down, also mainstream the informal waste collection system. Integrating the informal sector into the formal recycling ecosystem and improving their working conditions will enhance environmental and occupational safety. Establishing Resource Recovery Parks (RRPs) can facilitate waste exchange and support both formal and informal recycling efforts.
- The absence of accurate data on e-waste volume and composition impedes effective recycling strategies, and weak enforcement of existing legislation fails to ensure compliance with environmental standards. There is a need to inventorise e-waste data at a national and state-level. Harmonizing data collection and reporting will support the effective implementation of policies like the Battery Waste Management Rules, 2022, and the E-Waste Management Rules, 2022, which set annual targets for collection and treatment.
- Investment in research and development is needed to create innovative and cost-effective recycling technologies, and low awareness about recycling technologies among consumers and businesses further limits recycling efforts. To address this, the government could play a pivotal role by supporting R&D initiatives focused on enhancing efficiency and reducing recycling costs.
- Providing adequate incentives and effectively implementing waste policies are crucial steps, as is creating a market for recycled materials through incentives based on product quality and technology.

8.1.5 ESG

- On the environmental front, India should develop and enforce robust regulations to minimize industrial impacts, promote sustainable practices, and ensure rigorous Environmental Impact Assessments (EIAs) for new projects.
- Socially, India must prioritise worker rights and safety, engage positively with local communities, and advance diversity and inclusion within the workforce.

- India should implement the adoption of FPIC for mining and processing activities in indigenous lands. The Forest Conservation Rules of 2022 minimise FPIC requirements before granting environmental approvals and provides no powers to the Ministry of Tribal Affairs (MoTA) in the approval of projects affecting indigenous communities.
- In terms of governance, enhancing transparency and accountability through better financial reporting, ethical leadership, and stakeholder engagement is crucial.
- By strengthening these ESG standards, India can improve its environmental and social outcomes, boost investor confidence, and enhance its competitive position on the global stage.
- There needs to be a renewed focus on recycling collected revenues through bodies such as the District Mineral Foundation (DMF) to increase social welfare. Getting greater social acceptability of mining projects would also ensure that projects do not get delayed and there are no ensuing cost overruns.

8.2 Insights from Global Trends for India

India's strategy for critical minerals must be informed by global trends, geopolitical dynamics, and market conditions. Here are key insights related to supply, investments, price trends, tariffs, duties, non-tariff barriers, the bankability of contracts and agreements, and the development of metals exchanges. By leveraging these insights, India can effectively secure its supply chain and enhance its position in the global market for critical minerals.

Geopolitical tensions, such as those between the US and China, and sanctions on countries like Russia and Venezuela, have highlighted the need for diversified supply sources. India must explore partnerships beyond traditional markets to reduce dependency on any single nation. Forming strategic alliances with resource-rich countries, such as Australia, Canada, and certain African nations, can secure stable and long-term access to critical minerals. Diplomatic engagements and trade agreements should be leveraged to strengthen these ties.

India's strategic position as a potential counterweight to China is recognised by the West and its allies. This geopolitical dynamic has facilitated India's entry into initiatives such as the Minerals Security Partnership and its minerals agreement with Australia. Collaborating with India presents an opportunity to access new sources of capital and gain early access to a market with the potential for substantial future mineral demand. By incorporating India into agreements and frameworks, countries can tap into India's vast mineral resources and contribute to global mineral supply chains. By fostering collaboration with India, nations can advance their broader strategic interests in the Indo-Pacific region and beyond. Through partnerships and agreements, India can leverage its mineral wealth to drive economic growth and meet domestic and international demand for minerals.

India should continue to actively participate in multilateral trade and economic frameworks that prioritise critical minerals. By engaging in initiatives such as the Quad Critical Minerals Partnership Act, India can collaborate with other nations to secure responsible and reliable critical mineral supply chains. Such partnerships also provide technological, financial, and logistical support.

8.2.1 Tariffs, duties and non-tariff barriers

Understanding and navigating tariffs and trade policies is crucial. Countries with high tariffs on critical minerals can impact the cost and availability of these resources. India should negotiate favourable trade terms and seek exemptions or reduced tariffs for critical minerals in trade agreements. The non-tariff barriers include export restrictions, quotas, licensing requirements, and environmental standards. India should engage in international dialogues to address these barriers and ensure fair access to global markets. This can be achieved through bilateral or multilateral trade agreements and by participating in international forums such as the WTO.

8.2.2 Bankability of contract and agreements

The confidence of global investors in the stability and predictability of India's mining and minerals sector is crucial. Strengthening the legal framework, ensuring contract sanctity, and providing clear policies on investment incentives and mineral rights can enhance the bankability of contracts and agreements. Developing risk mitigation mechanisms, such as political risk insurance and investment guarantees, can attract foreign investments. Collaborating with international financial institutions and development banks to create a supportive investment environment is also beneficial.

8.2.3 Insufficiently developed Metals Exchange

India's lack of a developed metals exchange hampers transparent pricing and efficient trading of critical minerals. Developing a national or regional metals exchange could enhance price discovery, reduce market volatility, and attract global traders and investors. India should work towards integrating its metals exchange with global markets, adopting international standards for trading, and leveraging technology for real-time trading and price transparency. This would make Indian markets more attractive to international players and help stabilize prices.

8.2.4 China's global dominance

China's dominance of critical mineral supply chains is a particularly pressing concern for India. Tensions between India and China have accelerated over the last decades due to border disputes, China's growing influence in the Indo-Pacific, and increased geo-economic competition.

This is particularly true for minerals such as lithium which are predominantly traded on a regional basis. From a geopolitical perspective, it is essential for India to balance these interests by seeking to reduce its dependence on China while building its clean energy industry, particularly within a context of growing trade protectionism, China-India tensions, and fierce economic competition.

China's control of critical mineral supply chains, coupled with its growing willingness to use export restrictions, is a potential threat to India's climate and economic interests. As India develops its supply chain for clean energy technologies, it is imperative that it seek to diversify its critical mineral sourcing and not build exploitable vulnerabilities on China. This is particularly relevant against the backdrop of escalating India-China border tensions and geostrategic competition.

China's continuation of industrial policy at home and its push toward further industry consolidation will make it difficult for India, and other countries, to quickly diversify critical mineral markets. Additionally, India may often find itself competing overseas with Chinese investors, particularly in developing economies. Chinese investors benefit from state-support, technological advantages, and proven experience that will make them difficult competitors for India.

Nevertheless, growing international momentum to diversify supply chains and the geopolitical tensions between various countries and China opens a substantial opportunity for India. As countries seek to diversify away from China, they will require new sources of capital and new avenues of demand growth. India can provide both. By creating incentives to deploy more capital in the developing world and by growing its own demand for minerals, India can directly benefit from global efforts to diversify away from China and position itself as a crucial critical mineral investment and trade partner for the decades ahead.

8.2.5 Insights from mineral-rich countries

Mineral-rich countries aim to move up the value chain, demanding a larger piece of mineral value chains beyond supplying raw materials. Strategies include fostering private-led agreements, pursuing export bans on unprocessed ores, and forming public-private partnerships.

As India seeks to build its supply chains for critical minerals, it will be important to understand the interests and motivations of mineral-rich developing economies. Certain trends such as nationalisation and the formation of cartels threaten to constrain critical mineral investment and supply, thus harming India's supply chain security. Other trends, such as a renewed desire for value addition, provide both opportunities and threats to India's interests. For example, if India were to primarily seek to source unprocessed minerals from mineral-rich countries while building its own domestic processing capacity, it may encounter political and contracting obstacles. On the other hand, India could potentially gain a foothold within mineral-rich economies by helping provide financing and technical support for local value addition (Goel et al. 2023).

China's overseas investment strategy may provide a useful case study. By encouraging private overseas investment, China has successfully attained supply to meet its needs as the world's primary consumer of raw minerals. In some cases, Chinese foreign investments are tied to offtake agreements. In the DRC, for example, China's ownership of mining assets can be directly linked to the flow of approximately 80 percent of Congolese cobalt to China. China has also been the main investor in Indonesian nickel refining, which has helped keep refined Indonesian nickel flowing to the Chinese market.

India's strategy to access mineral supply will differ from China's playbook over the last decades. But Indian policymakers should learn, based on the Chinese model, that foreign investments can often be explicitly or implicitly tied to offtake agreements, particularly as critical mineral supply chains become increasingly vertically integrated with the participation of original equipment manufacturers in mining investments and offtake agreements. For India, a novel sourcing strategy may acknowledge and seize on the desire of mineral-rich countries to capture more value from their production. Such a strategy would allow India to position itself as a leader in the Global South, fill the financing gap in developing economies, and gain increased access to mineral supply (Goel et al. 2023).

India may prove an appealing partner for Australia and Canada as they seek to attract investment and find new sources of demand. China has overwhelmingly been the primary investor and source of demand for minerals over the last decade. As countries like Australia and Canada seek to wean off Chinese dependence, India can step into the resulting gap, positioning itself as an important investment partner and new market, and locking in future critical mineral supply.

8.2.6 Insights from importing countries

India's early efforts to build its own critical mineral supply chains will face the challenge of competing with industrial policies from other advanced economies. This challenge is both economic and political. Policies like the Inflation Reduction Act (IRA) have allocated substantial amounts of subsidy funding to support specific industries or initiatives. Due to the significant financial backing provided by these subsidies, it will be challenging for other countries or entities to compete with the beneficiaries of these policies. The large-scale capital deployment gives a competitive advantage to those receiving the subsidies, making it difficult for others to match their financial resources and incentives. But these policies have also shown the political pushback that any country pursuing aggressive subsidies will face. India therefore faces the hurdle of creating incentives to be an economically competitive critical mineral and manufacturing destination, but also ensuring that it does not make political enemies along the way.

On the international front, it will be important for India to act quickly to build stronger relationships with mineral-rich developing economies, as many advanced economies are already taking similar initiatives. Indian policymakers will need to assess what role ESG will take in their outward engagement, measuring the disadvantages—such as more barriers to investment in developing economies—and advantages—such as increased geopolitical and trade alignment with advanced economies and the future of the market (Goel et al. 2023).

8.2.7 Rising Plurilateral Partnerships and Frameworks

Advanced economies are actively seeking to diversify critical mineral markets through various plurilateral partnerships and frameworks. One notable example is the Minerals Supply Partnership (MSP), launched in 2022 and led by the United States, which includes Australia, Canada, Japan, South Korea, the EU, and India (which joined in 2023). The MSP aims to develop diverse and sustainable global supply chains for critical energy minerals by providing financial and diplomatic support for strategic projects. Critical minerals are also being integrated into broader trade and economic frameworks such as the Indo-Pacific Economic Framework for Prosperity and the Quadrilateral Security Dialogue (Quad).

India's participation in multilateral networks like the MSP, the Quad, and the IGF is essential for reinforcing its critical mineral strategy and securing supply chains. These partnerships offer India a collaborative platform with like-minded nations, helping to enhance the resilience and sustainability of its mineral supply. Additionally, technical expertise from organisations like the IGF can assist India in adopting best practices, improving the credibility and sustainability of its mining sector.

The Indian government is also planning strategic meets. The Ministry of Mines organised an Outreach Programme in November 2023 to involve international stakeholders in critical minerals auctions and global action. The G20 New Delhi Leaders' Declaration held in September 2023 acknowledged the role of critical minerals in energy transition and included principles for collaboration on critical minerals for energy transition proposed by the Indian government.

8.2.8 Increasing role of Multilateral Organisations

Multilateral organizations such as the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), Organisation for Economic Co-operation and Development (OECD), and the World Bank are expanding their efforts on critical minerals, each playing a distinct role. The IEA is enhancing its capacity to be the premier source of data and market tracking. IRENA, while known for its in-depth reports, has recently established the Collaborative Framework on Critical Materials for the Energy Transition to foster dialogue and coordinate activities among members. The OECD focuses on in-depth reports and supply chain transparency, while the World Bank centres on implementation through initiatives like its Global Energy and Extractives Practice and Climate-Smart Mining Initiative, ensuring mining practices are environmentally sustainable and beneficial to local communities.

These organisations offer valuable resources, data, and frameworks for managing critical minerals efficiently and sustainably. The IEA's data and market tracking capabilities help understand global critical mineral markets and trends. IRENA promotes dialogue and coordination among member states, and the World Bank ensures sustainable and community-beneficial mining practices.

By engaging with these organisations, India can prioritise investment in R&D for advanced extraction technologies and recycling methods, reduce dependency on imported minerals, and enhance domestic capabilities. This engagement can also improve transparency and sustainability standards, strengthening India's position in the global critical minerals landscape and ensuring economic resilience.

8.2.9 Increase in Bilateral agreements

Advanced economies are aware that they will not be able to independently meet their demand for critical minerals. This has led to an accelerating number of bilateral critical mineral agreements with mineral producing countries. As mentioned earlier, many of these agreements have been between advanced economies and Australia and Canada, such as the US-Canada agreement, EU-Canada agreement, and Australia's agreements with the United States, United Kingdom, India, South Korea, Japan, France, and Germany. Advanced net-importing economies have also signed agreements amongst themselves, such as the various 30D-related agreements discussed earlier.

India should proactively engage in and expand bilateral and multilateral agreements to secure a responsible and reliable supply of critical minerals. This involves building on existing partnerships with countries like Australia and Canada to ensure long-term supply and cooperation. Additionally, India should explore and establish new alliances with other mineral-rich nations to diversify its sources. Collaborating with advanced economies can provide access to shared resources, technology, and expertise. By leveraging its geopolitical and economic position, India can negotiate favourable terms in these agreements.

8.2.10 Rising importance of ESG considerations

India can learn significantly from the global emphasis on ESG criteria in the mining sector. ESG concerns address critical aspects such as environmental impact, social responsibility, and governance practices. Environmental criteria focus on minimising the negative effects of mining on the natural environment, while social criteria involve effectively managing relationships with employees, suppliers, customers, and communities. Governance criteria cover leadership quality, executive pay, audits, internal controls, and shareholder rights (Johnson, n.d.). As investors increasingly seek responsible investment opportunities, integrating ESG principles can enhance sustainability and accountability in mining practices. However, this integration also introduces uncertainties in mineral demand and supply due to evolving regulations and stakeholder expectations.

The focus on ESG principles is particularly relevant for India, especially given the challenges associated with shifting global processing capacity away from China. According to the IEA's 2023 Critical Minerals Market Review, critical mineral processing remains largely concentrated in China and is expected to continue in that direction. For countries with stringent ESG standards, establishing processing facilities domestically is challenging due to the significant environmental impact associated with mineral processing. For example, Malaysia, which hosts one of the few rare earth elements (REE) processing operations outside China, has faced substantial controversy and risk due to environmental issues.

Indian policymakers must carefully weigh the trade-offs of various ESG strategies as they seek to attract more processing capacity. By adopting sustainable mining practices, India can reduce its dependence on imported minerals, ensure ethical practices, and enhance operational efficiency. Engaging with local communities and addressing their needs can help mitigate risks of social unrest and regulatory backlash. Transparent and ethical governance practices will further minimise legal and reputational risks, contributing to long-term value creation in the mining sector.

Under the governance pillar, it is crucial to examine the provisions of relevant legislation to ensure that adequate powers and accountability are vested at the State level, especially since minerals are owned by the State Governments. A key area for improvement is the management of the concession system, where arms-length mechanisms should be employed to reduce conflicts of interest and improve transparency. Additionally, the establishment of quasi-independent authorities with diverse sectoral representation would enhance governance and decision-making. Modernising dispute resolution mechanisms is equally important, with a shift towards independent tribunals and adjudicating bodies rather than relying solely on government processes.

8.2.11 Growing Emphasis on Recycling

The global emphasis on recycling and the circular economy highlights the importance of sustainable development and resource efficiency. By focusing on minimising waste, extending product lifecycles, and creating a sustainable resource loop, India can conserve natural resources and reduce environmental impacts. Recycling not only conserves resources but also generates jobs in collection, processing, and manufacturing. Innovations in recycling technologies enable the efficient recycling of a broader range of materials. By adopting circular economy principles and forming alliances, India can promote sustainable practices and meet the increasing consumer demand for environmentally friendly products and services. Integrating these lessons into India's mining strategy can support sustainable growth and improve its global standing in the critical minerals market.

8.3 Challenges and opportunities with respect to six shortlisted CETMs

In this section, we provide you challenges and opportunities for India in each of the six shortlisted CETMs.

8.3.1 Copper

Challenge: India is not self-sufficient in copper ore production, relying on both indigenous mines and imported concentrates. Hindustan Copper Limited (HCL) is the only state-owned primary copper producer, while private sector companies import concentrates. Domestic copper demand is met through domestic production, imports, and recycling of scrap for secondary copper. Two other players are Hindalco Industries Ltd. and Vedanta Resources Limited. Adani Group's Kutch Copper Limited is constructing a 1 million tonne smelter refinery, with the first 500,000 tonnes set to start operating in 2024. HCL is the only vertically integrated copper company in India, while Hindalco and Vedanta rely on imported concentrates and own mines abroad.

Opportunity: India has large quantities of copper resources and must prioritise increasing mining operations. More private investments in copper mining from major domestic companies can boost domestic mineral production. Currently, PSUs have not been able to meet the domestic requirements for copper concentrates. To meet the growing copper demand, India should enhance its copper refining and downstream manufacturing capabilities. Reassessing trade terms with major copper ore suppliers like Chile, Indonesia, Peru, Australia, and Panama, and encouraging the use of scrap for secondary copper production are crucial steps. The government could incentivise smelters, refiners, and fabricators to use scrap, reducing import dependence and promoting circularity in the domestic supply chain. Finally, preparing a detailed demand estimation for future copper use across various sectors will help provide demand certainty for new market entrants.

8.3.2 Lithium

Challenge: The J&K lithium resources are currently at an inferred G3 stage, requiring further exploration to determine economically recoverable reserves. International experience shows it takes an average of 16.5 years to develop projects from discovery to first production (International Energy Agency 2021b). India's R&D expenditure in the lithium sector is significantly lower than that of resource-rich nations. The government needs to explore providing direct funding through grants and preferential loans to support R&D and pilot plant developments (IEA 2023b). Lithium, which has been processed in countries like China, is not eligible for the benefits provided under the free trade agreement between Australia and another country. (Free trade agreements often include provisions that allow for reduced tariffs, easier market access, and other economic advantages for goods traded between the signatory countries).

Opportunity: The establishment of lithium refineries in India is not only crucial for capitalising on current import opportunities but also for preparing the nation to leverage its domestic lithium reserves. By investing in refining capabilities today, India can build a robust industry ready to process domestically sourced lithium in the future. Four states—Andhra Pradesh, Gujarat, Odisha, and Tamil Nadu—have been identified as prime locations for lithium refineries due to their existing chemical processing infrastructure and proximity to ports (Goel et al. 2023). These states are part of the Petroleum, Chemicals & Petrochemicals Investment Regions (PCPIRs), which are designed to streamline the development of chemical industries.

India's strategic trade frameworks, particularly with Australia position the country favourably for importing lithium concentrates for domestic use or export. The Australia-India Strategic Research Fund offers grants to enhance collaboration on critical minerals processing, recycling, and India's strategic trade frameworks, particularly with Australia, Chile, and the US, position the country favourably for importing lithium concentrates for domestic use or export. tailings reclamation, which could provide India with essential raw materials and technologies.

8.3.3 Manganese

Challenges: A significant portion of India's manganese ore is exported in its raw form, preventing the country from fully capitalising on its manganese resources. Establishing a localised manganese value chain requires substantial investments in infrastructure, including smelters and refineries. There is a need for skilled labour to support the development of this value chain, which poses a challenge given the current job scarcity and declining number of mining engineering graduates. Adherence to stringent environmental regulations is necessary, adding complexity and cost to establishing and operating manganese processing facilities. India's inconsistent rankings in the Fraser Institute's Mining Attractiveness Index reflect a pessimistic investment climate in mining. Instances of authorities backtracking on permits and an uncertain regulatory environment further discourage private investment.

Opportunity: Establishing a localised manganese value chain would promote job creation and stimulate economic growth, enhancing the nation's overall economic resilience. A domestic manganese value chain would reduce India's dependence on imported manganese products, fostering self-reliance in critical minerals. Local processing would curtail the necessity to transport large quantities of manganese ore, contributing to a reduction in air pollution. MOIL operates several mines and plants, contributing significantly to India's manganese production and addressing nearly 46% of the country's total requirement for manganese dioxide ore. MOIL's diverse production capabilities, including high-grade ores for various industries, position it as a key player in developing a robust domestic manganese industry. Lower customs duties on raw manganese (2.5% Most Favoured Nation import duty) compared to finished products (10%) boost domestic demand. The Australia-India Economic Cooperation and Trade Agreement (ECTA) facilitates zero duty on many minerals, including manganese, promoting trade and investment. Amendments to the MMDR Act, the Atmanirbhar Bharat policy, and bilateral engagements with producer countries indicate positive moves to attract private investment in mining. These initiatives aim to create a more favourable investment climate and enhance India's capacity to develop its mineral resources.

8.3.4 REEs

Challenge: India heavily relies on China for the majority of its rare earth resources, highlighting a significant vulnerability in its supply chain, exposed during the 2020 border standoff. Despite possessing the world's fifth-largest resources of rare earth elements (REEs), India has not achieved self-sufficiency and continues to depend on imports of rare earth magnets and other value-added products. The value chain for REEs in India is underdeveloped, particularly in the midstream and downstream sectors. The industry is primarily controlled by the government-run Indian Rare Earths Limited (IREL). Currently most of the rare earths which are being recovered are in the form of placer deposits along the peninsular coastline Geologically, this indicates that there is a primary source somewhere inland, but exploration is needed to discover it. Again, the issue for increasing self-reliance comes back to high risk, high reward exploration, which can only be done by private sector using high technology and venture capital.

There are no direct programs dedicated to developing the REE value chain, and existing initiatives have not sufficiently addressed this gap. The technology required to convert rare earth oxides into metals or alloys is proprietary and controlled by a few countries, making it difficult for India to develop its own processing capabilities. Lack of local technology expertise and the absence of commercial-scale proven technology transfer are major barriers to establishing a comprehensive REE industry in India. Mining and extraction processes for rare earths are capital-intensive, energy-consuming, and produce toxic by-products, adding to the complexity and cost of developing a domestic REE industry.

Opportunity: India has significant potential with the world's fifth-largest resources of rare earth elements, particularly light rare earths, and the capability to purify Neodymium and Praseodymium to 99.9% purity. The FAME II initiative, aimed at promoting electric vehicles, is expected to drive demand for permanent magnets and related REE products, creating a significant opportunity for domestic REE development. Initiatives to boost REE demand could catalyse further investment and development within the sector. Substantial investments, technological transfers, and information support are necessary to establish processing units in the country, which can help India elevate its position in the global REE value chain. By focusing on developing the entire REE value chain, India can reduce its dependence on imports and enhance its strategic autonomy aligning with national goals for self-sufficiency.

8.3.5 Nickel

Challenge: India has relatively modest nickel reserves, primarily in the Sukinda Valley in Odisha, which is known for its lateritic nickel ores. Nickel is not produced from primary sources in India, and the entire demand, estimated at 45 KTPA (kilo tonnes per annum), is met through imports from countries like Indonesia, Russia, Canada, and Australia (Indian Bureau of Mines 2023b). The Nickel, Copper, and Acid Recovery Plant at Hindustan Copper Limited's (HCL) Indian Copper Complex (ICC) in Ghatshila, Jharkhand, aims to produce LME grade nickel metal, but no production has been reported from this project in recent years. The current capacity of electrolysers in India is estimated to be less than 1 GW, with the country's hydrogen demand being met by international manufacturers. Vedanta Resources' acquisition of Nicomet, a leading nickel and cobalt producer in Goa, and its annual production capacity of about 5,400 MTPA still may not fully meet India's domestic nickel demand.

Opportunity: The Nickel, Copper, and Acid Recovery Plant at Hindustan Copper Limited's (HCL) Indian Copper Complex (ICC) in Ghatshila, Jharkhand, aims to become the first unit in India to produce LME grade nickel metal, with potential capacity expansion after mine projects are completed (Mazumdar 2016). Vedanta Resources' acquisition of Nicomet, which produces high-quality battery-grade nickel sulphate crystals used in EV batteries, positions India as a player in the global EV battery market. Indigenous advancements in electrolyser technology present a pathway for improving domestic production capacity, reducing reliance on imports for hydrogen and related technologies. Vedanta's interest in acquiring lithium assets through its subsidiary Hindustan Zinc Limited aligns with the growing demand for lithium-ion battery production, presenting a strategic opportunity for India to expand its presence in the global battery market.

8.3.6 Silicon

Challenge: India has significant reserves of quartz, the primary source of silicon, with major deposits found in Rajasthan, Andhra Pradesh, Karnataka, and Tamil Nadu. Despite these substantial reserves, India has limited production of silicon metal. Most of the silicon used in the country is in the form of silicon wafers, alloys, and other compounds rather than pure silicon metal. Increasing investment in technology and infrastructure is crucial for boosting domestic silicon production. However, the demand of Silicon is rising significantly, due to ambitious Solar PV plans.

The production of silicon metal is energy-intensive, requiring arc furnaces that contribute to high production costs. Industrial electricity rates in India are relatively high, which significantly impacts the overall production expenses. A substantial portion of the production costs is linked to energy consumption. Factors such as the prices of coal, quartz, oil, natural gas, and electrodes further influence the cost of silicon metal production. The anticipated high production costs of silicon metal serve as a barrier to new entrants like India. The energy-intensive nature and associated costs make it challenging for India to compete globally. Besides, Quartz mining in India is concentrated among a limited number of players, which affects the scalability of silicon production. Given these challenges, India is unlikely to emerge as a significant silicon-producing and exporting nation in the near future.

Opportunity: The Production Linked Incentive (PLI) schemes in solar PV manufacturing have provided an initial impetus for domestic processing of silicon. These schemes aim to promote investment and enhance the manufacturing capacity within the country. With continued support from the industry and government initiatives, India's domestic silicon value chain can be built and strengthened over time. Focused efforts on research and development, technology adoption, and infrastructure development are essential.

8.4 Recommendations

In this section, we outline a series of strategic recommendations designed to strengthen India's mineral security needed for the country's technological and energy advancements up to 2050.

These recommendations provide a comprehensive framework that encompasses demand estimation, strategic stockpiling, enhanced exploration, improving domestic processing capabilities, recycling initiatives, adherence to ESG standards, and leveraging geopolitical relationships.

At the core of these recommendations is the need for a robust and comprehensive policy framework and its diligent implementation. India requires policies that encourage exploration and mining, build domestic capacity, promote private investment, build processing and refining infrastructure and ensure strategic reserves and supply security, especially during disruptions. Additionally, it is crucial to strengthen international collaborations, support Research and Development (R&D), and foster investments and responsible practices in recycling and Environmental, Social, and Governance (ESG) within the critical minerals sector.

Our recommendations are as follows:

8.4.1 Promote Domestic Mineral Exploration and Processing

1. **Advancement in Technology**: The advancement of technologies in mineral exploration, extraction, and processing is crucial for improving mineral resource utilisation in India. Cutting-edge technologies such as remote sensing, geophysical surveys, and geochemical analysis are revolutionising mineral exploration. Remote sensing and satellite imagery provide detailed geological maps, identifying potential mineral-rich areas with greater accuracy. Modern extraction techniques such as automated drilling and blasting technologies are significantly improving the efficiency and sustainability of mining operations. Innovations in mineral processing can lead to higher recovery rates, reduced energy consumption and reduced long-term costs. It also helps promote sustainability. While GSI has access to wide geological data, the data needs constant upgradation, and critical mineral projections require more advance technologies.

2. **Incentivise mineral exploration in India**: Exploring India's significant geological potential is essential for unlocking the country's vast mineral, including critical mineral, resources. The Mines and Minerals (Development and Regulation) Amendment Act, 2023, introduced the Exploration Licence (EL) in August 2023 as a new type of mineral concession. This licence permits leaseholders to conduct reconnaissance and prospecting operations, aiming to attract mining companies to invest their expertise and resources in India. One of the concerns regarding Exploration Licenses (EL) is that an exploration company will only receive revenue for a successfully explored mine site after the site is auctioned and operational (Chadha, Sivamani, and Bansal 2023b). This process can take years or might never materialise, depending on the complexity of the deposit, geography, and the time required to obtain necessary clearances.

   For instance, the Ghorabhurani-Sagasahi Iron Ore Mine located in a greenfield captive mine, was auctioned in 2016 but only began production in late 2021, taking nearly six years to receive the required clearances (Bansal & Kapoor, 2022). Furthermore, the exploration company would only receive a portion of the auction premium owed by the mining company to the state government, which is determined only once the auction occurs. Another concern is that ELs might be granted solely for 'certain deep-seated and critical minerals.' Instead of restricting ELs to the minerals listed under Schedule 7, it would be more prudent to permit ELs for all minerals, allowing exploration companies to decide which minerals warrant exploration (Chadha, Sivamani, and Bansal 2023b).

   Consequently, the current EL regime may not provide sufficient investment incentives for private explorers (Chadha, Sivamani, and Bansal 2023b). By broadening the scope of ELs, improving revenue models, accelerating clearance and operational timelines for successfully explored mine sites (to reduce the wait time for exploration) and by enhancing incentives for private explorers, the Indian government can unlock India's vast mineral potential.

3. **Extending CL regime:** The Composite Licence (CL) regime consolidates various types of mineral concessions into a single licence that covers multiple stages of mineral development, from exploration to mining. One effective way to incentivise exploration and mining is to extend the existing Composite Licence (CL) regime to incorporate specific elements of the Exploration Licence (EL). For greenfield blocks with no known presence of minerals (i.e., below G4 level), we recommend the following:

   a. Eligible parties should bid based on the share of the mineral value they would pay to the state government upon successful discovery and mining (Chadha, Sivamani, and Bansal 2023b). This creates a competitive environment and ensures that the state benefits from successful exploration and mining activities.

   b. The CL should be expanded to include reconnaissance activities, allowing for a larger maximum area grantable to exploration companies. This approach increases the likelihood of discovering new mineral resources.

   c. The reconnaissance component of the CL should be grantable for areas up to 1000 km^2, with safeguards to ensure companies conduct exploration activities within a specified timeframe. Leaseholders should be required to periodically provide evidence of work done. This ensures that the granted areas are actively explored and not left idle.

   After three years of reconnaissance, the leaseholder should relinquish 75% of the original area. If there is sufficient evidence of mineral content, according to existing CL norms, the leaseholder should be allotted an area of 25 km^2 within the explored area for further prospecting and subsequent mining of specific minerals. This ensures focused exploration efforts and efficient use of resources (Chadha, Sivamani, and Bansal 2023b).

   By incorporating these elements, the Composite Licence (CL) regime can better support greenfield exploration projects with no known presence of minerals, making the process more attractive to private investors and exploration companies.

4. **Increasing the ambit of National Mineral Exploration Trust:** The National Mineral Exploration Trust (NMET) was established in 2015 to expedite mineral exploration in India by raising necessary funds. Mining companies are required to contribute 2% of their monthly royalty dues to the trust. The MMDR Amendments 2021 introduced the Notified Exploration Agency (NEA), which can receive funding from the NMET. Any exploration agency accredited by the National Accreditation Board for Education and Training of the Quality Council of India can apply to become a NEA (Chadha, Sivamani, and Bansal 2023b). However, private sector participation in the NEA scheme has been limited, with most funding directed to the Geological Survey of India (GSI) and other government agencies. To boost critical mineral exploration, NMET funds could be more extensively allocated to private exploration agencies with the requisite technical expertise. Additionally, EL holders could receive incentives through the NMET to further encourage their participation.
5. **Improving Domestic Processing Capabilities:** India has to strategically build domestic processing capabilities to reduce the global dependence on China. Supporting the development of processing infrastructure, and permitting procedures through incentives, such as a capital subsidy or a PLI scheme, and streamlined regulation is the key. This can reduce India's reliance on external processors and help its trade partners to invest in alternative processing locations. It can also help in both job creation and value creation. For instance, GOI has recognised the importance of rare earth elements (REEs) by moving them from the Atomic mineral list to the critical mineral list. This transition requires establishing protective measures to manage radioactive by-products as REE minerals are associated with radioactive elements like uranium and thorium. GOI should prioritise establishing robust protective measures to manage radioactive by-products. This includes allocating resources for research and development of innovative technologies for safe and efficient management of radioactive by-products.
6. **Setting up Government recognised labs for mineral processing:** There are currently three regional mineral processing labs, and 17 PSUs involved in research and development activities to enhance mineral processing techniques and technologies in India. This includes exploring innovative methods for extraction, beneficiation, and refining of minerals, leading to increased efficiency and reduced costs.

   Apart from R&D labs, the domestic mineral processing sector can be further strengthened by establishing specialised government accredited mineral processing labs in each state. These accredited labs can provide technical assistance and advisory services to stakeholders involved in mineral processing activities. This includes offering guidance on best practices, troubleshooting issues, and optimising processes to maximise productivity and minimise processed mineral production costs. Additionally, accredited labs can contribute to capacity-building initiatives aimed at developing a skilled workforce for the mineral processing industry. By offering training programs and workshops, these labs help can help prepare a qualified workforce equipped with the necessary expertise to drive innovation in India's mineral extraction and processing. By conducting thorough testing and analysis, these labs can help ensure that operations adhere to environmental, health, and safety standards, thereby mitigating risks associated with mining and processing and promoting responsible resource management.

   The presence of accredited mineral processing labs would instil confidence among investors and industry stakeholders. By providing assurance of quality and reliability, these labs help attract investment in critical mineral processing projects, thereby stimulating India's economic growth and development in long-term.

8.4.2 Promote International Co-operation

1. **Developing Overseas resources:** Recognising the geographical concentration of production, it's imperative to encourage exploration and investment in countries with economically viable reserves that may not be currently exploited, such as in Africa. The creation of joint working groups between government, academic and industry in both regions can facilitate more meaningful exchanges. Incentives, such as tax breaks, credit guarantees or research grants, can encourage Indian mining companies to explore and develop resources in untapped regions, reducing dependence on a few producing countries.

2. **Stockpiling Minerals:** India must be able to withstand short-term supply chain disruptions. By maintaining reserves of these minerals, India can enhance supply chain resilience, ensuring continuity in key industries despite potential supply disruptions. Stockpiling also helps stabilise prices, mitigating market volatility and supporting economic stability. For instance, if the global market trends show high fluctuations in lithium carbonate prices, a crucial raw material for lithium-ion batteries, India can selectively stockpile it for short-term needs and collaborate with other countries to build common-interest stockpiles for the long term.

   However, strategic stockpiling presents challenges such as storage costs, potential resource depreciation, and the risk of market distortion. Over-reliance on stockpiled reserves could also discourage exploration and the development of alternative sources. Therefore, while strategic stockpiling offers numerous benefits, careful management and consideration of potential drawbacks are essential to ensure its effectiveness in securing India's critical mineral supply chain.

3. **Standardise contracts:** Standardise contracting frameworks to simplify negotiations and promote long term contracts is important. Clear and uniform guidelines for contract negotiations, licensing, permits, and legal frameworks can simplify the process and incentivise investment in green projects in emerging economies. Standardised contracts enhance transparency and attract private sector companies and investors.

4. **International Diplomacy:** Participation in various multilateral frameworks/agreements, strengthening relations with key countries and forging bilateral partnerships can be instrumental in securing a stable supply.

   a. **Ensuring Strategic Alignment of Critical Minerals with India's Foreign Policy:** GoI should prioritise strategic alignment between critical minerals and India's foreign policy objectives. Leveraging India's role as a counterbalance to China, both for developed and developing nations, could serve as a focal point for India's critical minerals and foreign policy strategy. However, navigating alignment challenges, such as determining engagement with Russia on critical minerals, requires careful consideration.

   b. **Participation in the Mineral Security Partnership (MSP):** India's entry into the MSP in 2023 signals its commitment to aligning with the US and its allies in addressing mineral security challenges. Potential advantages include increased investment inflows into India's critical mineral industry and collaboration on research and development. At the same time, participation in the MSP entails compliance with its principles, potentially requiring alignment with the high Environmental, Social, and Governance (ESG) standards upheld by MSP partners. Engagement in the MSP offers India access to a wider network of global allies, providing valuable technical, financial, and scientific resources. Such alliances are crucial for India's positioning in the evolving geopolitical landscape of critical minerals.

   c. **Forging Other multilateral agreements:** GOI should actively leverage its geopolitical relationships and multilateral agreements, such as Quad, IPEF and BRICS to support its critical mineral strategy. This includes engaging in diplomatic efforts to ensure stable trade relationships, diversifying trade partners, and engaging in international collaborations with other critical mineral-consuming nations. This can include sharing best practices, coordinating efforts to secure critical mineral supplies, and exploring opportunities for joint ventures and investments in critical mineral projects.

d. **Strengthening Relationships with Key Countries:** India should concentrate on deepening ties with countries like Australia and Argentina, which welcome international investment in their critical minerals value chains. Strengthened trade and investment agreements with these nations can facilitate reduced tariffs on mineral imports to India and promote outward investments. India should expand cooperation with Africa beyond minerals to encompass the broader energy transition. Leveraging Africa's mineral resources, interest in diversifying investments away from China, and focus on value addition aligns with India's objectives of sourcing critical minerals and offering an alternative development model.

e. **Facilitating Government-to-Government Partnerships:** Government-level collaborations are crucial for fostering cooperation on critical minerals, particularly with countries like Brazil and Chile. Such partnerships could provide India with preferential access to mineral off-take and strengthen ties with vital developing economies. Through such ties, India can also enhance geopolitical influence, learn from sustainable and responsible mining practices of other countries, ultimately supporting its clean energy transition and technological advancement.

f. **Learning from ONGC Videsh Limited (OVL):** Drawing insights from ONGC Videsh Limited's engagement model, particularly its partnerships with consuming and producing countries, can benefit Khanij Bidesh India Limited (KABIL). KABIL can benefit from the extensive knowledge and expertise OVL has gained through its international engagements. Emulating OVL's approach, KABIL can form strategic partnerships with both CETM-consuming and producing countries. OVL's investment in infrastructure in partner countries has been instrumental in securing resources. KABIL can adopt a similar strategy, investing in mining, processing, and transportation infrastructure in key regions. By leveraging OVL's model, KABIL can diversify its sources of critical raw materials, reducing dependence on any single country or region. (More in Annexure-6).

g. **Review the use of ISDS in bilateral agreements:** ISDS mechanisms can help in mitigating contract risks for investors and private companies operating in high-risk geographies. However, from an ESG perspective, ISDS mechanisms can limit the ability of resource-rich nations to amend regulations to better support mining-affected communities and receive optimal royalties from mining operations, so they need to be carefully considered in India's future bilateral agreements.

8.4.3 Regular Assessments of the CETM sector

Updating and assessing the CETM sector frequently and effectively to understand the criticality, substitutability and assess vulnerabilities arising from geopolitics is also important.

1. **Assessing and updating the critical minerals list:** The list of minerals which are critical for a country depends on various factors, including changing geopolitics, new mineral resource discoveries, and the commercial viability of substitute minerals and technologies. Hence, we recommend the following to policymakers to ensure the list of the most critical minerals is updated:

   a) Updating the assessment of critical minerals every two to three years is essential to stay aligned with evolving domestic and global scenarios. This is a best practice globally that India should adopt, starting with the minerals identified in this study. The assessment should consider a range of factors that could impact the resilient supply of these minerals to India.

b) Based on the assessment results, minerals should be classified according to the factors that most influence their criticality. For instance, some minerals might be deemed more critical due to concentrated supply chains, while others might be due to their significant economic importance. Categorising these minerals will help policymakers develop strategies to ensure resilient supply chains.

c) A critical minerals assessment usually captures the situation at a single point in time. However, future changes in domestic and international policies can influence a mineral's criticality. Factors such as substitutability, new technologies, price fluctuations, and shifts in domestic manufacturing can alter the criticality of a mineral. Therefore, it is beneficial not only to compute current criticality but also to project future mineral requirements by end-use sector. This approach would provide policymakers with insights into which minerals might become critical in the future.

2. **Assessing Vulnerabilities:** GOI should conduct periodic vulnerability assessments on the impact of CETM supply chain disruptions on its clean energy manufacturing plans and develop resilience plans and preparedness measures to anticipate and mitigate future supply shocks, such as through strategic stockpiles and diversification of supply. Through periodic vulnerability assessments and the development of resilience plans, the GOI can ensure the steady progress of its clean energy manufacturing initiatives as well as long-term energy security and economic stability.

3. **Support development of critical demand estimation model for India:** There is a need for the Ministry of Mines to support the development of a sophisticated critical mineral demand estimation model for India as a nodal agency, bringing together relevant ministries such as Ministry of Chemicals and Fertilisers, Ministry of Heavy Industries, Ministry of Electronics and Information Technology and Ministry of New and Renewable Energy, amongst others. The ministry could develop a programme for mineral demand modelling in conjunction with civil society organisations and academia. Findings from this programme could be used to inform future updates of India's criticality framework, identify strategic sourcing opportunities domestically as well as provide direction for KABIL and Indian missions in critical mineral bearing countries and guide India's mineral

8.4.4 Incentivise Recycling and Circularity

Improve material efficiency by providing incentives for recycling, streamlining recycling processes, and technology upgradation in recycling.

1. **Incentives for the Recycling Sector:** Incentives for the use of recycled products are essential to create a viable market for recycled materials which would augment the promotion of the recycling process. There is a need to develop a graded incentive system based on key parameters such as the quality of recycled products, the efficiency of recycling and recovery, technology adopted, investments, and potential implications on the state economy

2. **Inclusion of Informal Sector:** The informal sector is an important component of recycling. Understanding their needs and integrating them into the formal ecosystem is crucial. Start-ups in the field can play a vital role in the system in the form of waste aggregators. Also, there is a need to improve the working conditions of the informal sector in a secure environment, encompassing environmental, economic, and occupational safety aspects to protect them from related hazards. There has been a start towards this in the form of empanelment with the pollution control boards and more recyclers coming under the GST net.

3. **Establishment of Resource Recovery Parks (RRPs):** The RRPs will facilitate the exchange of waste from various streams to provide related benefits to all types of engaged recyclers in the park. RRPs can engage and support the informal sector in waste recycling and collection activities. For this RRPs should be strategically located in dedicated zones to facilitate the

movement of informal actors, who play a pivotal role in waste collection efforts.

4. **Circular Economy and Indigenisation Initiatives:** India must initiate mineral sector circular economy by exporting recycled materials and empowering domestic recyclers to access global markets until local demand strengthens. Implementing a domestic data-sharing framework between industries and the government can track the level of indigenisation achieved. Incentives can be offered for sourcing the majority of raw materials and machinery domestically.
5. **Data Harmonisation for Effective Policy Implementation**: There is a significant dearth of data regarding electronic waste recycling. The recently enacted Battery Waste Management Rules, 2022 and the E-Waste Management Rules, 2022 have broadened the scope of previous regulations to encompass newer battery categories like automotive, electric vehicle, industrial, and portable batteries. These rules set specific annual targets for collection and treatment. However, there remains a need to standardize data collection procedures across various sources to facilitate the effective implementation of these policies.
6. **Government Incentives and Support:** The government can offer incentives such as tax rebates to make battery recycling more economically viable for companies within the country. The government ensure that the regulations enacted, are implemented and monitored on a timely basis. Additionally, government funding can support research and development in recycling, helping to develop efficient processes and create jobs in the recycling sector.
7. **Recognition of Recycling Entities**: Recognising and acknowledging the different entities involved in the recycling chain, such as collectors, dismantlers, and recyclers, is important. This can help in promoting transparency, accountability, and professionalism within the recycling industry.
8. **Streamlining Recycling Processes**: Streamlining recycling processes to reduce the number of intermediaries can lower operational costs and improve the quality of recycled materials. By minimising middlemen, resources can be redirected towards enhancing the efficiency and sustainability of recycling operations.
9. **Technological Advancements in Recycling**: Investing in technological advancements in recycling processes is essential for improving efficiency and reducing losses. Moving away from pyro metallurgical methods that result in burning losses can enhance economic benefits. Moreover, focusing on recycling alloys rather than base metals can help in managing costs effectively and maximizing the value of recycled materials.

8.4.5 Adopting improved ESG Practices

Mining and processing companies must prioritise adherence to Environmental, Social, and Governance (ESG) standards and utilise mining waste productively to reduce pollution, improve public health and promote sustainability.

1. **Urgent Need for adoption of ESG Standards in the Mining Industry:** Globally, various reports capture the diverse aspect and risks of ESG with respect to critical minerals in the mining sector. By integrating global ESG standards into the mining sector, companies can enhance the sustainability, transparency, and resilience of the CETM supply chain, ultimately supporting secure supply. The ESG transition in the mining sector should comprise four key aspects, namely (a) trust among the mining communities, (b) reporting and monitoring via third-party audits, (c) traceability (via life-cycle assessments related data collection, and building inventory for public consumption), and (d) consumer awareness creation about the sustainability of various products.
2. **Capacity-Building and Educational Programs:** Awareness of ESG principles among the industry and other relevant stakeholders will play a critical role. Therefore, capacity-building and educational programs should

be incorporated into the curriculum at the multiple levels, including training of government officials and integrating ESG into industry training programs.

3. **Sharing of Benefits with Associated Communities:** Industries working in the mining sector can also contribute at the community level. Involving the community as part of the decision-making process and sharing of benefits would give projects the 'social license to operate'. Also, there are relevant funds such as DMF (District Mineral Fund) and NMET (National Mineral Exploration Trust) which are still not fully operational. For instance, DMF's objective is to address the social aspect and if operated well, could reduce pacify community discontent as a result of mining activities.
4. **Support mining industry through progressive policies:** To tackle ESG challenges, the GOI should provide support to the mining industry by simplifying permitting processes, offering financial incentives for sustainable mining practices, and enforcing rigorous environmental and social standards. Addressing issues such as human rights, land use, and water consumption will enhance the industry's sustainability and minimize potential delays.
5. **Battery Passports:** The European Parliament's battery and battery waste regulation introduced the concept of a Digital Battery Passport, approved on June 14, 2023. A battery passport is an electronic record for each battery sold, detailing its source, material composition, manufacturer, performance specifications, durability, and recycling information. Given India's emphasis on domestic battery production through initiatives like the Production Linked Incentive (PLI) for Advanced Cell Chemistry, there is potential to adopt a native version of the battery passport in the early stages of developing a local battery value chain. This will support quality assurance and environmental responsibility from production to recycling.
6. **Mining Wastelands Utilisation:** Mining-generated wastelands should be repurposed for productive use, promoting sustainable land management practices. This promotes sustainable land management by restoring ecosystems, supporting biodiversity, and creating economic opportunities for local communities.

8.4.6 Promoting Innovation:

Improving coordination and capacity building across stakeholders and organisations is important to raise domestic capability. The government can help set up a domestic critical mineral innovation ecosystem by fostering collaboration between academia and industries engaged in critical mineral mining and processing. Firstly, the government can establish dedicated platforms or consortia where academia and industry representatives can convene to exchange knowledge, ideas, and research findings related to critical mineral extraction and processing technologies. Additionally, the government schemes such as Science and Technology Yojana for *Aatmanirbhar Bharat* in Mining Advancement (SATYABHAMA) can widen their scope from research funding to promotion of technology transfer and knowledge sharing between academia and industry, facilitating the adoption of cutting-edge technologies and best practices in mineral exploration, extraction, and processing. Furthermore, incentivising joint research projects through grants and funding schemes can encourage collaborative efforts between academic institutions and industry players, facilitating the development of innovative solutions and technologies tailored to the needs of the mineral sector. This will drive innovation, efficiency, and sustainability in the critical mineral sector, enhancing India's self-reliance and competitiveness.

9

ANNEXURES

9 ANNEXURES

Annexure-1

Critical Minerals for selected jurisdictions

The following table provides a comparison of the CETMs based on various global critical mineral strategies, CETMs shortlisting studies of India and the official CETMs list of India by Ministry of Mines.

Minerals	USA	EU	JPN	CAN	AUS	CHN	KOR	IND CSEP (2022)	IND CEEW (2016)	IND MoM (2023)
Aluminium	✓	✓		✓		✓				
Antimony	✓	✓	✓	✓	✓	✓	✓	✓		✓
Arsenic	✓						✓			
Barite	✓	✓					✓	✓	✓	
Beryllium	✓	✓	✓		✓		✓	✓		✓
Bismuth	✓	✓		✓	✓		✓			✓
Borate		✓					✓	✓	✓	
Caesium	✓			✓			✓			
Cadmium										✓
Chromium	✓		✓	✓	✓	✓	✓	✓	✓	
Coal						✓				
Coal-seam gas						✓				

Minerals	USA	EU	JPN	CAN	AUS	CHN	KOR	IND CSEP (2022)	IND CEEW (2016)	IND MoM (2023)
Cobalt	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coking coal		✓								
Copper			✓	✓		✓				✓
Diamond			✓							
Fluorite	✓	✓	✓	✓		✓		✓		
Gallium	✓	✓	✓	✓	✓		✓	✓		✓
Germanium	✓	✓	✓	✓	✓		✓			✓
Gold			✓			✓				
Graphite	✓	✓		✓	✓	✓		✓		✓
Hafnium	✓	✓			✓		✓	✓		✓
Helium	✓			✓	✓					
Indium	✓	✓	✓	✓	✓		✓			✓
Iron						✓		✓		
Lead			✓							
Limestone								✓	✓	
Lithium	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Magnesium	✓	✓	✓	✓	✓		✓	✓		
Manganese	✓		✓	✓	✓		✓	✓		
Molybdenum			✓	✓		✓	✓		✓	✓

Minerals	USA	EU	JPN	CAN	AUS	CHN	KOR	IND CSEP (2022)	IND CEEW (2016)	IND MoM (2023)
Natural gas						✓				
Natural rubber		✓								
Nickel			✓	✓		✓	✓	✓		✓
Niobium	✓	✓	✓	✓	✓		✓	✓	✓	✓
Oil						✓				
Phosphorus		✓	✓			✓	✓	✓	✓	✓
Platinum group metals	✓	✓	✓	✓	✓		✓	✓		✓
Potash	✓			✓		✓			✓	✓
Rare earth	✓	✓	✓	✓	✓	✓	✓		✓	✓
Rhenium	✓		✓		✓		✓			✓
Rubidium	✓									
Scandium	✓	✓		✓	✓					
Selenium							✓			✓
Shale gas						✓				
Silicon		✓					✓		✓	✓
Silver			✓							
Strontium	✓	✓	✓				✓	✓	✓	✓
Tantalum	✓	✓	✓	✓	✓		✓			✓

Minerals	USA	EU	JPN	CAN	AUS	CHN	KOR	IND CSEP (2022)	IND CEEW (2016)	IND MoM (2023)
Tellurium	✓			✓			✓			✓
Tin	✓		✓	✓		✓	✓	✓		✓
Titanium	✓	✓	✓	✓	✓		✓			✓
Tungsten	✓	✓	✓	✓	✓	✓	✓	✓		✓
Uranium	✓			✓		✓				
Vanadium	✓	✓	✓	✓	✓		✓		✓	✓
Zinc			✓	✓						
Zirconium	✓		✓		✓	✓	✓			✓

The concentration metric has been computed utilising the Herfindahl-Hirschman Index (HHI), which gauges the degree of concentration. As per the United States Department of Justice, an HHI of less than 1500 is considered less concentrated (highlighted in green), 1500 to 2000 is moderately concentrated (highlighted in orange), and 2500 and above is highly concentrated (highlighted in red).

Annexure-2

Concentration of mineral production of Six key CETMs crucial for green transition

Mineral	Global Production in 2021 (metric tonnes)	Number of Producing Countries	Major Mining Countries	Concentration (HHI)
Copper	21,415,370	60	Chile (26%) Peru (11%) Democratic Republic of Congo (9%)	1097
Lithium	2,32,530	12	Australia (49%) Chile (28%) China (13%)	3380
Manganese	21,219,335	36	South Africa (33%) Gabon (20%) Australia (15%)	1862
Nickel	2,812,251	28	Indonesia (42%) Philippines (14%) Russia (7%)	2110
Rare Earth Oxides	269,203	10	China (62%) United States (16%) Myanmar (10%)	4315
Silicon	8,378,000	16	China (72%) Russia (7%) Brazil (5%)	5238

Sources: (Reichl and Schatz 2023);(USGS 2023)(data for 2021); Author's Computation

Annexure-3

India's current imports of critical mineral commodities

Total weight and value of imports by India for selected critical mineral commodities, grouped by critical mineral category

Sl.	Year	Reporter country	Partner country	Category	Stage	Import value (m USD)	Import weight (tons)
1	2022	India	World	Copper	Raw & Processed/Refined	3,271.93	1,129,753.99
2	2022	India	World	Silicon	Raw & Processed/Refined	822.37	311,963.39
3	2022	India	World	Lithium	Raw & Processed/Refined	202.30	1,247,063.40
4	2022	India	World	Nickel	Raw & Processed/Refined	53.03	3,750.25
5	2022	India	World	Manganese	Raw & Processed/Refined	33.69	22,760.28
6	2022	India	World	Rare Earths	Raw & Processed/Refined	9.76	1,087.63

Note: These combined stages include the Harmonized System (HS) codes from the annexure that are considered raw or processed/refined materials (e.g. copper includes HS260300, HS282550, and HS282741).

Top 10 import partners, in value of imports for selected critical mineral commodities, grouped by critical mineral category

Sl.	Year	Category	Partner country	Rank	Stage	Import value (m USD)	Import weight (tons)
1	2022	Copper	Chile	1	Raw & Processed/Refined	932.33	404,621.00
2	2022	Copper	Indonesia	2	Raw & Processed/Refined	929.09	268,449.80
3	2022	Copper	Australia	3	Raw & Processed/Refined	428.05	91,583.44
4	2022	Copper	Peru	4	Raw & Processed/Refined	316.72	132,729.31
5	2022	Copper	Panama	5	Raw & Processed/Refined	216.25	90,975.30

Sl.	Year	Category	Partner country	Rank	Stage	Import value (m USD)	Import weight (tons)
6	2022	Copper	Papua New Guinea	6	Raw & Processed/Refined	135.70	39,210.50
7	2022	Copper	Brazil	7	Raw & Processed/Refined	101.43	40,430.84
8	2022	Copper	Canada	8	Raw & Processed/Refined	77.35	20,403.00
9	2022	Copper	Malaysia	9	Raw & Processed/Refined	66.79	21,628.30
10	2022	Copper	Other Asia, nes	10	Raw & Processed/Refined	64.66	19,389.00
11	2022	Rare Earths	China	1	Raw & Processed/Refined	4.29	867.82
12	2022	Rare Earths	Japan	2	Raw & Processed/Refined	3.35	136.45
13	2022	Rare Earths	USA	3	Raw & Processed/Refined	0.72	19.65
14	2022	Rare Earths	Germany	4	Raw & Processed/Refined	0.54	15.48
15	2022	Rare Earths	Austria	5	Raw & Processed/Refined	0.27	14.11
16	2022	Rare Earths	Belgium	6	Raw & Processed/Refined	0.15	1.90
17	2022	Rare Earths	France	7	Raw & Processed/Refined	0.14	4.92
18	2022	Rare Earths	Singapore	8	Raw & Processed/Refined	0.09	20.32
19	2022	Rare Earths	Slovenia	9	Raw & Processed/Refined	0.09	4.00
20	2022	Rare Earths	Rep. of Korea	10	Raw & Processed/Refined	0.04	0.75
21	2022	Rare Earths	United Kingdom	11	Raw & Processed/Refined	0.04	1.93

Sl.	Year	Category	Partner country	Rank	Stage	Import value (m USD)	Import weight (tons)
22	2022	Lithium	Belgium	1	Raw & Processed/Refined	47.64	3,279.67
23	2022	Lithium	United Arab Emirates	2	Raw & Processed/Refined	32.60	878,138.00
24	2022	Lithium	China	3	Raw & Processed/Refined	26.78	46,128.98
25	2022	Lithium	Jordan	4	Raw & Processed/Refined	22.14	31,691.29
26	2022	Lithium	Norway	5	Raw & Processed/Refined	14.73	215,963.00
27	2022	Lithium	Russian Federation	6	Raw & Processed/Refined	12.77	1,424.11
28	2022	Lithium	USA	7	Raw & Processed/Refined	5.95	525.08
29	2022	Lithium	France	8	Raw & Processed/Refined	5.51	2,191.43
30	2022	Lithium	Germany	9	Raw & Processed/Refined	5.1	292.11
31	2022	Lithium	Singapore	10	Raw & Processed/Refined	4.33	121.93
32	2022	Manganese	China	1	Raw & Processed/Refined	21.6	7,483.72
33	2022	Manganese	South Africa	2	Raw & Processed/Refined	3.95	9,580.00
34	2022	Manganese	Belgium	3	Raw & Processed/Refined	2.56	2,354.45
35	2022	Manganese	Netherlands	4	Raw & Processed/Refined	1.56	166.75
36	2022	Manganese	Peru	5	Raw & Processed/Refined	0.67	1,501.86
37	2022	Manganese	Germany	6	Raw & Processed/Refined	0.60	162.97
38	2022	Manganese	Poland	7	Raw & Processed/Refined	0.55	103.35

Sl.	Year	Category	Partner country	Rank	Stage	Import value (m USD)	Import weight (tons)
39	2022	Manganese	Turkey	8	Raw & Processed/Refined	0.38	135.63
40	2022	Manganese	Zambia	9	Raw & Processed/Refined	0.34	806.40
41	2022	Manganese	USA	10	Raw & Processed/Refined	0.31	56.25
42	2022	Nickel	Australia	1	Raw & Processed/Refined	33.95	1,431.22
43	2022	Nickel	Belgium	2	Raw & Processed/Refined	7.10	1,055.23
44	2022	Nickel	Japan	3	Raw & Processed/Refined	3.74	449.12
45	2022	Nickel	Sweden	4	Raw & Processed/Refined	2.79	184.24
46	2022	Nickel	China	5	Raw & Processed/Refined	2.73	159.91
47	2022	Nickel	South Africa	6	Raw & Processed/Refined	1.70	304.38
48	2022	Nickel	France	7	Raw & Processed/Refined	0.52	80.04
49	2022	Nickel	Other Asia, nes	8	Raw & Processed/Refined	0.26	54.24
50	2022	Nickel	Singapore	9	Raw & Processed/Refined	0.11	10.16
51	2022	Nickel	Rep. of Korea	10	Raw & Processed/Refined	0.10	20.00
52	2022	Silicon	China	1	Raw & Processed/Refined	367.70	128,142.67
53	2022	Silicon	Germany	2	Raw & Processed/Refined	112.14	28,205.34
54	2022	Silicon	Malaysia	3	Raw & Processed/Refined	49.43	41,505.41
55	2022	Silicon	USA	4	Raw & Processed/Refined	39.47	7,670.99
56	2022	Silicon	Thailand	5	Raw & Processed/Refined	30.35	6,703.91

Sl.	Year	Category	Partner country	Rank	Stage	Import value (m USD)	Import weight (tons)
57	2022	Silicon	Viet Nam	6	Raw & Processed/Refined	29.46	25,567.29
58	2022	Silicon	China, Hong Kong SAR	7	Raw & Processed/Refined	28.97	10,629.31
59	2022	Silicon	Belgium	8	Raw & Processed/Refined	25.88	3,538.26
60	2022	Silicon	Japan	9	Raw & Processed/Refined	23.75	2,615.78
61	2022	Silicon	Rep. of Korea	10	Raw & Processed/Refined	22.94	3,774.09

Note: These combined stages include the HS codes from tab 1 that are considered raw or processed/refined materials (e.g. copper includes HS260300, HS282550, and HS282741).

Annexure-4

Methodology for trade data on six key CETM's Harmonised System (HS) codes and sources

The table below provides an overview of the methodology adopted to undertake the trade analysis, including the HS codes for the relevant critical minerals as well as stages (raw, refined).

Methodology

Category	Name	HS Code	UN Comtrade description	Stage
		Copper		
Copper	Copper ores and concentrates	260300	Copper ores and concentrates	Raw
Copper	Copper oxides and hydroxides	282550	Copper oxides and hydroxides	Processed/refined
Copper	Copper chlorides	282741	Chloride oxides and chloride hydroxides; of copper	Processed/refined
Copper	Copper sulphates	283325	Sulphates; of copper	Processed/refined
		Lithium		
Lithium	Lithium oxide and hydroxide	282520	Lithium oxide and hydroxide	Processed/refined
Lithium	Lithium carbonates	283691	Carbonates; lithium carbonate	Processed/refined
Lithium	Mineral substances, including spodumene	253090	Mineral substances; n.e.c. in chapter 25	Raw
Lithium	Lithium chlorides	282739	Chlorides; other than of ammonium, calcium, magnesium, aluminium, iron, cobalt, nickel and zinc	Processed/refined
		Manganese		
Manganese	Manganese dioxide	282010	Manganese dioxide	Processed/refined
Manganese	Manganese oxides, excluding manganese dioxide	282090	Manganese oxides; excluding manganese dioxide	Processed/refined

Category	Name	HS Code	UN Comtrade description	Stage
Manganese	Manganese Sulphates	283329	Sulphates; n.e.c. in item no. 2833.2	Processed/refined
Nickel				
Nickel	Nickel oxides and hydroxides	282540	Nickel oxides and hydroxides	Processed/refined
Nickel	Nickel chlorides	282735	Chlorides; of nickel	Processed/refined
Nickel	Nickel sulphates	283324	Sulphates; of nickel	Processed/refined
Silicon				
Silicon	Silicon	280461	Silicon; containing by weight not less than 99.99% of silicon	Processed/refined
Silicon	Silicon	280469	Silicon; containing by weight less than 99.99% of silicon	Processed/refined
Silicon	Silicon dioxide	281122	Silicon dioxide	Processed/refined
Silicon	Silicon carbides	284920	Carbides; of silicon, whether or not chemically defined	Processed/refined
Silicon	Silicones in primary forms	391000	Silicones; in primary forms	Processed/refined
Rare Earth Elements				
Dysprosium (Heavy REE)	Rare earth-metals	280530	Earth-metals, rare; scandium and yttrium, whether or not intermixed or interalloyed	Processed/refined
Dysprosium (Heavy REE)	Rare earth-metals compounds	284690	Compounds, inorganic or organic (excluding cerium), of rare-earth metals, of yttrium, scandium or of mixtures of these metals	Processed/refined

Varying costs of setting up lithium processing plant at various sites globally (2022 data)

Project Name	Owners	Country	Mining Method	Processing plant cost ($M)	Share of initial capital cost (%)	Hydroxide conversion plant cost ($M)	Hydroxide plant capacity
Piedmont	Piedmont lithium inc (100% owner)	United States (North Carolina)	Open pit	615	62	408	30,000 t/y LiOH
Karibib	Lepidico Ltd. (Venturer) 80% Private interest venture 20%	Namibia	Open pit	112	72	85	5,600 t/y LiOH
Clayton valley	Schlumberger ltd. (Optionee) 100% ; Pure energy minerals ltd (optioner)	United States (Nevada)	Brine	100	34	27	6,563 t/y LiOH
Whabouchi	Investissement Quebec (Venturer) 50%; Livent Corp (Venturer) 50%	Canada	Open pit, underground	730	75	399	21,116 t/y LiOH
Zinnwald	Zinnwald lithium PLC (owner 100%)	EU (Germany)	underground	238	71	116	6,885 t/y LiOH
South-West Arkansas	Standard lithium Ltd (optionee) 100% ; TETRA technology Inc (optioner)	United States	Brine extraction	433	50	91	17,121 t/y LiOH

Source: (S&P Global 2022b)

Annexure-5

Bottom-up economic importance of various minerals based on each technology

The bottom-up economic importance, calculated by considering the effect on cost of various minerals, weighted by market share, is provided below. A maximum of six technologies were considered for this analysis based on their necessity or wide-spread use in a technology. This is evaluated against the minerals' normalised supply risk by taking a root mean square to provide the final selection metric score.

Bottom-up economic importance of various minerals based on each technology

	Solar PV		Wind		EV motor		Battery		Electrolyser		Grid	
	Mineral list	Bottom-up economic importance	Mineral list	Bottom-up economic importance	Mineral list	Bottom-up economic importance	Mineral list	Bottom-up economic importance	Mineral list	Bottom-up economic importance	Mineral list	Bottom-up economic importance
Mineral 1	Silicon	0.4553966	Copper	0.42958495	Copper	0.535368009	Lithium	0.610143017	Nickel	0.815854571	Copper	0.658259862
Mineral 2	Silver	0.242498689	Zinc	0.296222151	Neodymium	0.353246425	Graphite	0.163026923	Platinum	0.184145429	Bauxite	0.341740138
Mineral 3	Bauxite	0.163583252	Nickel	0.128347205	Light Rare Earths	0.109578483	Copper	0.118033011				
Mineral 4	Copper	0.128979103	Chromium	0.090989739	Iron	0.001672514	Bauxite	0.085110868				
Mineral 5	Tin	0.007864579	Manganese	0.029169139	Boron	0.00013457	Fluorine	0.022719571				
Mineral 6	Zinc	0.001677777	Neodymium	0.025686815			Phosphorus	0.000966611				

Bottom-up supply risk of various minerals based for each technology

	Solar PV		Wind		EV motor		Battery		Electrolyser		Grid	
	Mineral list	Bottom-up supply risk	Mineral list	Bottom-up supply risk	Mineral list	Bottom-up supply risk	Mineral list	Bottom-up supply risk	Mineral list	Bottom-up supply risk	Mineral list	Bottom-up supply risk
Mineral 1	Tin	0.491514771	Manganese	0.436517913	Boron	0.295411691	Graphite	0.321181647	Platinum	0.411690761	Bauxite	0.127278441
Mineral 2	Bauxite	0.127278441	Chromium	0.378692646	Light rare earths	0.249842866	Phosphorus	0.280955374	Nickel	0.295097423	Copper	0.078252671
Mineral 3	Copper	0.078252671	Nickel	0.295097423	Heavy rare earths	0.249842866	Fluorine	0.206159648				
Mineral 4	Silicon	0.085795097	Light rare earths	0.249842866	Iron	0.234129478	Lithium	0.210873664				
Mineral 5	Silver	0.043683218	Copper	0.078252671	Copper	0.078252671	Bauxite	0.127278441				
Mineral 6	Zinc	0.001571339	Zinc	0.001571339			Copper	0.078252671				

Final selection metric score (RMS of supply risk and bottom-up economic importance)

	Solar PV		Wind		EV motor		Battery		Electrolyser		Grid	
	Mineral list	Selection metric score	Mineral list	Selection metric score	Mineral list	Selection metric score	Mineral list	Selection metric score	Mineral list	Selection metric score	Mineral list	Selection metric score
Mineral 1	Silicon	0.463407878	Manganese	0.437491402	Copper	0.54105673	Lithium	0.645555732	Nickel	0.867583523	Copper	0.662894808
Mineral 2	Silver	0.246401781	Copper	0.436653994	Light rare earths	0.272816608	Graphite	0.360188045	Platinum	0.450997585	Bauxite	0.364672626
Mineral 3	Bauxite	0.20726621	Nickel	0.321800395	Iron	0.234135452	Fluorine	0.207407761				

Annexure-6 Learnings from OVL

ONGC Videsh LTD (OVL) is a subsidiary of India's Oil and Natural Gas Corporation (ONGC). OVL, which is 100% owned by ONGC and was formed in 1965, focuses on oil and gas outside of India. Its actions include exploration, development, and production of assets. OVL has parallels to KABIL, given that it was established to help India source natural resources through overseas investments and production. OVL production of oil and equivalent gas was 14.9 MMT as of 2020, and it held 587 MMT of reserves that same year (ONGC, n.d.).

Over the last two decades, OVL has invested in a variety of jurisdictions, including high-risk countries such as Iraq, Libya, South Sudan, and Venezuela. It has also invested in developing natural resource jurisdictions, like Vietnam, and established, lower-risk producers like the United Arab Emirates (ONGC Videsh, n.d.). OVL transactions are subject to various approval processes, including from a committee of secretaries and the cabinet committee on economic affairs (Madan and Baker 2007). Investments are also subject to meeting a fixed internal rate of return.

OVL has had a mixed history. On one hand, it has grown into one of India's largest companies and its second largest petroleum company, producing an estimated 30 percent and 24 percent of India's domestic production of oil and natural gas, respectively. OVL currently has a participating interest in 35 oil and gas projects in 15 countries. Its returns have historically been higher than domestic investments in oil and gas, while it is seen as contributing to increasing global supply and helping satisfy Indian consumption (Madan and Baker 2007).

But OVL has also faced various criticisms over the years. These criticisms include the argument that OVL diverts Indian resources away from the development of India's national oil and gas industry and that not all the oil and gas production from OVL's operations flow directly back to India. Critics also cite how OVL projects, such as the Iran-Pakistan-India pipeline, do not pay sufficient head, and are at times in conflict with India's foreign policy priorities.

These tensions, and OVL's general model, have obvious parallels to the challenges KABIL faces on sourcing critical minerals from overseas. KABIL, like OVL, will likely find opportunities in overseas investment, including attractive rates of return and an ability to quickly grow into a significant national company. At the same time, KABIL will also face similar concerns as OVL on issues such as how to most responsibly allocate natural resources and how a national corporation can operate in harmony with the country's foreign policy interests. However, KABIL will have the benefit of learning from OVL's experience and leveraging its relationships. KABIL can learn from OVL's approval structure and relationship with the Indian Ministry of External Affairs to implement a structure that coordinates with the rest of the national government. While most OVL partner countries are not large critical mineral producers, KABIL can leverage existing OVL relationships in countries such as Brazil and Vietnam for critical mineral projects.

KABIL will also benefit from drawing lessons from OVL's model of engagement with consuming and producing countries. In the past, OVL partnered with Chinese and Japanese national oil corporations in various transactions. Those partnerships served a dual purpose, both creating stronger pools of financing and shifting a competitor into a partner. A similar approach, albeit perhaps with different countries, may be an attractive model for KABIL to pursue. Importantly, OVL has also engaged with producing countries by listening to and investing in their interests. For example, OVL built refineries and upgraded pipelines in Sudan, invested in a refinery in Venezuela, trained workers in Algeria and Sri Lanka, and invested billions in rail, refining, and power in Nigeria (Madan and Baker 2007). Given the current trends in mineral-rich countries, KABIL would be well-served to study OVL's investments in infrastructure and partner-country value addition. Replicating such a playbook could help KABIL gain preferential access and longer-lasting, more sustainable partnerships.

Annexure-7 Summary of main policies of major countries

A summary of the main policy of major countries and the European Commission is given below. These policies collectively reflect a global effort to secure critical minerals necessary for advancing technology, renewable energy, and sustainable development goals, while also reducing dependence on imports and promoting environmental sustainability.

EUROPEAN COMMISSION

Critical Raw Minerals Act: The main tenets generally include the following:

a. Establishing a list of minerals considered critical due to their economic importance and supply risk. Regularly reviewing and updating this list based on changes in market demand, technological advancements, and geopolitical factors.
b. Encouraging the exploration and production of critical minerals within the country to reduce dependency on foreign sources. Providing incentives such as tax breaks, grants, and subsidies to companies engaged in the exploration and mining of these minerals.
c. Investing in research and development to improve the efficiency and sustainability of mining and processing technologies. Ensuring that mining and processing activities adhere to high environmental and social standards.
d. Supporting innovation in recycling and the development of alternative materials to reduce the demand for critical minerals.
e. Implementing measures to minimise the ecological footprint of mining operations, including the management of waste and the rehabilitation of mining sites.
f. Developing strategies to diversify supply sources and reduce vulnerabilities in the supply chain. Encouraging the stockpiling of critical minerals to buffer against supply disruptions.
g. Engaging in partnerships and agreements with other countries to secure access to critical minerals.
h. Promoting international standards and best practices for the mining and processing of critical minerals.
i. Establishing a clear regulatory framework to oversee the exploration, production, and trade of critical minerals.
j. Creating or designating government bodies responsible for the implementation and enforcement of the act.
k. Recognising the strategic importance of critical minerals for national security and economic stability. Incorporating critical minerals into broader industrial and economic policies to ensure a coherent and comprehensive approach.

USA:

1) Critical Minerals and U.S Public Policy: The policy focus on ensuring the responsible and reliable supply of minerals that are essential for the nation's economic and national security. Here are its key principles:

- Establishing a list of minerals deemed critical to the U.S. economy and national security due to their essential role in manufacturing, technology, and defence. Regularly reviewing and updating this list to reflect changing market demands and geopolitical risks.
- Encouraging the exploration and development of domestic mineral resources to reduce reliance on foreign sources.
- Providing incentives, such as tax credits and grants, to support the mining and processing of critical minerals within the United States.
- Investing in research and development to advance technologies for the efficient and sustainable extraction, processing, and recycling of critical minerals.
- Supporting innovation in alternative materials and substitutes to decrease dependency on critical minerals. Enhancing the resilience of critical mineral supply chains by diversifying sources and reducing vulnerabilities.

- Promoting the stockpiling of critical minerals to mitigate the impact of supply disruptions.
- Ensuring that mining and processing operations adhere to high environmental and social standards. Implementing measures to minimize environmental impacts, including waste management and site rehabilitation.
- Forming strategic partnerships and agreements with other countries to secure access to critical minerals and ensure stable supply chains.
- Promoting international standards and best practices for mining and processing critical minerals.
- Establishing a clear and efficient regulatory framework to oversee the exploration, production, and trade of critical minerals.
- Creating or designating government bodies responsible for coordinating and implementing critical minerals policies.
- Recognising the strategic importance of critical minerals for national security and economic stability.
- Integrating critical minerals policy into broader national security and economic strategies.
- Raising public awareness about the importance of critical minerals and the challenges associated with their supply. Promoting education and workforce development programs to build expertise in critical minerals-related fields.
- Encouraging the recycling of critical minerals from end-of-life products to reduce dependence on primary sources.
- Supporting initiatives to develop a circular economy that maximises the reuse and recycling of materials.

2) CHIPS and Science Act (2022): The CHIPS Act aims to boost domestic manufacturing of semiconductor chips in US, leading to an immediate private investment surge of $50 billion in the American semiconductor manufacturing sector.

I. **Objective**: Boost domestic manufacturing of semiconductor chips.

II. **Impact**: Led to a $50 billion surge in private investment in the semiconductor sector.

III. **Materials Focus**: Gallium and germanium, essential for semiconductors.

3) Inflation Reduction Act (IRA) (2022): The IRA provides multiple incentives for manufacturers of green technologies in US. It mandates that manufacturers of renewable energy, solar, wind, batteries, electric vehicles (EVs), and other clean energy projects must meet specified domestic content requirements to receive additional tax credits

I. **Objective**: Provide incentives for green technology manufacturers.

II. **Provisions**: Tax credits for manufacturers of renewable energy, solar, wind, batteries, and EVs meeting domestic content requirements.

III. **Initiatives**: American Battery Materials Initiative with $2.8 billion funding for expanding domestic battery manufacturing.

IV. **Tax Credits**: New tax credits for domestic processing of critical minerals under sections 13501 and 13502.

CHILE

National Mineral Policy: This Policy of Chile focuses on ensuring the sustainable development of its mineral resources, given the country's significant role as a global leader in copper and other mineral productions. The main points of Chile's mineral policy include the following:

a. Promoting sustainable mining practices that minimize environmental impact. Implementing strict regulations for environmental protection, waste management, and site rehabilitation. Encouraging the use of eco-friendly technologies in mining operations.

b. Enhancing the competitiveness of the Chilean mining sector in the global market.

c. Providing incentives for investment in mining and related industries. Supporting technological innovation and modernization in mining operations.

d. Promoting the exploration of new mineral deposits to ensure a steady supply of resources. Efficiently managing existing mineral resources to maximize their economic benefit. Encouraging research and development in mining technology and geology.

e. Establishing a clear, stable, and transparent legal and regulatory framework for mining activities. Ensuring that regulations are aligned with international standards and best practices. Simplifying administrative procedures to attract and facilitate investments.

f. Ensuring that mining activities contribute to the socio-economic development of local communities. Promoting the inclusion and participation of local communities in decision-making processes. Addressing the social impacts of mining, including labour conditions and community health.

g. Developing and maintaining the infrastructure necessary for efficient mining operations, such as transportation networks and energy supply. Enhancing logistics and supply chain management to support the mining industry.

h. Investing in education and training programs to develop a skilled workforce for the mining sector. Promoting research and academic programs related to mining and geology. Ensuring high safety standards and labour conditions in the mining industry.

i. Encouraging the adoption of advanced technologies in exploration, extraction, and processing of minerals. Supporting innovation in sustainable mining practices and renewable energy integration. Fostering partnerships between the government, industry, and academia to drive technological advancements.

j. Promoting international cooperation in mining technology, best practices, and regulatory standards. Strengthening trade relations to ensure access to global markets for Chilean minerals. Participating in international forums and agreements related to mining and mineral resources.

k. Encouraging the diversification of the economy to reduce dependency on mineral exports. Promoting value-added industries related to mining, such as metallurgy and manufacturing.

Annexure-8 Government-led Initiatives and Strategies of Major Countries

United Kingdom: Critical Minerals Strategy: The UK's Critical Minerals Strategy is committed to maximising the production of critical minerals across the entire value chain, encompassing mining, refining, manufacturing, and recycling processes. This holistic approach aims to stimulate job creation, foster economic growth, and safeguard both communities and the natural environment. The main tenets of this strategy generally include:

- Developing and maintaining a list of critical minerals that are essential for the UK's economic and strategic interests. Regularly reviewing and updating this list based on changing technological, economic, and geopolitical factors.
- Promoting the exploration, development, and production of critical minerals within the UK. Providing incentives for mining companies to invest in domestic critical mineral projects.
- Diversifying the sources of critical minerals to reduce dependency on a limited number of foreign suppliers. Building resilient supply chains through strategic partnerships and collaborations with other countries.
- Investing in research and development to advance technologies for the efficient and sustainable extraction, processing, and recycling of critical minerals.
- Supporting innovation in alternative materials and substitutes to reduce reliance on critical minerals.
- Ensuring that mining and processing activities adhere to high environmental and social standards. Implementing measures to minimise the ecological footprint of mining operations, including waste management and site rehabilitation.
- Promoting the recycling of critical minerals from end-of-life products to reduce the need for primary extraction. Supporting initiatives that develop a circular economy, maximizing the reuse and recycling of materials.
- Engaging in international partnerships and agreements to secure access to critical minerals Promoting global standards and best practices for the mining and processing of critical minerals.
- Establishing a clear and effective regulatory framework to oversee the exploration, production, and trade of critical minerals. Creating or designating government bodies responsible for coordinating and implementing the critical minerals strategy.
- Recognising the strategic importance of critical minerals for national security and economic stability. Integrating critical minerals policy into broader national security and economic strategies.
- Investing in education and training programs to develop a skilled workforce for the critical minerals sector. Promoting research and academic programs related to mining, geology, and materials science.
- Raising public awareness about the importance of critical minerals and the challenges associated with their supply. Engaging stakeholders, including industry, academia, and local communities, in the development and implementation of the strategy.

Australia: Critical Minerals Strategy 2023–2030: Critical Minerals Strategy 2023–2030 aims to secure the supply of essential minerals critical to the economy, technological advancements, and national security. One of its objectives is to incentivise private investment in the downstream processing of critical minerals. Grants have been given under the Critical Minerals Development Programme to strengthen domestic supply chains and support mining technology research. Close to AUD$ 50 million have been allocated to 13 projects. The main tenets of this strategy include:

- Comprehensive mapping and identification of critical mineral resources.
- Promoting exploration and development of domestic mineral resources to reduce reliance on imports.
- Diversifying sources of critical minerals to mitigate supply chain risks.
- Building strategic reserves and stockpiles to buffer against supply disruptions.
- Ensuring that mining practices adhere to high environmental and social standards. Implementing measures to minimise environmental impacts and promote site rehabilitation.
- Investing in research and development to advance technologies for the efficient and sustainable extraction, processing, and recycling of critical minerals. Supporting innovation in alternative materials and substitutes to decrease dependency on critical minerals.
- Recognising the strategic importance of critical minerals for national security and economic stability. Integrating critical minerals policy into broader national security and economic strategies.
- Forming strategic partnerships and trade agreements with other countries to secure access to critical minerals. Promoting international standards and best practices for the mining and processing of critical minerals.
- Establishing a clear and efficient regulatory framework to oversee the exploration, production, and trade of critical minerals. Creating or designating government bodies responsible for coordinating and implementing critical minerals policies.
- Raising public awareness about the importance of critical minerals and the challenges associated with their supply. Promoting education and workforce development programs to build expertise in critical minerals-related fields.
- Encouraging the recycling of critical minerals from end-of-life products to reduce dependence on primary sources. Supporting initiatives to develop a circular economy that maximises the reuse and recycling of materials.
- Providing financial incentives such as tax breaks, grants, and subsidies to support the exploration, mining, and processing of critical minerals. Encouraging private sector investment in critical minerals projects.

Annexure-9 Offtake agreements between various companies for battery minerals

The table provides an overview of recent offtake agreements for battery minerals as discussed in the section 5.3 on contracting and financing practices.

Companies	Tenure	Geographies	Commodity	Prices	Amount (tonnes or $)
Prime Planet Energy & Solutions (PPES) buying from ioneer	5-year contract	Nevada, United States	Lithium carbonate	Adjusted quarterly based on agreed price formula	4,000 tonnes annually
Tesla buying from Liontown Resources	5-year contract	United States and Australia	Lithium spodumene concentrate	-	Starting 100,000 tonnes in 2024 and growing to 150,000 tonnes in subsequent years
Tesla buying from Talon	6-year contract	United States	Nickel	Linked to the London Metals Exchange (LME) official cash settlement price for nickel	75,000 metric tonnes
Tesla buying from Indonesia (entity unknown)	5-year contract	United States and Indonesia	Nickel	-	$5 billion
General Motors buying from Vale Canada	Long-term	Canada	Nickel sulphate	-	25,000 metric tonnes starting in 2026
BMW Group buying from Livent (US-based)		From Argentina	Lithium Hydroxide	-	$335 million
Renault buying from Managem Group	MoU signed 7-year agreement	Morocco	Cobalt sulphate	-	5,000 tonnes annually beginning in 2025
Renault buying from Vulcan Energy	5-year	Germany	Lithium	-	6,000 tonnes - 17,000 tonnes annually beginning 2026

Companies	Tenure	Geographies	Commodity	Prices	Amount (tonnes or $)
Stellantis buying from Vulcan Energy	Extended to 10-year	Germany	Lithium	-	81,000 - 99,000 metric tonnes
Stellantis buying from Alliance Nickel	5-year	Australia	Nickel and cobalt sulphate	Linked to index prices	170,000 tonnes of nickel sulfate and 12,000 tonnes of cobalt sulphate
LG Chem buying from Piedmont's North American Lithium	4-year term	Canada	Lithium	Floor price of $500/ton and a ceiling price of $900/ton for the life-of-mine term	200,000 metric tonnes
SK On buying from Lake Resources	5-year term, potential extension of 5 more years	Australia	Lithium	-	15,000 tonnes of lithium for the first two years and 25,000 tonnes of lithium from the third year
LG Energy Solutions and Electra	3-year term	Canada	Cobalt sulphate		7,000 tonnes
LG Energy Solutions and Snow Lake Resources	10-year term starting in 2025 (MoU)	Canada	Lithium hydroxide		20,000 tonnes
LG Energy Solutions and Avalon Advanced Materials	5-year term starting in 2025 (MoU)	Canada	Lithium hydroxide		11,000 tonnes

Annexure-10 Acquisition of Stakes by OEMs in Mining Companies

The table provides an overview of recent acquisitions of States by OEMs in Mining Companies that is discussed in the section 5.3 on contracting and financing practices.

Companies	Acquired company / joint venture	Stake / Ownership	Commodity	Comments
CATL (specifically Sichuan CATL) (China)	CMOC (Democratic Republic of the Congo)	25% stake worth $3.7 billion	Cobalt	
CATL-led consortium	Yacimientos del Litio Bolivianos (Bolivia)	$1.4 billion in project's first phase	Lithium	
LG Chem	Piedmont Lithium	5.7% stake for $75 million	Lithium spodumene concentrate	
LG Energy Solutions	Queensland Pacific Metals	7.5% stake	Cobalt and nickel	Under a 10-year contract, QPM will provide 7,000 tonnes of nickel and 7,000 tonnes of cobalt per year to LGES
BYD	6 unnamed lithium mines in Africa		Lithium oxide	6 unnamed lithium mines in Africa containing more than 25 Mt of ore grading 2.5% lithium oxide
BYD	Chengxin Lithium	5.11% in shares, investment of $300 million	Lithium	
General Motors	Vale Canada	Potentially $2 billion (unconfirmed)	Nickel-sulfate	
SK On	Lake Resources (Australia)	10% stake	Lithium	Rights to secure up to 230,000 tonnes for ten years starting from the fourth quarter of 2024

Companies	Acquired company / joint venture	Stake / Ownership	Commodity	Comments
General Motors	Lithium Americas	$650 million investment	Lithium	To develop Nevada's Thacker Pass lithium mining project
Stellantis	Vulcan Energy (Australian-German lithium startup)	8% stake worth $52 million	Lithium	
Stellantis	Alliance Nickel	$10 million for 11.5% stake	Nickel and Cobalt sulfate	
Vedanta	Nicomet	Outright purchase	Nickel and cobalt	

Annexure-11 Joint ventures as well as OEMs building critical mineral refinery / production plants

The table provides an overview of recent join ventures as well as OEMs building critical mineral refinery/production plants that is discussed in the section 5.3 on contracting and financing practices.

Companies	Location	Investment amount	Announced	Commodity	Comments
Tesla	Texas Gulf Coast	> $1 billion	October 2022	Lithium hydroxide	
Volkswagen Group	Indonesia	$5 billion	July 2022	Nickel ore production and processing plant	
CATL and local state-owned groups	Indonesia	$6 billion		Mining-to-batteries complex	Include nickel mining and processing, battery materials, recycling, and battery manufacturing facilities
LG Energy Solution consortium	Indonesia	$9 billion	December 2020	EV battery value chain	Including smelting and refining of nickel, and manufacturing cathode materials
Toyota and Panasonic - Prime Planet Energy and Solutions	Japan and Korea	-	February 2020	EV battery value chain	
General Motors, BASF, POSCO and Vale	Canada	-	July 2022	Battery hub	Including raw materials, cathode and recycling operations

Annexure-12 Status of India's Critical Minerals Auction

Summary	Tranche 1	Tranche 2	Tranche 3	Tranche 4
Total Blocks	20	18	7	21
Fresh blocks	20	18	0	10
Reauctioned blocks	0	0	7	11
MLs	4	1	0	1
CLs	16	17	7	20
Preferred bidder announced	6	0	4	-
<3 Technically Qualified Bidders (TQB)	11	9	0	-
No bids	2	5	0	-
Unknown status	1	4	3	-

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