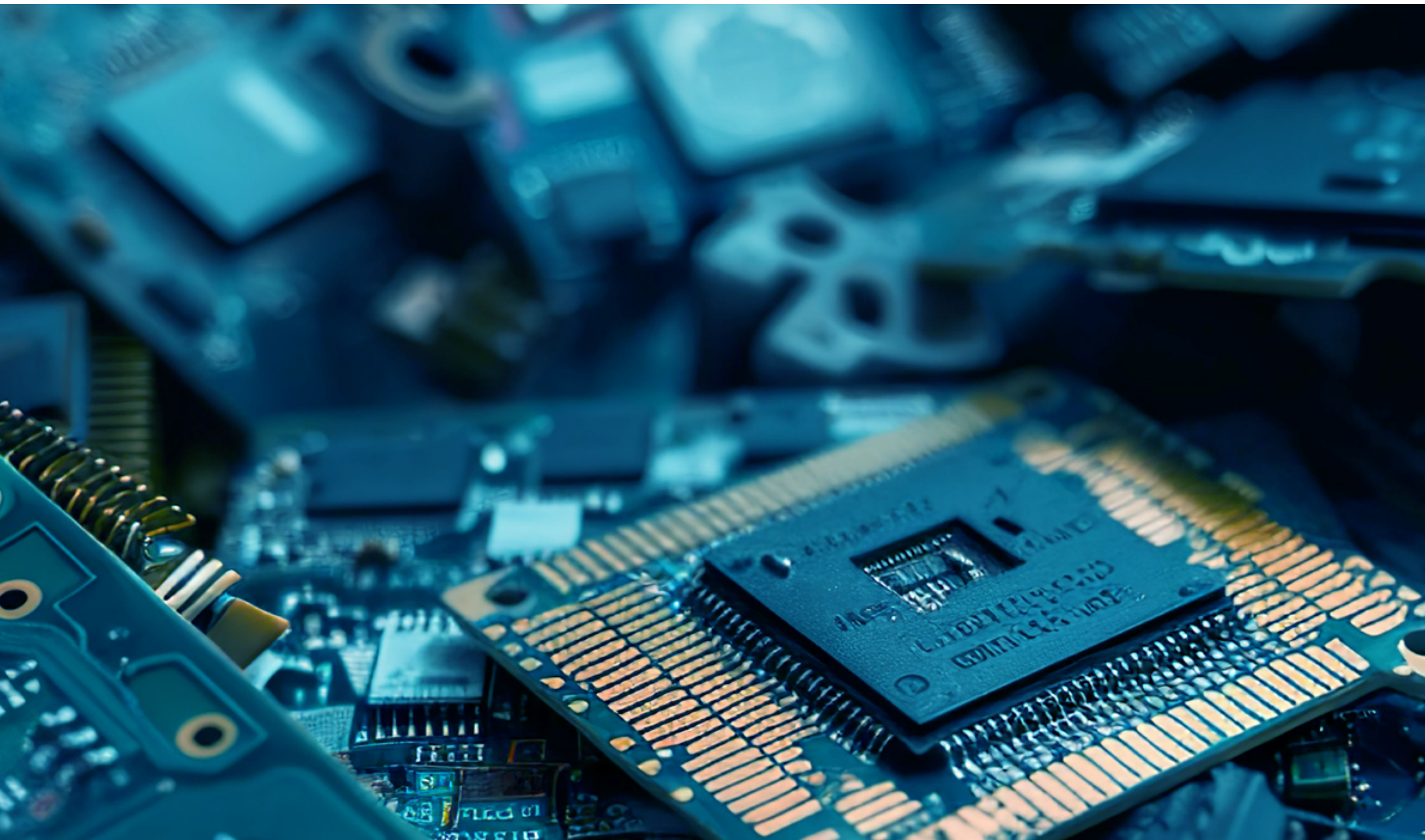
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Progress by innovation

A2D Accelerate to Demonstrate Facility



Market Assessment on Critical Minerals Innovation in Developing Countries

DECEMBER 2024

Columbia Center on Sustainable Investment
A JOINT CENTER OF COLUMBIA LAW SCHOOL AND COLUMBIA CLIMATE SCHOOL

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Market Assessment on Critical Minerals Innovation in Developing Countries - Columbia Center on Sustainable Investment (CCSI) and Columbia Engineering

TABLE OF CONTENTS

AUTHORS AND ACKNOWLEDGMENTS

This market assessment was conducted by the Columbia Center on Sustainable Investment (CCSI) and the Fu Foundation School of Engineering and Applied Science at Columbia University under the overall guidance of Mr. Peter Warren, A2D Facility Manager, and Ms. Valeria Arroyave Cardozo, A2D Facility Critical Minerals Project Coordinator, within the Division of Climate Innovation and Montreal Protocol of the United Nations Industrial Development Organization (UNIDO). This effort was made possible through the support of the United Kingdom's Department for Energy Security and Net Zero (DESNZ).

Authors from **Columbia Center on Sustainable Investment (CCSI)**: Martin Dietrich Brauch, Laura Garcia Cancino, Ben Baraga. Graduate Research Assistants: Burulgul Sultanova, Chhavi Maggu, Ruihong Li.

Authors from **Fu Foundation School of Engineering and Applied Science**: Behzad Vaziri, D.R. Nagaraj. Graduate Research Assistants: Akshay Malhotra, Angeliki E Stougiannou, Sumanth Uppuluru.

The project team would like to thank the survey respondents and interviewed experts (see Appendix C) for their invaluable time and insights; Thanos Bourtsalas for his contribution to the work at the early stages of project development and research; Perrine Toledano and Lisa Sachs for their feedback and guidance throughout the project; Reet Chatterjee for his editorial assistance; and Tobias Mülling and Angélica Knuth for their graphic design and communications support.

UK Government

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Our mandate is reflected in Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", but UNIDO's activities contribute to all the SDGs.UNIDO's vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind.

Columbia Center on Sustainable Investment
A JOINT CENTER OF COLUMBIA LAW SCHOOL AND COLUMBIA CLIMATE SCHOOL

The Columbia Center on Sustainable Investment (CCSI), a joint center of Columbia Law School and Columbia Climate School at Columbia University, is a leading applied research center and forum dedicated to the study, practice, and discussion of sustainable international investment. Our mission is to develop and disseminate practical approaches and solutions, as well as to analyse topical policy-oriented issues, in order to maximise the impact of international investment for sustainable development. The Center undertakes its mission through interdisciplinary research, advisory projects, multi stakeholder dialogue, educational programmes, and the development of resources and tools.

Columbia | Engineering
The Fu Foundation School of Engineering and Applied Science

The mission of The Fu Foundation School of Engineering and Applied Science is to expand knowledge and advance technology through research, while educating students to become leaders informed by an engineering foundation. Enriched with the intellectual resources of a global university in the City of New York, we push disciplinary frontiers, confront complex issues, and engineer innovative solutions to address the grand challenges of our time. We create a collaborative environment that embraces interdisciplinary thought, integrated entrepreneurship, cultural awareness, and social responsibility, and advances the translation of ideas into practical innovations.

LIST OF ACRONYMS AND ABBREVIATIONS

A

A2D	Accelerate-to-Demonstrate Facility
ADB	Asian Development Bank
AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
AIIB	Asian Infrastructure Investment Bank
ASP	Asia and the Pacific
AU	African Union

B

BEV	Battery Electric Vehicle

C

CCSI	Columbia Center on Sustainable Investment

D

DBSA	Development Bank of Southern Africa
DLE	Direct Lithium Extraction
DRC	Democratic Republic of the Congo

E

EITI	Extractive Industries Transparency Initiative
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle

G

GII	Global Innovation Index

H

HPAL	High-Pressure Acid Leaching

I

IDB	Inter-American Development Bank
IEA	International Energy Agency
IFC	International Finance Corporation
IRENA	International Renewable Energy Agency

J

JETP	Just Energy Transition Partnership
JOGMEC	Japan Oil, Gas and Metals National Corporation

L

LAC	Latin America and the Caribbean

M

MDB	Multilateral Development Bank
MOU	Memorandum of Understanding
MSP	Mineral Security Partnership

O

ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development

P

PGM	Platinum Group Metals

R

R&D	Research and Development
REE	Rare Earth Elements
RISE	Resilient and Inclusive Supply-Chain Enhancement Partnership

S

SDG	Sustainable Development Goal
SEZ	Special Economic Zone
SME	Small and Medium Enterprise

T

TRL	Technology Readiness Level

U

UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
WEF	World Economic Forum
WGI	World Governance Indicators
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

Executive Summary

This section presents the key findings of the comprehensive market assessment presented throughout this report and recommendations to ramp up innovative clean energy and other decarbonization technologies in the mid- and downstream segments of critical minerals value chains in developing countries.

Key Findings

This assessment examines **technological innovation in critical minerals in developing countries**, focusing on the **midstream** (processing and refining) and **downstream** segments (manufacturing, extraction from secondary sources, and end-of-life treatment). It navigates the nexus of stakeholders, policies, initiatives, financial mechanisms, technologies, and impacts on the Sustainable Development Goals (SDGs). Starting from an analysis of 30 countries during Phase 1, deep-dives were conducted during Phase 2 in three from each developing region: **Africa, Asia and the Pacific (ASP), and Latin America and the Caribbean (LAC)**.

A robust **enabling environment** is essential for innovation in critical minerals, requiring institutional capacity and financial and technical resources within the government to shape conducive policy, legal, and regulatory frameworks; accessible, affordable, and sufficient finance from public and private institutions; and partnerships and other collaborative initiatives among stakeholders at the national, regional, and global levels.

The 30 developing countries were rated according to their **policy readiness** level: 50% rated high in renewable energy targets and policies for technological innovation, research and development (R&D), and critical minerals processing and refining; 30% in policies for assembly and manufacturing; and 6.7% in policies for circular economy, recycling, and waste management.

Common in developing countries' successes in fostering an enabling environment for critical minerals innovation are **policy frameworks that emphasise domestic industrial development** beyond the exploration and extraction phase. Policy efforts are often **structured in a way to reinforce rather than compete with other development priorities**, such as the development of the upstream segment, economic diversification, infrastructure development, education and upskilling, environmental sustainability, access to clean energy, and poverty eradication.

Initiatives by international organizations, governments, industry, and other stakeholders support technological innovation in critical minerals in developing countries. A total of **100** global, regional, and national initiatives were analysed, including financing mechanisms **(53%)** and other initiatives **(47%)**; they seek to either finance innovation projects or build up the enabling environment for mid- and downstream activities. **Gaps** in these initiatives include the need for greater scale; finer coordination among them as to policy interventions, minerals, and segments to be prioritised in different markets; and increased sharing of knowledge and data on technologies and their drivers and barriers.

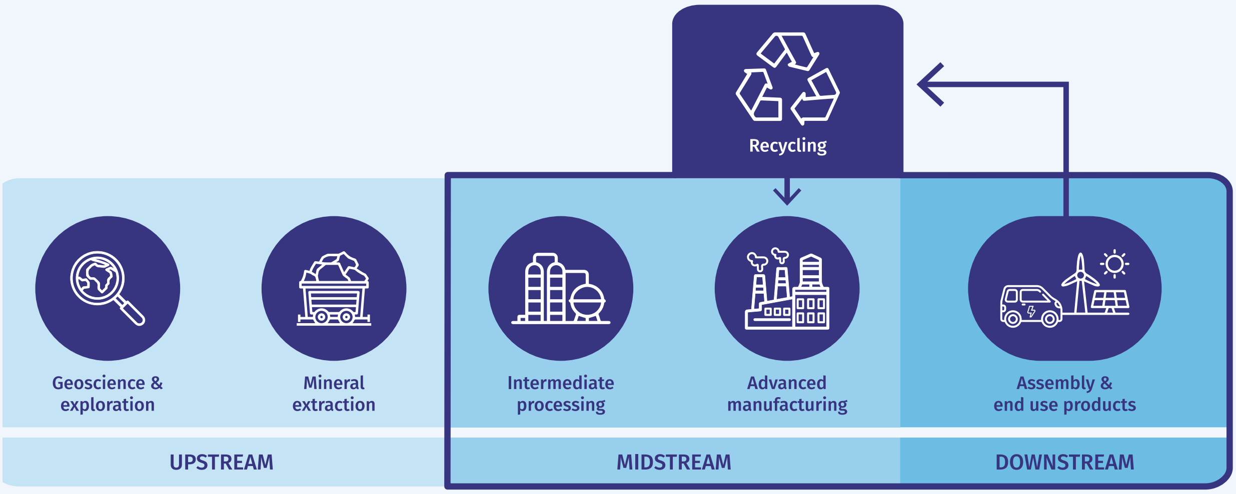
Technological innovation in critical minerals in developing countries relies primarily on technology transfer from developed countries. With that said, **homegrown technological innovation in the mid- and downstream segments is slowly emerging in developing countries**, supported by policy frameworks, incentives, and initiatives implemented largely within the last half-decade.

Mid- and downstream activities offer **substantial opportunities for developing countries** to advance various SDGs, including decarbonisation, poverty eradication, gender equality, affordable and clean energy, industrialisation, technological innovation, infrastructure development, circularity, and environmental stewardship.

1. Introduction

This summary presents the findings of a comprehensive market assessment of innovative clean energy and other decarbonisation technologies in the mid- and downstream segments of critical minerals value chains in developing countries. The market assessment was commissioned by the United Nations Industrial Development Organization (UNIDO) and conducted by a team of economic, legal, policy, and engineering experts from the Columbia Center on Sustainable Investment (CCSI) and the Fu Foundation School of Engineering and Applied Science at Columbia University. It encompasses the collection and analysis of quantitative and qualitative primary data and the production of secondary data and leverages the research team's deep technical knowledge and extensive network of industry stakeholders.

Starting from an analysis of 30 countries during Phase 1 (see Section 2 of the report), deep-dives were conducted during Phase 2 (see Section 3 of the report) in three countries from each developing region: Africa, Asia and the Pacific (ASP), and Latin America and the Caribbean (LAC). The assessment covers various dimensions. It maps out key policies, innovators, technologies, stakeholders, and initiatives in technological innovation in critical minerals value chains. It also identifies specific projects and countries with the potential for such technologies, the financial delivery mechanisms by which investment and expertise will be carried out to them, and the potential impacts of the technologies on the achievement of key Sustainable Development Goals (SDGs). This assessment focuses on the mid- and downstream segments of critical minerals value chains.



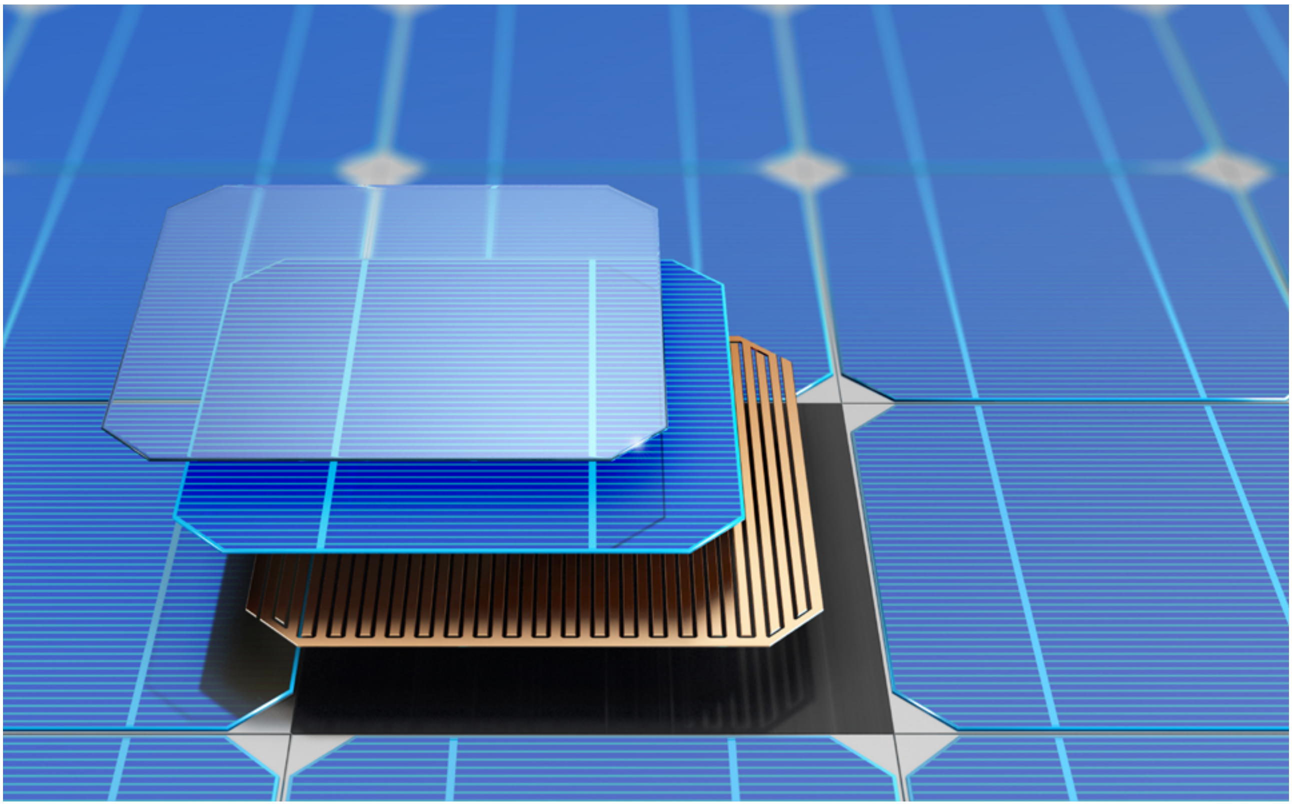
- **Midstream:** encompasses the processing and refining of critical minerals into usable forms as well as the recovery of resources from mining by-products such as process tailings, electrorefining sludge, and pyrometallurgical slag.
- **Downstream:** extends beyond the manufacturing, assembly, and distribution of final products, and also covers the recovery, repurposing, and recycling of valuable materials from secondary resources, such as end-of-life manufactured goods.

The strategic evaluation of mid- and downstream technologies and markets in this assessment will be useful for activities and organizations focused on accelerating innovation in critical minerals in developing countries. Initiatives such as the Accelerate-to-Demonstrate (A2D) Facility are instrumental in facilitating the development, deployment, and scale-up of technological innovation in developing countries.

While several lists of critical minerals exist, this market assessment zooms into energy critical minerals that play a key role in energy storage, the production of strong permanent magnets, and the production and catalysis of renewables-based hydrogen (see more details about the selection of critical minerals in Section 1 of the report).

List of
Critical minerals analysed

- Lithium
- Nickel
- Manganese
- Cobalt
- Graphite
- Rare Earth Elements (REEs)
- Copper
- Platinum Group Metals (PGMs)



The Technology Readiness Level (TRL) is used as the criterion to systematically select and evaluate relevant technologies. The TRL is a scale used to assess the maturity of a particular technology during its development. It consists of nine levels. This scale is widely used to evaluate the progress of technology development and its readiness for deployment or commercialisation.

Deployment	9	ACTUAL SYSTEM PROVEN IN OPERATIONAL ENVIRONMENT
	8	SYSTEM COMPLETE AND QUALIFIED
	7	SYSTEM PROTOTYPE DEMONSTRATION IN OPERATIONAL ENVIRONMENT
Development	6	TECHNOLOGY DEMONSTRATED IN RELEVANT ENVIRONMENT
	5	TECHNOLOGY VALIDATED IN RELEVANT ENVIRONMENT
	4	TECHNOLOGY VALIDATED IN LAB
Research	3	EXPERIMENTAL PROOF OF CONCEPT
	2	TECHNOLOGY CONCEPT FORMULATED
	1	BASIC PRINCIPLES OBSERVED

This assessment focuses on companies and technologies at maturity levels of TRL 6–7 within developing countries. However, in the field of mineral processing and extractive metallurgy, technology development and implementation—from conception to commercialisation—are expensive, labour-intensive, and slow (occurring over 5–15 years depending upon type and complexity of the technology). This is a significant barrier for companies and start-ups in developing countries. Consequently, companies in developed countries often look for opportunities to transfer their mature technologies and know-how to developing countries. Therefore, to capture such opportunities, this report also covers more mature technologies and innovations from developed countries at TRL 8–9 to the extent they present the opportunity of being transferred to developing countries. To summarise, the following TRL ranges are covered:

- **Target TRL 6–7:** This range is chosen for technologies in developing countries. They would likely be at higher TRL in the developed countries, but may still require validation and refinement in relevant local and regional environments in developing countries.

- **Target TRL 8–9:** This range is chosen for technologies in developed countries that are ready for deployment, and thus have potential for replication in developing countries. These technologies have been proven in operational environments and are ready for commercialisation or large-scale implementation.

The technologies analysed in this assessment can be grouped into five major categories:

Physical-mechanical	• Sorting, flotation, magnetic separation, gravity separation, electrostatic, triboelectric, eddy current separation
Hydrometallurgy	• Leaching: Inorganic acids, organic acids, inorganic bases, oxidising and reducing agents, inorganic compounds, complexing agents, water, microbes • Leach solution concentration and metal extraction
Pyrometallurgy	• Roasting, calcining, sintering, pelleting and briquetting, smelting, volatilisation (retorting), refining, segregation
Electrometallurgy	• Electrowinning, electrorefining, molten salt electrolysis, electrochemical separations
Bio-based	• Biomining (biometallurgy), bioleaching, biosorption, phytomining.

Most often, critical minerals extraction from secondary sources (mid- and upstream) comprises technologies from a combination of these categories. Although many of the technologies in these categories are mature, there are many that are either recently developed or emerging. Novel sorting methods, phytomining, and several bio-based processes are examples of emerging technologies.

This market assessment also examines the interplay between technological innovation in the mid- and downstream segments of critical minerals value chains and the SDGs. The theory of change as well as the qualitative and quantitative assessments, link policies, initiatives, and innovations to specific SDGs, with a focus on poverty eradication, gender equality, clean energy, and climate action. This analysis includes data compilation, stakeholder interviews, and thematic analyses to uncover the multifaceted impacts of technological advancements on sustainable development, culminating in actionable recommendations for policymakers, industry leaders, and financiers—including the A2D Facility and climate finance delivery mechanisms and programmes—on priorities and opportunities to channel development and climate finance to critical minerals innovation and to leverage innovation to achieve the SDGs.

2. Phase 1: Market Assessment of 30 Developing Countries

During Phase 1 of the market assessment (see Section 2 of the report), out of the 131 countries and territories outside of Europe on the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) List of Official Development Assistance (ODA) Recipients, 30 developing countries of focus were identified based on criteria including mid- and downstream critical minerals imports, policy readiness, and governance and innovation indicators.

- Countries in Africa: Egypt, Kenya, Mauritius, Morocco, Namibia, Nigeria, Senegal, South Africa, Tanzania, Tunisia, Zambia
- Countries in ASP: Cambodia, Georgia, India, Indonesia, Jordan, Kazakhstan, Malaysia, Philippines, Thailand, Türkiye, Viet Nam,
- Countries in LAC: Argentina, Bolivia, Brazil, Colombia, Dominican Republic, Ecuador, Mexico, Peru

Phase 1 achieved a macro-level understanding of the relevant stakeholder groups and their actual and potential roles in technological innovation in the mid- and downstream segments of critical minerals value chains.

Stakeholders relevant to technological innovation in the mid-and downstream segments of critical minerals value chains span across the public and private sectors. Phase 1 focused on a preliminary mapping of global and regional stakeholders, and, to a lesser degree, national stakeholders, through a preliminary identification and categorisation of who these stakeholders are and what roles they play. The mapping led to a broader understanding of the major players and their roles, facilitating a macro-level perspective on stakeholder dynamics.

During Phase 1, the enabling **policy and regulatory environment** of the 30 countries selected was evaluated, assessing aspects such as renewable energy frameworks, legal frameworks for mining, fiscal incentives affecting decarbonisation technologies, and circular economy regulations or frameworks that support sustainable resource management and recycling. This preliminary assessment served to rank the countries based on their innovation-friendly environments and identify those with the greatest potential for fostering technology development in the mid- and downstream segments of critical minerals value chains.

TABLE. **Analysis of policy, legal, and regulatory environments in the 30 Phase 1 developing countries**

	Africa	ASP	LAC
High	Morocco Namibia South Africa Zambia	India Indonesia Türkiye	Argentina Brazil Mexico
Medium	Egypt Tanzania Tunisia	Georgia Kazakhstan Malaysia Philippines Thailand	Bolivia Colombia Peru
Low	Kenya Mauritius Nigeria Senegal	Cambodia Jordan Viet Nam	Dominican Republic Ecuador

Countries rated **high** implemented comprehensive and robust policies and incentives that encourage technological innovation, facilitate advanced critical mineral processing, support domestic industries that manufacture or assemble products derived from critical minerals, and promote the circular economy. Countries rated **medium or low** are still in the process of establishing comprehensive policy and regulatory infrastructure. Even in nascent policy frameworks, there is a trend toward R&D, innovation, sustainability, and circularity.

The analysis of **initiatives** identified and evaluated ongoing and emerging collaborative efforts aimed at developing, deploying, and scaling up technological innovations in the mid- and downstream segments of critical minerals value chains that help overcome challenges in these segments, improve their efficiency, and contribute to the SDGs, notably climate action and clean energy goals.

Phase 1 focused on mapping global and regional initiatives, and, to a lesser degree, national ones, to provide a high-level understanding of the landscape of relevant initiatives, such as partnerships, collaborations, and consortia including public and private stakeholders within critical minerals value chains, and programs by international organisations and governments.

TABLE. Landscape of initiatives (Phase 1)

Initiative	Type	Key technologies involved	Key stakeholders involved	Geographic focus
World Economic Forum's UpLink	Platform for innovators to present their solutions to global challenges	• Waste management systems • Greenhouse gas emission reduction innovations • Resource efficiency technologies	• Startups • Academic institutions • Industry	• Global
Prospect Innovation	Accelerator for technological innovation in the mining sector	• Energy generation and storage • Recycling and recovery • Robotics, mobility, and hardware • Data capture, analytics, and AI • Carbon capture • Synthetic Biology	• Research institutions • Mining companies • Venture capital firms	• Americas • ASP • Europe
Global Battery Alliance (GBA)	Public–private partnership that promotes sustainable battery value chains	• Battery recycling • Tracking methods for batteries in the value chain ("Battery Passport")	• Government • Civil society • Industry	• Africa • Asia • Europe
World Bank Group's Climate Smart Mining (CSM) Initiative	Initiative to provide guidance and technical support on decarbonisation and sustainability in mineral value chains in developing countries	• Critical minerals recycling • Reusing and repurposing EOL materials	• Government • International organizations • Local communities	• Developing countries
Activate.org	Fellowship that supports entrepreneurial scientists and engineers in developing technologies for global challenges	• Broad; supports original ideas of its fellows	• Academia • Government • Corporations • Philanthropic foundations	• United States

The analysis of **financial delivery mechanisms** identified and categorised various funding sources and support mechanisms relevant to facilitating the development, deployment, and scaling up of technological innovations in the mid- and downstream segments of critical minerals value chains.

Phase 1 focused on mapping global and regional mechanisms, and, to a lesser degree, national ones, to provide a high-level understanding of the landscape of relevant financial delivery mechanisms. The preliminary mapping categorised them according to the predominant public or private nature of their funding source, to help guide stakeholders in identifying financing opportunities and gaps and evaluating the potential roles of various financing sources and models in supporting technological innovation.

TABLE. **Landscape of financial delivery mechanisms (Phase 1)**

Public Sources	Private Sources
• Multilateral Development Banks (MDBs) • Multilateral Climate Finance Funds • National Development Banks • Bilateral Development Agencies • Government Grants and Subsidies • Sovereign Wealth Funds (SWFs)	• Venture Capital • Corporate Venture Capital • Private Equity • Accelerators and Incubators • Private Banks • Impact Investment Funds

3. Phase 2: Deep-Dive Market Assessment of Nine Developing Countries

For Phase 2 of the market assessment (see section 3), out of the 30 Phase 1 countries, nine countries were selected for a deep dive: Namibia, South Africa, and Zambia (Africa); India, Indonesia, and Türkiye (ASP); and Argentina, Brazil, and Mexico (LAC). A comprehensive methodology was used to evaluate and rank countries' level of enabling environment for technology innovation in the mid- and downstream segments of the critical minerals value chain, based on weighted quantitative and qualitative indicators of their policy and technology readiness, the long-term financial sustainability of technological innovation, and knowledge production and sharing (see Appendix A for methodological details).

Phase 2 achieved a deeper understanding of the relevant technologies and markets in the nine selected countries, based on the continued collection of quantitative and qualitative data from the review of written materials (policy documents, legal frameworks, and various reports) as well as interviews with various stakeholders from international organizations, governments, financial institutions, mining companies, industry associations, and academic and research institutions, among others.

A robust **enabling environment** is essential for technological innovation in the mid- and downstream segments of critical minerals value chains, requiring institutional capacity and financial and technical resources within the government to shape conducive policy, legal, and regulatory frameworks; accessible, affordable, and sufficient finance from public and private institutions; and partnerships and other collaborative initiatives among stakeholders at the national, regional, and global levels.

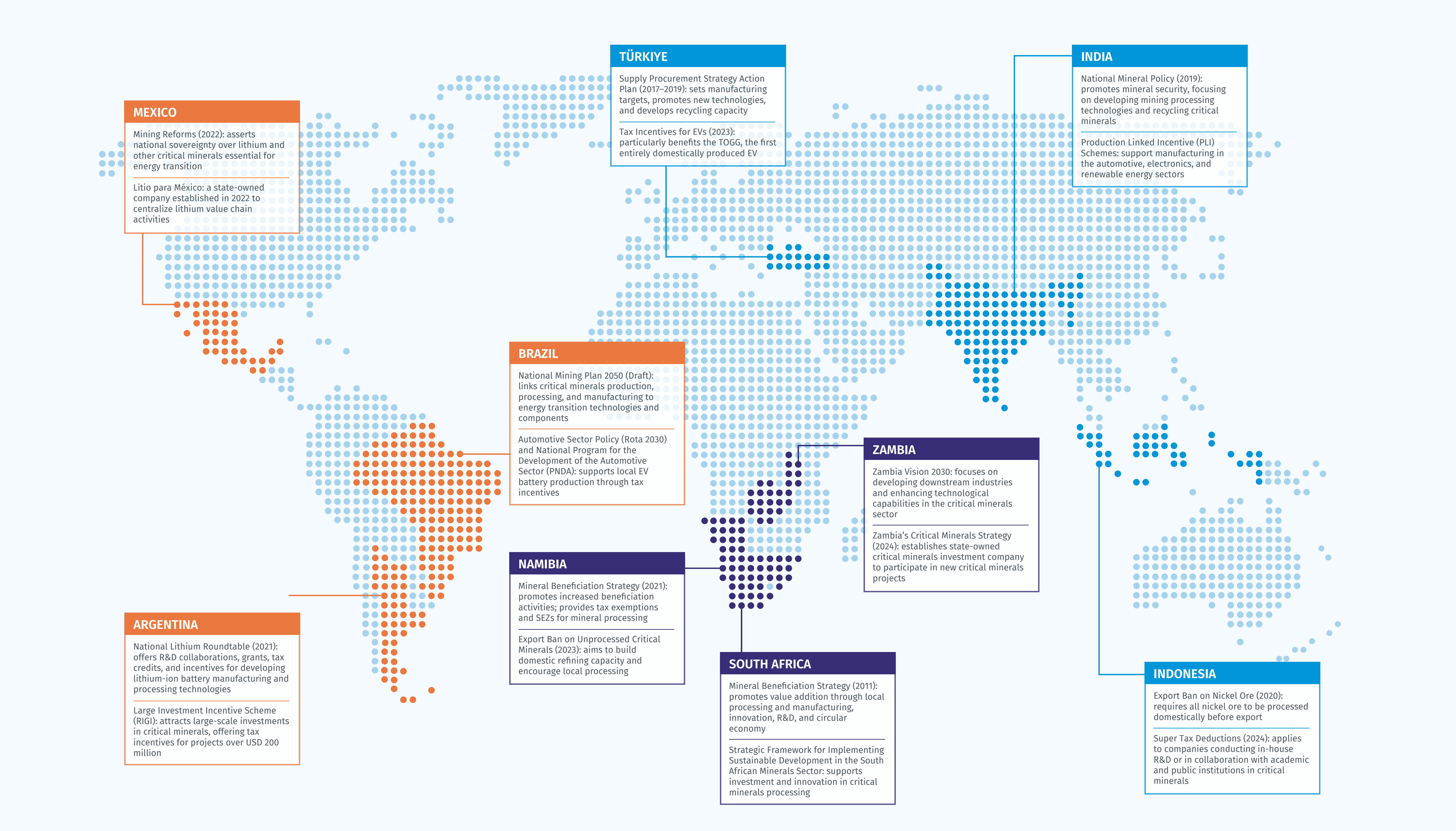
Common among developing countries' successes in fostering such an environment are **policy, legal, and regulatory frameworks that emphasise domestic industrial development** beyond the exploration and extraction phase. Policy efforts in developing countries to advance the mid- and downstream segments, and technological innovation within them, are often **structured in a way to reinforce rather than compete with other development priorities**, such as the development of the upstream segment, economic diversification, infrastructure development, education and upskilling, environmental sustainability, access to clean energy, and poverty eradication.

Numerous R&D initiatives and investments exist in developing countries, particularly in deep-dive countries. Successful initiatives prioritise R&D frameworks and stakeholder collaboration. **National research institutions** like Argentina's National Scientific and Technical Research Council (CONICET), Brazil's Centre for Mining Technology (CETEM), and South Africa's Council for Scientific and Industrial Research are increasingly partnering with mining, renewable energy, and battery companies to broaden access to funding for innovative projects. Investment into **critical mineral and clean energy hubs** like Brazil's Mining Hub and Mexico's Sonora Plan also empower innovation through funding and capacity building for workers. Once innovative projects yield results, successful governments continue to invest in and incentivise their adoption; for example, Türkiye pushed tax incentives for its first domestically-produced EV in 2023.

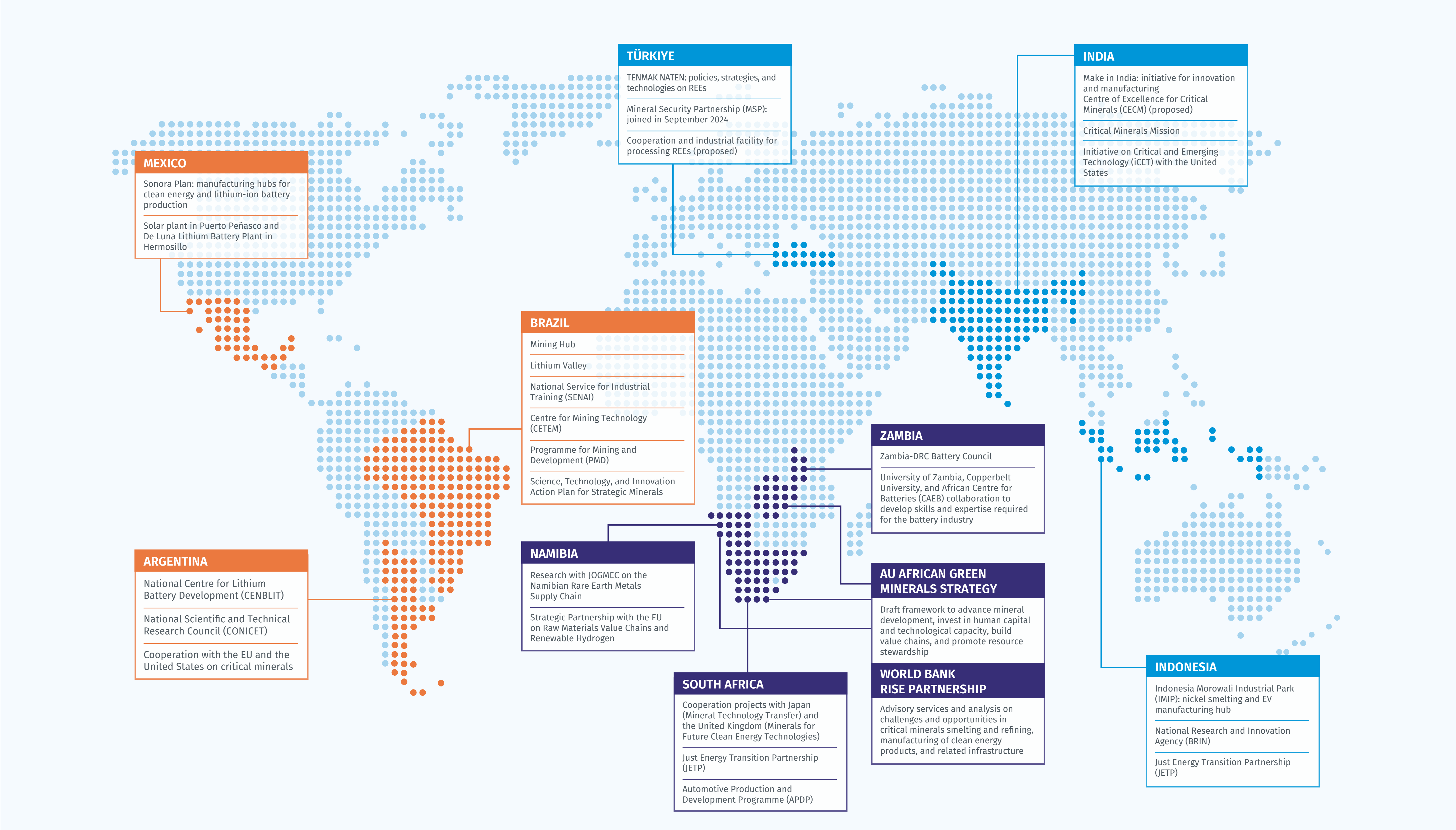
Domestic financial delivery mechanisms through grants and loans provided by national governments and development banks are at the core of enabling innovation in developing countries, often supported by incubators and complemented by private sources, including venture capital and impact funds. Direct funding from national development banks also play a large role in successfully providing financial sustainability for innovation projects, as the Development Bank of South Africa provided over USD 1 billion in lending for renewable energy projects.

International funders and partnerships are also integral to the success of innovative projects in critical minerals. International organizations facilitate initiatives such as UNIDO's A2D Facility, which accelerates the commercialisation of innovative clean energy technologies in developing countries focusing on critical minerals, or the World Bank's RISE Partnership in Southern Africa,

POLICY HIGHLIGHTS IN AFRICA, ASP, AND LAC COUNTRIES



INITIATIVES IN AFRICA, ASP, AND LAC COUNTRIES



offering technical assistance and policy advice to governments as well as finance for governments and the private sector. Collaborative initiatives with development partners—including Australia, China, the EU, Japan, the United Kingdom, and the United States—with all Phase 2 developing countries are commonplace (for example, the Minerals Security Partnership, the United States–India Initiative on Critical and Emerging Technology, the EU–Zambia Memorandum of Understanding on a Partnership on Sustainable Raw Materials Value Chains, the Australia–India Strategic Research Fund, and the United Kingdom–South Africa Partnership on Minerals for Future Clean Energy Technologies). Relationships include strict funding from partners—for example, the Chinese government provided Indonesia with USD 7.3 billion in investments in 2023 through the Belt and Road Initiative (BRI)—as well as research initiatives like Namibia's joint statement of cooperation with the Japan Organization for Metals and Energy Security (JOGMEC).

A key takeaway from the assessment is that **technological innovation in the mid- and downstream segments of the value chain in developing countries relies primarily on technology transfer** from developed countries. With that said, **homegrown technological innovation in the mid- and downstream segments of the critical minerals sector is slowly emerging in developing countries**. Existing technologies are nascent, supported by policy frameworks, incentives, and initiatives implemented largely within the last half-decade. The map indicates noteworthy technologies arising from indigenous technological development, minerals of focus, and technological trends in the nine deep-dive developing countries.

Such technological innovations in the mid- and downstream segments of critical minerals value chains and their enabling policy frameworks have the potential to contribute to **advancing the SDGs in developing countries**. Mineral beneficiation strategies can develop the domestic workforce and industry, relating to SDGs 1 and 9. The growing workforce coupled with targeted interventions can promote opportunities for women in mining communities, bolstering SDG 5. Mid- and downstream activities produce components essential to renewable energy systems and decarbonisation technologies, contributing to clean energy transitions and climate change mitigation under SDGs 7 and 13. Finally, embedding circular economy innovation into mid- and downstream

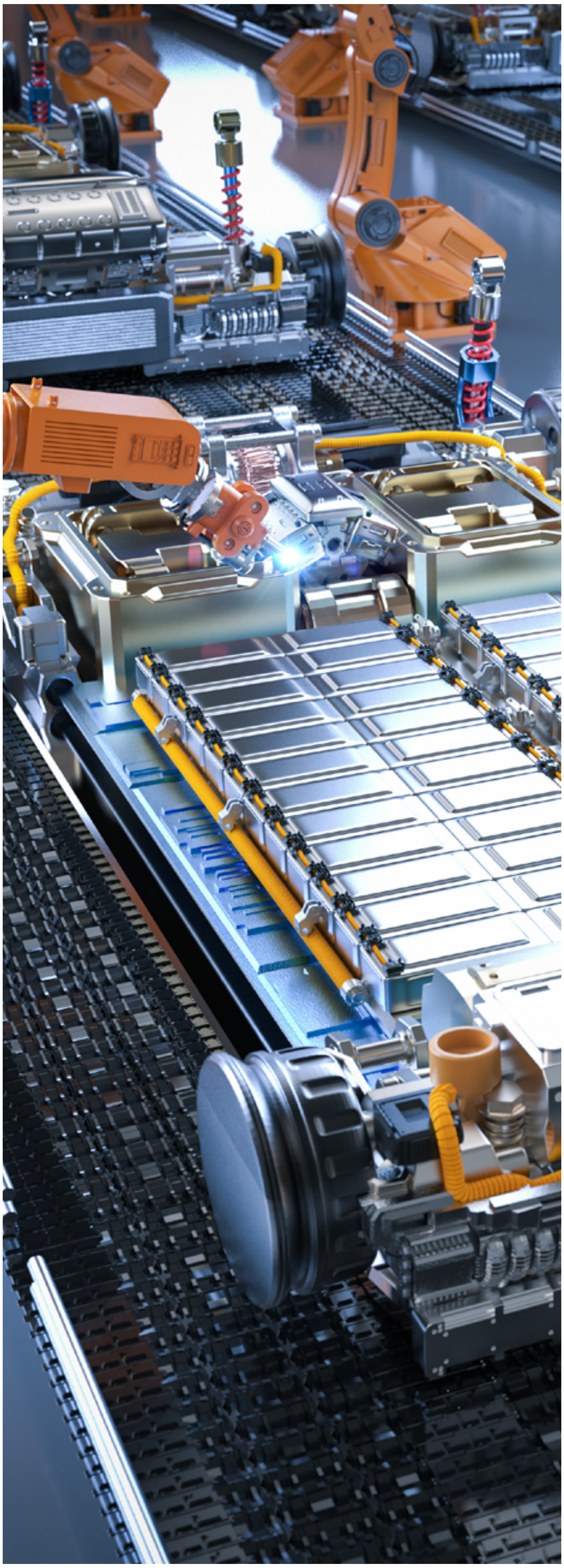


TABLE. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
Africa	Sustainable Energy Fund for Africa (SEFA) (AfDB)	Finance for governments and technical assistance grants for public and private entities	USD 95 million	SEFA 1.0: 2011–2020 SEFA 2.0: 2021–2030
	Green Investment Programme Africa (GIPA) (AfDB)	Investment in low-carbon projects by MSMEs	Not specified	2023–2033
	Youth Entrepreneurship and Innovation Multi-Donor Trust Fund (AfDB)	Technical and financial support to youth- and women-led startups and SMEs	USD 40 million	2017–2025
	Innovation & Entrepreneurship Lab (AfDB)	Incubator and financial support for startups	USD 9.5 million	2019–2025
	Africa Circular Economy Facility (ACEF) (AfDB)	Circular economy policy support for governments, business support for startups and SMEs	USD 4.3 million	2022–2026 with possibility of extension
Namibia	Namibia Industrial Development Agency (NIDA)	Financing mechanism for government-identified priorities in the industrial sector	Not specified	Not applicable
	Development Bank of Namibia (DBN)	Funding for renewable energy projects	Not specified	Not applicable
	Bank Windhoek's Sustainability Bond	Partly allocated towards renewable energy projects	USD 23.1 million	Annual; first tranche was in 2021
	Roadmap for the EU–Namibia strategic partnership on sustainable raw materials value chains and renewable hydrogen	Turning the Port of Walvis Bay into a critical minerals hub for processing and refining	USD 1.1 billion	2021–2027
South Africa	South Africa's Industrial Development Corporation's (IDC) Beneficiation Strategic Business Unit (SBU)	Funding for businesses processing critical metal products to expand their production capacity	From USD 60,000 to 60 million per business	Not applicable
	Development Bank of South Africa's (DBSA) Renewable Energy Independent Power Producer Procurement Programme (REIPPP)	Senior debt to renewable energy projects	USD 1 billion	Seventh Bid Submission Phase ended April 2024
	DBSA Climate Finance Facility (CFF)	Green bank for climate change infrastructure projects	USD 110 million	Launched 2019, 5-yr implementation period, 20-year lifespan
	DBSA Embedded Generation Investment Programme (EGIP)	Funding for local innovation in PV and wind energy generation, especially for Black-owned businesses	USD 200 million	Launched in 2019, no definitive end date
	DBSA Green Fund	Funding of up to USD 1.5 million for project preparation and technical support, and USD 4 million for investment	USD 63 million	Launched in 2012, no definitive end date
Zambia	Strategic partnership between the EU and Zambia (Global Gateway)	Funding for projects involving local value addition and technology development in critical minerals value chains	Not specified	2023–2030
	World Bank's Scaling Solar Initiative	Advisory services, contracts, financing, and insurance, enabling governments and utilities to transparently procure affordable solar power	USD 100 million	Launched 2015; ongoing; projects take 2 years
	Citizens Economic Empowerment Commission of Zambia (CEEC)	Pursues value chain development by investing in local industry, albeit mostly in the agriculture sector	Not specified	Ongoing; est. 2006

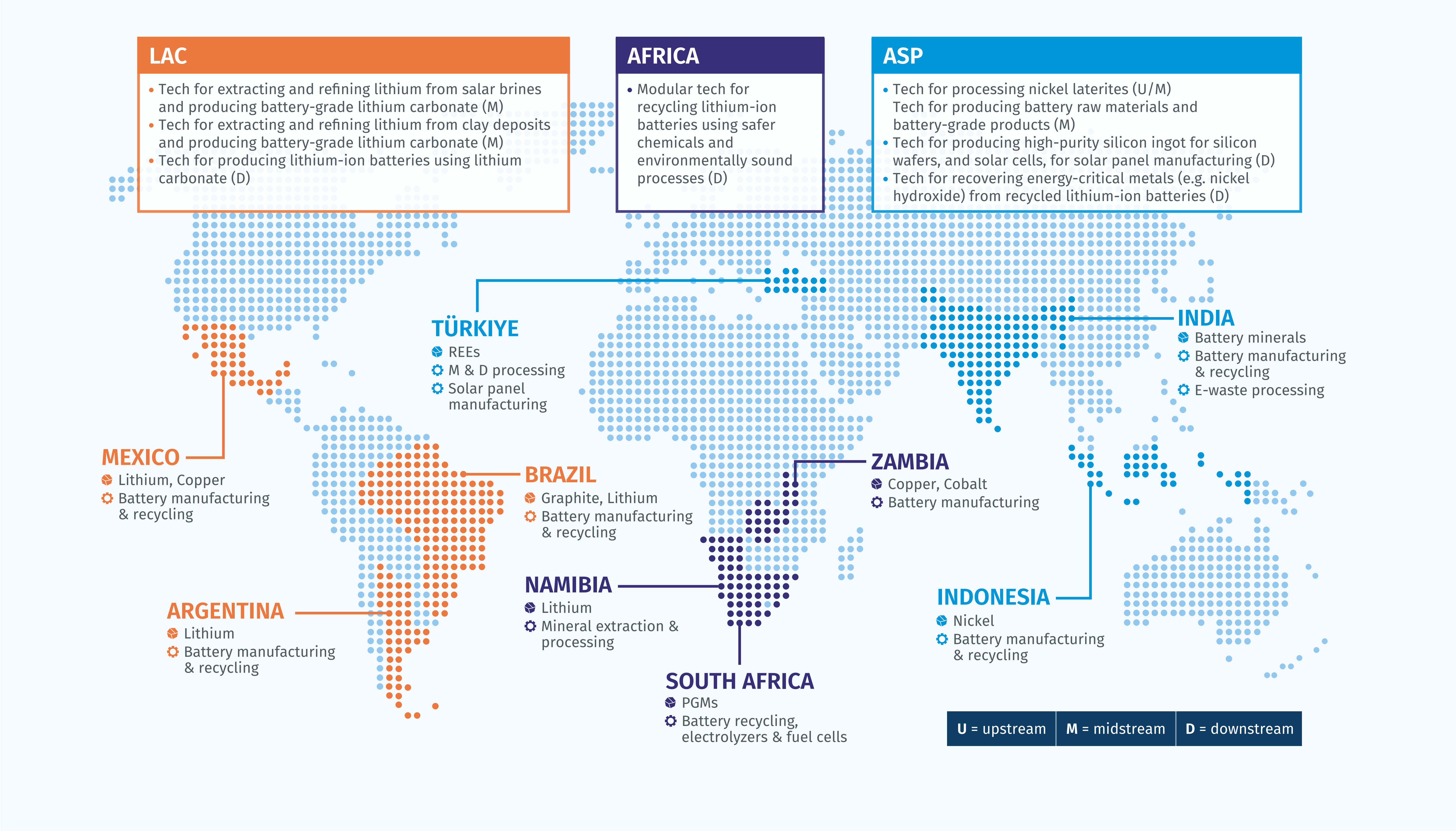
TABLE. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
ASP	Asian Development Bank (ADB) and potential facility for critical minerals value addition	Loans, grants, guarantees for downstream projects in EV battery manufacturing	Not specified	Not applicable
	Asian Infrastructure Investment Bank's (AIIB) Venture Capital (VC) Investment Programme for Green and Technology-Enabled Infrastructure	Small-scale VC funds to early-stage companies to support sustainable green technological innovation and innovative business models	USD 130 million	Est. December 2022, "three-year captive VC investment programme
India	Australia–India Strategic Research Fund (AISRF)	Grants for collaborative R&D projects, including in downstream processing, recycling, and tailings reclamation of critical minerals	Between USD 0.3 and 0.7 million	Round 15 application window: Jan–Mar 2023
	CSIR-National Institute for Interdisciplinary Science and Technology (NIIST)	Support for projects advancing critical minerals extraction and beneficiation techniques	USD 50 million	Announced Aug 2024
	Government initiatives Digital India and Startup India	Support for entrepreneurs with seed funding for research and innovation in multiple sectors, including critical minerals	Not specified	Digital India: July 2015 Startup India: January 2016
India and Türkiye	Minerals Security Partnership (MSP) Finance Network	Co-financing from development finance institutions and export credit agencies for projects in critical minerals value chains	Not specified	Announced 2022, no end date
Indonesia	China's Belt and Road Initiative	Investments in infrastructure, including for critical minerals value chains	USD 7.3 billion	Announced 2013, could last until 2049
India	World Bank's Accelerating the Market Transition for Distributed Energy programme	Grants and loans for solar energy and battery storage projects, including by supporting SMEs to adopt new technologies	USD 1.01 billion	Launched March 2024
	Turkish Growth and Innovation Fund (TGIF), backed by an EUR 60 million commitment from the European Investment Fund (EIF)	Equity investment in innovative and technology-oriented businesses with high growth potential	USD 218 million	Est. 2016
	High Technology Investment Programme (HIT-30)	Incentives for battery production, semiconductor manufacturing, and other EV-specific technology.	USD 30 billion	2024–2030

TABLE. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in Argentina, Brazil, and Mexico

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
LAC	Inter-American Development Bank (IDB)	Financing for projects that enhance the value chain for critical minerals, facilitate public-private partnerships, and improve resource efficiency	Not specified	Not Applicable
Argentina	International Finance Corporation (IFC)	Loan for developing the Sal de Vida lithium operation in Catamarca	USD 180 million	July 2023
	International Finance Corporation (IFC) RenovAr programme	Financing renewable energy projects	USD 11 billion as of May 2024	Launched 2016, fully implemented by 2025
Brazil	Brazil Critical Minerals Fund, a partnership between the National Bank for Economic and Social Development (BNDES), the mining company Vale, and the Ministry of Mines and Energy	Stimulating investments in critical minerals, targeting SME projects to enhance supply chain capabilities for clean energy technologies and decarbonisation beyond extraction	USD 200 million	Mobilises investments in March 2025
	Funding Authority for Studies and Projects (FINEP)	Grants, loans, and equity investments for companies, universities, and research institutions	USD 7 billion in the period 2024–2028	2024–2028
	New Industry Brazil (NIB) programme, a partnership between Brazil's Funding Authority for Studies and Projects (FINEP) and BNDES	Financing technological innovation at an interest rate of 1.7% per annum	USD 3.5 billion	2024–2033
Mexico	Nacional Financiera (NAFIN)	Development funding allocated for sustainable debt into projects that help to achieve the SDGs	USD 395 million	Launched in 2021 USD 326 million due 2031 USD 65 million due 2026
	Banco Nacional de Obras y Servicio Públicos (BANOBRAS)	Funding for social and environmental development projects, notably in infrastructure and energy	Not specified	Not applicable
	Banco Nacional de Comercio Exterior (BANCOMEXT)	Loans for direct and indirect exporters in critical minerals value chains	USD 3 million	Not specified

TECHNOLOGICAL INNOVATION IN DEVELOPING COUNTRIES



processes contributes to responsible consumption and production under SDG 12 and supports reducing environmental impacts in line with SDG 15.This summary of findings understates that the mid- and downstream segments of critical minerals value chains in developing countries, and technological innovation within them, vary **highly across regions and countries, depending on their focus minerals and on the various SDG impacts considered**. The following recommendations are based on broad trends across three completely different contexts, and will have to be carefully implied with the local political and technological environment in mind. Specific recommendations tailored to governments, innovators, and other stakeholders in (or seeking to operate in) the various developing countries covered by this assessment lie outside the scope of this work.

SDG ASSESSMENT - THEORY OF CHANGE	
Direct Linkages	
1 NO POVERTY	Mid- and downstream activities can drive poverty alleviation and economic growth by creating jobs, fostering skill diversification, and increasing government revenues.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Investment in R&D and mid- and downstream facilities promotes industrial development, technological innovation, and expansion of resilient infrastructure.
13 CLIMATE ACTION	Mid- and downstream activities produce components essential for renewable energy systems and decarbonisation technologies, reducing local and global emissions.
Indirect Linkages	
5 GENDER EQUALITY	Targeted interventions can promote gender equality by encouraging women's participation in technical and leadership roles and reducing time poverty for women.
7 AFFORDABLE AND CLEAN ENERGY	Mid- and downstream activities produce components essential for clean energy technologies. Local operations support just transitions and renewable energy deployment.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Mid- and downstream activities can promote responsible consumption and production by enabling efficient refining, manufacturing, and recycling practices that minimise impacts.
15 LIFE ON LAND	Innovation in the mid- and downstream segments can reduce the impact on terrestrial ecosystems by minimising emissions, waste, and stress on water, land, and biodiversity.

TABLE. Enabling environment in the deep-dive countries

	STRENGTHS	AREAS FOR IMPROVEMENT
AFRICA	• Mineral beneficiation strategies • Bilateral cooperation with developed countries (e.g. EU-Namibia Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen [USD 1.1 billion]; South Africa-UK Minerals for Future Clean Energy Technologies Partnership; partnership between Zambia and the Japan Organization for Metals and Energy Security) • Regional initiatives (e.g. African Green Minerals Strategy and DRC-Zambia Battery Council) • Industrial development agencies • Policies advancing SDGs	• Circular economy, recycling, and waste management policies • Power and logistics infrastructure constraints to industrial development • Government institutional capacity to build up and enforce regulatory frameworks • Policies advancing SDGs
ASP	• Circular economy, recycling, and waste management policies • Tax incentives for technology development • Special Economic Zones (SEZs) for industrialisation and downstream activities • Cooperation with developed countries: Minerals Security Partnership • National financial mechanisms (e.g. Make in India; Indonesia Battery Corporation; Turkish Growth and Innovation Fund [USD 218 million]) • Policies advancing SDGs	• Regional cooperation and initiatives • Reliance on imported fossil fuel–based energy • Policies advancing SDGs
LAC	• Financial incentives for companies in mid- and downstream segments (e.g. tax rebates and exemptions) • State-owned company for lithium value chain • R&D frameworks and initiatives • Industry-led initiatives to coordinate stakeholders: Mining Hub • Multilateral development bank (MDB) support (e.g. International Finance Corporation [IFC] loans and Inter-American Development Bank [IDB] programmes) • Policies advancing SDGs	• Stringent circular economy policies on critical minerals • Policies governing mid- and downstream activities are fragmented across different ministries and minerals, lacking cohesive national frameworks • Regional cooperation and initiatives • Policies advancing SDGs

Ten Recommendations to Ramp up Technological Innovation in the Mid- and Downstream Segments

International support to developing country governments and stakeholders in the innovation ecosystem should be increased, including through technical assistance, capacity building, policy advice, and access to finance.

International and regional organizations and development finance institutions should build on initiatives for the **enabling environment** (e.g. World Bank's RISE Partnership) and **specific innovation projects** (e.g. UNIDO's A2D Facility).

A global multi stakeholder platform should be created to coordinate initiatives, foster collaboration, and share knowledge and data on technological innovation. UNIDO is well-positioned to house such a platform.

UNIDO should lead in ensuring the **continuous gathering, transparency, and analysis of data on innovation**—for example, through rolling surveys and public databases—going beyond the discrete exercise of this assessment.

Developing country policy should provide regulatory guidelines, support domestic collaborations, and offer innovation incentives; **developed country policy** should promote international cooperation, facilitate knowledge and technology transfer, and provide access to finance.

Developing countries should prioritise the **development of energy, communications, and logistics infrastructure** to address broader industrial development constraints, in line with the SDGs and national priorities and strategies.

Special programmes should be created to support **small and medium enterprises (SMEs)** involved in technological innovation in developing countries to partner with other stakeholders and access funding opportunities, including UNIDO's A2D Facility.

Policymakers should **incentivise circular policies and practices** through regulations, incentives, and innovation funding; the private sector should **strengthen the business case for circularity** by showcasing cost savings, new revenue streams, and improved resource efficiency.

Industry-led initiatives to coordinate mining value chain stakeholders around common challenges and priorities for innovation—such as Brazil's Mining Hub and other initiatives led by mining associations—should be encouraged and expanded.

Besides fostering technological innovation in developing countries, international organizations and governments should put in place **regulatory and financial conditions to facilitate technology transfer** from companies based in developed countries.

1

Introduction

This section introduces the objectives, scope, approaches, and phases of the work presented throughout this report—a comprehensive market assessment of innovative clean energy and other decarbonization technologies in the mid- and downstream segments of critical minerals value chains in developing countries.

OBJECTIVES OF THE REPORT

This report presents the findings of a comprehensive market assessment of innovative clean energy and other decarbonisation technologies in the mid- and downstream segments of critical minerals value chains in developing countries. The market assessment was commissioned by the United Nations Industrial Development Organization (UNIDO) Accelerate-to-Demonstrate (A2D) Facility and conducted by a team of economic, legal, policy, and engineering experts from the Columbia Center on Sustainable Investment (CCSI) and the Fu Foundation School of Engineering and Applied Science at Columbia University. It encompasses the collection and analysis of quantitative and qualitative primary data and the production of secondary data and leverages the research team's deep technical knowledge and extensive network of industry stakeholders.

The assessment covers various dimensions. It maps out key policies, innovators, technologies, stakeholders, and initiatives in technological innovation in critical minerals value chains. It also identifies specific projects and countries with the potential for such technologies, the financial delivery mechanisms by which investment and expertise will be carried out to them, and the potential impacts of the technologies on the achievement of key Sustainable Development Goals (SDGs).

The strategic evaluation of mid- and downstream technologies and markets in this assessment will be useful for activities and organizations focused on accelerating innovation in critical minerals in developing countries. Initiatives such as the Accelerate-to-Demonstrate (A2D) Facility are instrumental in facilitating the development, deployment, and scale-up of technological innovation in developing countries.[1] The assessment culminates in actionable recommendations for policymakers, industry leaders, and financiers—including the A2D Facility and climate finance delivery mechanisms and programmes—on priorities and opportunities to channel development and climate finance to critical minerals innovation and to leverage technological advancements innovation to achieve the SDGs.

1) "Accelerate-to-Demonstrate (A2D) Facility," United Nations Industrial Development Organization (UNIDO), UNIDO, https://a2dfacility.unido.org/web.

MARKET SEGMENTS: MID- AND DOWNSTREAM

This assessment focuses on the mid- and downstream segments of critical minerals value chains (see Figure 1), defined as follows:

- **Midstream**: encompasses the processing and refining of critical minerals into usable forms as well as the recovery of resources from mining by-products such as process tailings, electrorefining sludge, and pyrometallurgical slag.
- **Downstream**: extends beyond the manufacturing, assembly, and distribution of final products, and also covers the recovery, repurposing, and recycling of valuable materials from secondary resources, such as end-of-life manufactured goods.

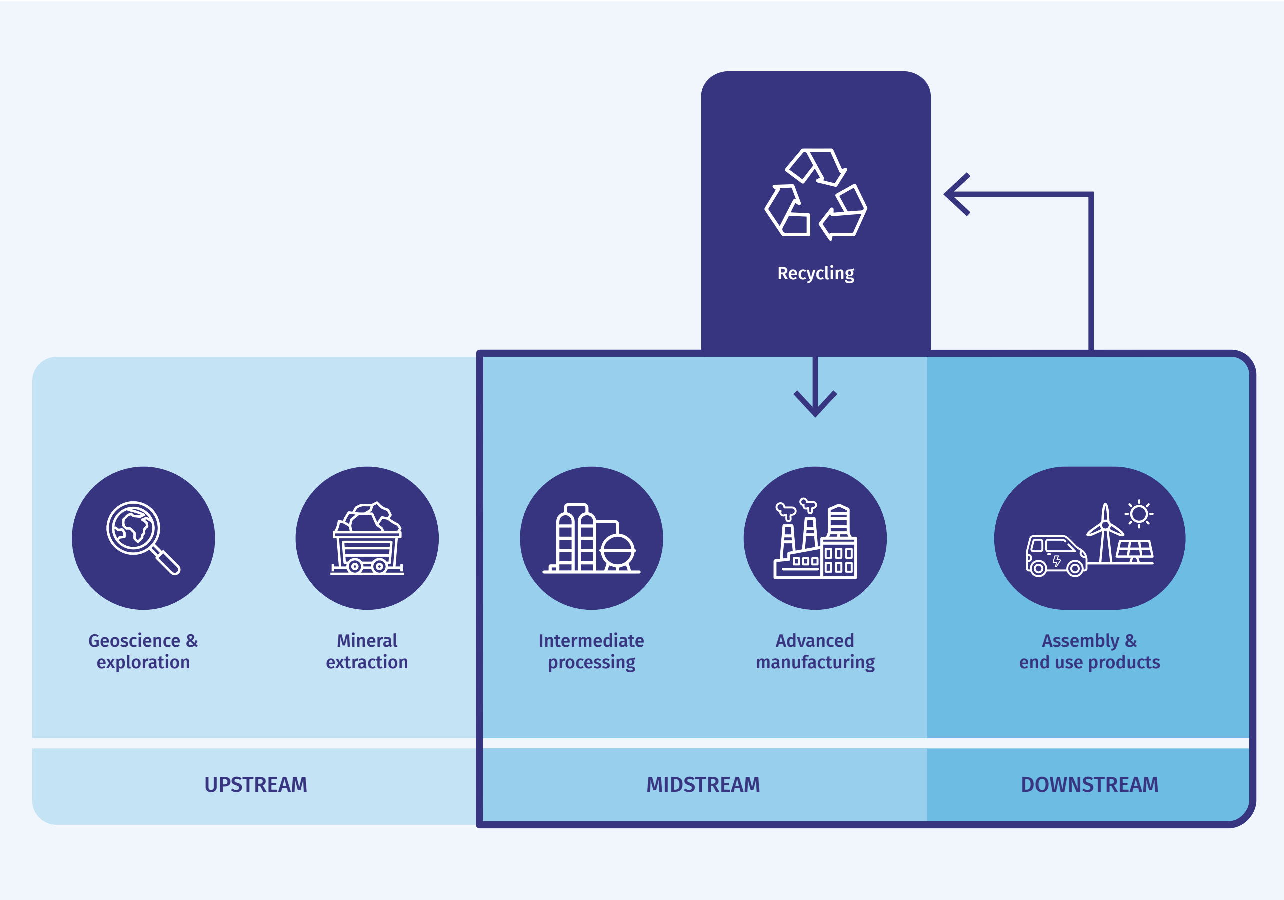


Figure 1. Schematic illustrating the lifecycle stages of critical minerals. This market assessment focuses on the mid- and downstream segments of critical mineral value chains.

Source: Adapted from Government of Canada (2022).[2]

2) Government of Canada, "The Canadian Critical Minerals Strategy, From Exploration to Recycling: Powering the Green and Digital Economy for Canada and the World," 9 December, 2022, https://www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html.

The assessment focuses on midstream technologies essential for manufacturing high-demand goods in high-tech and renewable energy sectors, and on downstream technologies for recovering, repurposing, and recycling materials that contain critical minerals. The study of technologies for physical separation and preparation for re-entry into the cycle was prioritised. While certain technologies analysed in this report may be similar to those used in upstream processes (mining and extractive metallurgy), upstream activities of exploration and extraction of critical minerals from primary sources and the technologies applied in those activities lie outside the scope of this assessment.[3]

3) The traditional demarcations of up-, mid-, and downstream processing tend to be blurry under certain conditions and depending on a particular technology used and the particular critical minerals involved. For example, if a plant engaged in mining and processing also produces a higher-grade mineral product with modifications to the process or a different technology, then all or part of the midstream processing is merged with upstream processing. With copper, for example, traditional demarcations may still be valid; however, for lithium and nickel processing, for example, demarcations between up- and midstream may be blurry. Acknowledging these nuances and the role that the upstream segment has in providing a platform for mid- and downstream activities, this assessment allowed some flexibility in considering technologies.

CRITICAL MINERALS

Critical minerals are fundamental components of a wide range of technologies, especially for the transition to renewables-based energy systems. The supply and demand dynamics of critical minerals are influenced by geopolitical factors, mining and processing challenges, and their limited availability in economically viable concentrations. Depending on the country, region, and sector, and their respective needs, several lists of critical minerals have been published. Figure 2 shows 52 minerals (out of 79 stable, non-radioactive, naturally-occurring ones) deemed "critical" by the United States Departments of Energy (DOE) and of the Interior (DOI), as published in "2023 Final Critical Materials List."

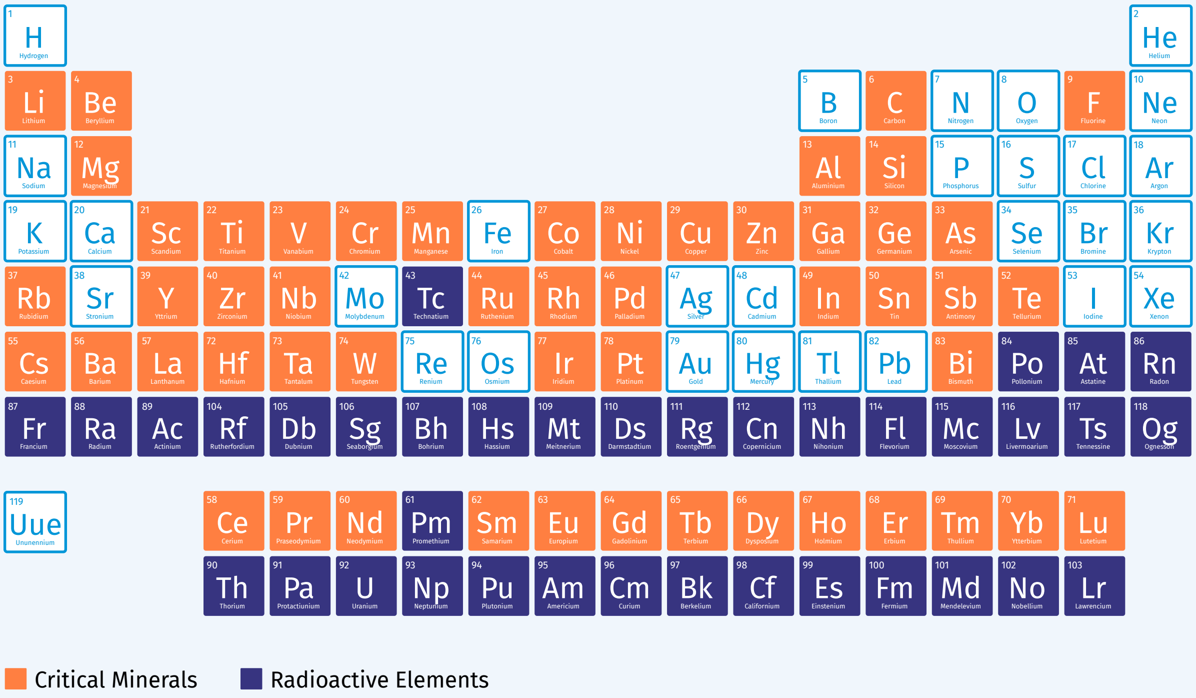


Figure 2. Periodic table indicating critical minerals according to various definitions and designations.

Source: Prepared by the authors based on U.S. Department of Energy (2023).[4]

4) "What Are Critical Materials and Critical Minerals?," United States Department of Energy, https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals.

To emphasise the role that these elements play in the global transition to clean energy, the U.S. DOE designated 18 elements from this general list as Critical Materials for Energy, which is also known as "The Electric Eighteen": aluminium, cobalt, copper, dysprosium, electrical steel, fluorine, gallium, iridium, lithium, magnesium, natural graphite, neodymium, nickel, platinum, praseodymium, silicon, silicon carbide, and terbium.[5]

In addition to primary sources (i.e. mined ores from mineral deposits), many of the critical minerals (or metals) are extracted from a wide range of secondary sources. For example, most of the production of gallium and tellurium comes from secondary sources, therefore depending on mid- and downstream processes. Figure 3 shows some examples of the midstream and downstream processes making up these secondary sources, as well as their constraints. As demonstrated by the selected key constraints, the market hinges on vastly diverse factors ranging from economic to social impact-driven ones.

5) "What Are Critical Materials and Critical Minerals?," United States Department of Energy.

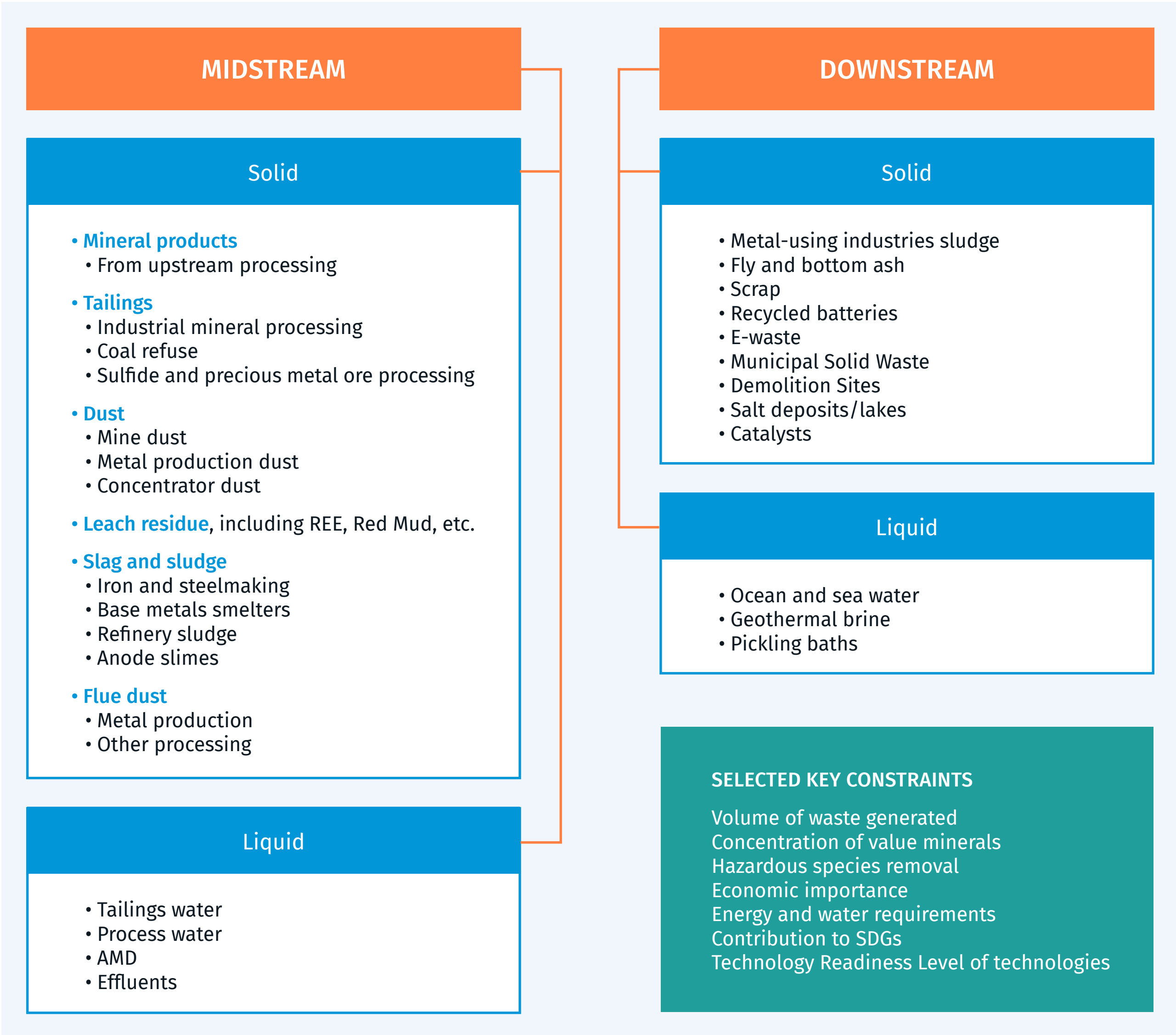


Figure 3. Examples of secondary sources and selected key constraints

Source: Prepared by the authors based on data from various sources.[6]

Notes: In the midstream segment, mineral products from upstream processing are the most important source for critical minerals; extraction from all other listed midstream sources is relatively small to negligible. In the downstream segment, the most important sources are recycled batteries, e-waste and catalysts; extraction from all other sources is relatively small to negligible.

---

6) Jeanette B. Berry, Juan J. Ferrada, L. R. Dole, and Moonis Ally, *Sustainable Recovery of By-Products in the Mining Industry* (Oak Ridge: Oak Ridge National Laboratory, 2001), https://www.lesdole.com/AIChE2001.pdf; "What are Critical Minerals?," Unlocking the Potential of Unconventional Critical Mineral Resources, United States Department of Energy, https://arcgis.netl.doe.gov/portal/apps/MapSeries/index.html?appid=d1fb02d6ba6249b4807e8b3b9931639c; United States Department of Energy: Office of Fossil Energy and Carbon Management - Division of Minerals Sustainability, *Multi-Year Program Plan for Division of Minerals Sustainability* (Washington, DC: Department of Energy, October 2021), https://www.energy.gov/sites/default/files/2021-10/MSD%20Multi-Year%20Program%20Plan%202021_0.pdf; Anne J. Whitworth, James Vaughan, Gordon Southam, Antony van der Ent, Philip N Nkrumah, Xiaodong Ma, and Anita Parbhakar-Fox, "Review on Metal Extraction Technologies Suitable for Critical Metal Recovery from Mining and Processing Wastes," *Minerals Engineering* 182 (2022), https://doi.org/10.1016/j.mineng.2022.107537; Jeff Gillow, *Unconventional Sources of Critical Minerals: Opportunities for Recovery from Mined Materials in the Copper and Gold Environment* (Amsterdam: Arcadis, November 2023), https://www.pnnl.gov/sites/default/files/2023-11/Remplex%20Submission%2043%20%20421.pdf; S. Ramachandra Rao, "Resource Recovery and Recycling from Metallurgical Wastes," *Waste Management Series* 7, (2006): 1–581, https://www.sciencedirect.com/bookseries/waste-management-series/vol/7/suppl/C; Maria Gavrilescu, "Microbial Recovery of Critical Metals from Secondary Sources," *Bioresource Technology* 344, (2022), https://doi.org/10.1016/j.biortech.2021.126208; Chukwunwike O. Iloeje, Fiseha Tesfaye, Alexandra E. Anderson and Joseph Hamuyuni, "Recovery of Rare Earth and Critical Metals from Unconventional Sources" *Journal of Metals* 74, (2022): 990–992, https://doi.org/10.1007/s11837-022-05155-w; Andrew McCarthy and Peter Börkey, "Mapping Support Primary Secondary Metal Production," (OECD Environment Working Paper No. 135, Paris: OECD Publishing, 2018), https://www.oecd-ilibrary.org/environment/mapping-support-for-primary-and-secondary-metal-production_4eaa61d4-en;

Robert C. Dunne, S. Komar Kawatra, and Courtney A. Young, *SME Mineral Processing & Extractive Metallurgy Handbook* (Englewood: Society for Mining, Metallurgy, and Exploration, 2019), https://app.knovel.com/kn/resources/kpSMEMPEM1/toc.

The International Energy Agency (IEA) also lists minerals and metals that are critically important for the energy transition, alongside the technologies for which they are relevant (see Figure 4).

Moreover, the British Geological Survey (BGS) published a list of critical minerals in 2021.[8] The mineral criticality in this report is assessed based on the role of critical minerals in providing the UK government with the opportunity to reduce greenhouse gas emissions to net zero by 2050. This includes aggressive EV technology and production progress, transforming the energy system to introduce more wind energy, and considerable growth in hydrogen production. Consequently, the list of critical minerals provided by the BGS is directly related to the clean energy transition and can be studied independently of geological and geopolitical considerations. Figure 5 shows the critical minerals assessment that was concluded by the BGS.

	Lithium	Nickel	Manganese	Cobalt	Graphite	REEs	Copper	PGMs
Solar PV	low	low	medium	low	low	low	high	low
Wind	low	medium	low	low	medium	high	high	low
Hydro	low	low	low	low	low	low	medium	low
CSP	low	medium	high	low	low	low	medium	low
Bioenergy	low	low	medium	low	low	low	high	low
Geothermal	low	high	low	low	low	low	low	low
Nuclear	low	medium	low	low	low	medium	medium	low
Electricity networks	low	low	medium	low	low	low	high	low
EVs and battery storage	high	high	high	high	high	high	high	low
Hydrogen	low	high	high	low	low	medium	low	high

● = high ● = medium ● = low

Figure 4. Critical mineral needs for selected energy technologies

Source: Adapted from International Energy Agency (2022).[7]

Notes: Shading indicates the relative importance of minerals for a particular clean energy technology. CSP = concentrating solar power; EV = electric vehicle; PGMs = platinum group metals; PV = photo-voltaic; REEs = rare earth elements.

7) International Energy Agency, *The Role of Critical Minerals in Clean Energy Transition* (Paris: International Energy Agency, May 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

8) British Geological Survey, *UK Criticality Assessment of Technology Critical Minerals and Metals* (Nottingham: British Geological Survey, June 2022), https://www.bgs.ac.uk/download/uk-criticality-assessment-of-technology-critical-minerals-and-metals.

Figure 5. UK criticality assessment of technology critical minerals and metals

Source: BGS (2021).[9]

The significant overlap among the U.S. DOE-DOI, IEA, BGS, and other lists examined reveals a strong global need for these critical minerals. In order to bring attention to the most important elements and provide a deep analysis of the critical minerals market in developing countries, this market assessment is limited to this overlap of "Energy critical minerals" that were found to play a key role in the global clean energy transition. Below is the final list of minerals considered critical for purposes of this report. It includes elements that are critical for energy storage, the production of strong permanent magnets, and the production and catalysis of renewables-based hydrogen:

1. **Lithium**: Used extensively in lithium-ion batteries for electric vehicles (EVs) and energy storage systems. Demand for lithium is expected to grow significantly as EV and battery production increases.

9) British Geological Survey, *UK Criticality Assessment of Technology Critical Minerals and Metals*.

2. **Nickel**: Important for high-energy-density batteries, which are crucial for EVs. Nickel helps improve battery life and performance.

3. **Manganese**: Key metal in lithium-ion batteries, wind turbines, and solar energy systems.

4. **Cobalt:** Used in battery cathodes, particularly for high-energy-density lithium-ion batteries used in EVs and portable electronics.

5. **Graphite:** A key component in the anodes of lithium-ion batteries.

6. **Rare Earth Elements (REEs):** Used in permanent magnets for wind turbines and EV motors; enhances the durability of magnets at high temperatures; used in high-efficiency magnets and phosphors.

7. **Copper:** Essential for electrical wiring, motors, and renewable energy infrastructure, owing to its high electrical conductivity.

8. **Platinum Group Metals (PGMs):** Used in fuel cells for hydrogen-powered vehicles, catalytic converters, and electronics.

TECHNOLOGY READINESS LEVELS: DEFINITION AND SCOPE

The Technology Readiness Level (TRL) was used as the criterion to systematically select and evaluate relevant technologies. The TRL is a scale used to assess the maturity of a particular technology during its development. It consists of nine levels (as shown in Figure 6). This scale is widely used to evaluate the progress of technology development and its readiness for deployment or commercialisation.

Deployment	9	ACTUAL SYSTEM PROVEN IN OPERATIONAL ENVIRONMENT
	8	SYSTEM COMPLETE AND QUALIFIED
	7	SYSTEM PROTOTYPE DEMONSTRATION IN OPERATIONAL ENVIRONMENT
Development	6	TECHNOLOGY DEMONSTRATED IN RELEVANT ENVIRONMENT
	5	TECHNOLOGY VALIDATED IN RELEVANT ENVIRONMENT
	4	TECHNOLOGY VALIDATED IN LAB
Research	3	EXPERIMENTAL PROOF OF CONCEPT
	2	TECHNOLOGY CONCEPT FORMULATED
	1	BASIC PRINCIPLES OBSERVED

Figure 6. Technology Readiness Level (TRL)

Source: TWI (n.d.).[10]

This assessment focuses on companies and technologies at maturity levels of TRL 6–7 within developing countries. However, in the field of mineral processing and extractive metallurgy, technology development and implementation—from conception to commercialisation—are expensive, labour-intensive, and slow (occurring over 5–15 years depending upon type and complexity of the technology). This is a significant barrier for companies and start-ups in developing countries. Consequently, companies in developed countries often look for opportunities to transfer their mature technologies and know-how to developing countries. Therefore, to capture such opportunities, this report also covers more mature technologies and innovations from developed countries at TRL 8–9 to the extent they present the opportunity of being transferred to developing countries. To summarise, the following TRL ranges are covered:

- **Target TRL 6–7**: This range is chosen for technologies in developing countries. They would likely be at higher TRL in the developed countries, but may still require validation and refinement

10) "What Are Technology Readiness Levels?," The Welding Institute, https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels.

in relevant local and regional environments in developing countries.

- **Target TRL 8–9**: This range is chosen for technologies in developed countries that are ready for deployment, and thus have potential for replication in developing countries. These technologies have been proven in operational environments and are ready for commercialisation or large-scale implementation.

The selection process began with a comprehensive review of scientific literature, industry reports, and patent databases to assess current technological developments globally. Technologies were then filtered based on the TRL criteria, ensuring relevance to either developing or developed countries. Following this, technologies were assessed for their applicability to the clean energy sector, specifically their use of critical minerals. This step involved analysing the mineral requirements of each technology and their potential impact on the clean energy value chain. Innovative midstream and downstream technologies were identified next, focusing on their novelty and potential to enhance efficiency and sustainability in mineral processing and product manufacturing. Lastly, each technology's environmental impact was evaluated. Technologies demonstrating substantial reductions in greenhouse gas emissions, water usage, and energy consumption were prioritised. This evaluation was based on both theoretical assessments and empirical data where available.

KEY TYPES OF TECHNOLOGICAL INNOVATIONS ASSESSED

A wide range of technologies, in various stages of development and TRLs, are available for consideration and assessment. These can be assessed based on TRL:

1. Mature (high TRL)
2. Recently developed and in various stages of implementation (intermediate TRL)
3. Emerging technologies (currently around TRL 5, but with high potential for rapid development and implementation).

The technologies can be grouped into five major categories (see Figure 7):

a. Physical-mechanical
   - Sorting, flotation, magnetic separation, gravity separation, electrostatic, triboelectric, eddy current separation

b. Hydrometallurgy
   - Leaching: Inorganic acids, organic acids, inorganic bases, oxidising and reducing agents, inorganic compounds, complexing agents, water, microbes
   - Leach solution concentration and metal extraction

c. Pyrometallurgy
   - Roasting, calcining, sintering, pelleting and briquetting, smelting, volatilisation (retorting), refining, segregation

d. Electrometallurgy
   - Electrowinning, electrorefining, molten salt electrolysis, electrochemical separations

e. Bio-based
   - Biomining (biometallurgy), bioleaching, biosorption, phytomining.

Additional description, analysis, and TRL levels are described below. Most often, critical minerals extraction from secondary sources comprises technologies from a combination of these categories. Although many of the technologies in these categories are mature, there are many that are either recently developed or emerging. Novel sorting methods, phytomining, and several bio-based processes are examples of emerging technologies. Some of the key technologies identified are presented in Figure 7 and Table 1.

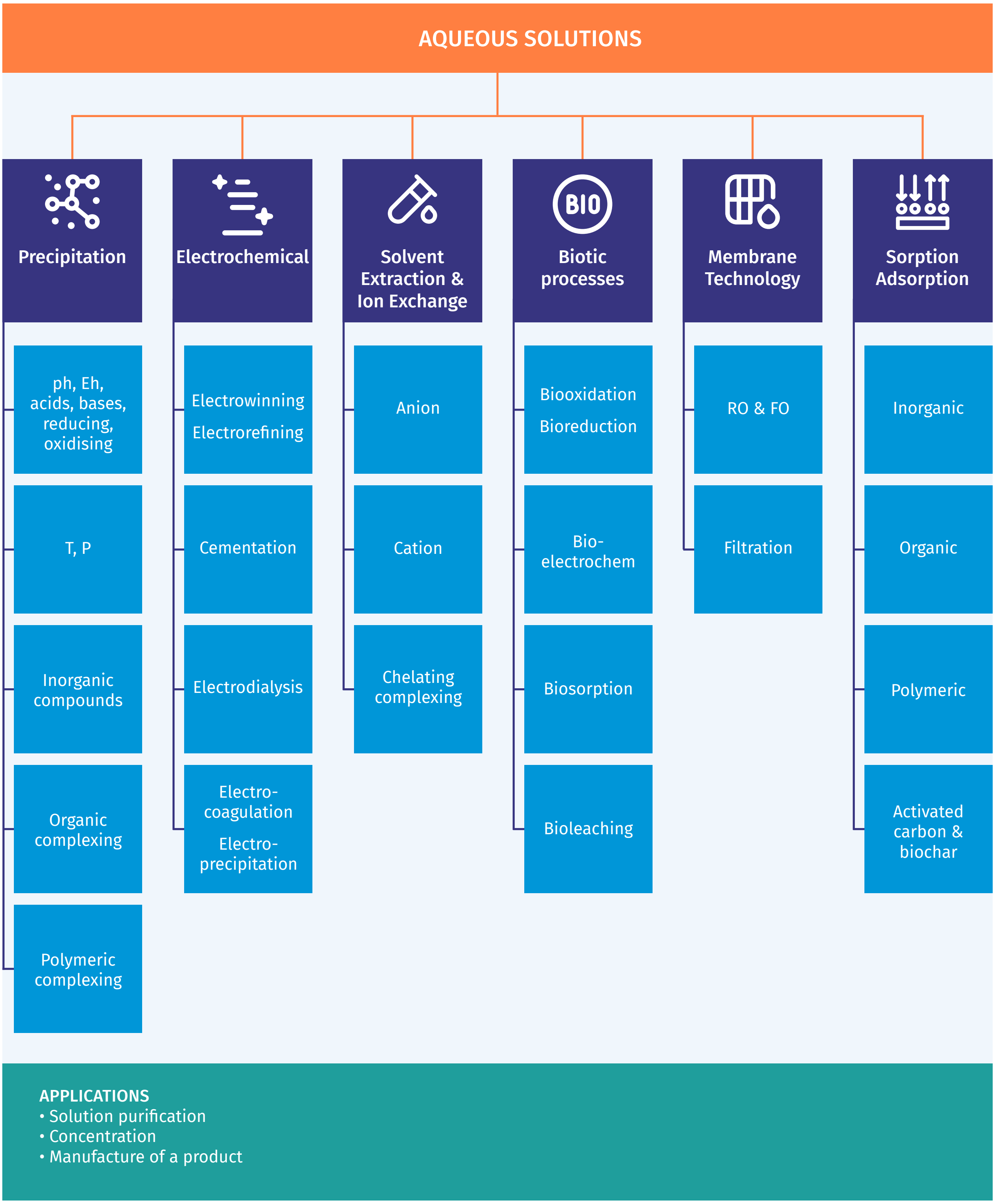


Figure 7. Separation methods for leach solutions.

Source: Prepared by the authors.

Notes: Most of these technology categories can be considered mature; however, significant advances have been made recently and many novel features are emerging.

TABLE 1. Solids material sorting methods grouped into three categories: new, intermediate, and mature

Technology	Principle	Manufacturer*	TRL Level
Prompt gamma neutron activation analysis (PGNAA)	Neutron activation / gamma energy emission	Scantec, ThermoFisher, PANalytical	**New**
Magnetic resonance spectroscopy (MRS)	Resonant frequency of molecules	CSIRO	**New**
Timegated Raman Spectroscopy	Pulsed Raman Fluorescence Suppression	Timegate	**New**
X-ray transmission (XRT)	Relative absorption of high energy X-rays	Steinert, TOMRA	**Intermediate**
X-ray fluorescence (XRF) spectroscopy	Inner shell electron excitation	MineSense, Rados, Steinert, IMA	**Intermediate**
Microwave-infrared (MW/IR)	Microwave absorption, heat radiation		**Intermediate**
Laser-induced breakdown spectroscopy (LIBS)	Electron excitation/ light emission	Secopta, LDS, LSA	**Intermediate**
Hyperspectral analysis	Reflectance/ absorption	Steinert	**Intermediate**
Electromagnetic (EM)	Electromagnetism/ Induction	TOMRA, Steinert, MineSense	**Intermediate**
Radiometric (scintillometer)	Radioactivity	TOMRA, Rados	**Mature**
UV/X-ray luminescence (X-Ray/UV-L)	Luminescence through X-ray or UV stimulation	TOMRA, De Beers	**Mature**
Laser-induced fluorescence (LIF)	High-energy photonic emission	IMA, AIS Sommer	**Mature**
Near-infrared spectroscopy (NIR)	Reflection/absorption of NIR	Steinert, TOMRA and many others	**Mature**
Photometric	Chromatic reflectance/ absorption	Steinert, TOMRA	**Mature**

Note: Significant effort has been made to develop and improve sensors, which has led to novel sorting technology.

Source: Compiled by the authors based on information from various sources.[11]

11) Christopher Robben and Hermann Wotruba, "Sensor-Based Ore Sorting Technology in Mining—Past, Present and Future," *International Journal of Minerals, Metallurgy and Materials* 9, (2022): 523, https://doi.org/10.3390/min9090523; Xianping Luo, Kunzhong He, Yan Zhang, Pengyu He and Yongbing Zhang, "A Review of Intelligent Ore Sorting Technology and Equipment Development," *International Journal of Minerals, Metallurgy and Materials* 29, (2022): 1647–1655, https://doi.org/10.1007/s12613-022-2477-5; Ciprian Cimpan, Anja Maul, Michael Jansen, Thomas Pretz, and Henrik Wenzel, "Central Sorting and Recovery of MSW Recyclable Materials: A Review of Technological State-of-the-Art, Cases, Practice and Implications for Materials Recycling," *Journal of Environmental Management* 156 (2015): 181–199, http://dx.doi.org/10.1016/j.jenvman.2015.03.025; Sohrab Jam, "Innovations in Recycling: Advanced Sorting Technologies & Circular Economy Models," *Medium*, March 6, 2024, https://medium.com/@sohrabjam/innovations-in-recycling-advanced-sorting-technologies-circular-economy-models-8f8d55f8357a; "Innovations in Advanced Sorting Technologies for Recyclable Materials," Recycling Inside, January 26, 2024, https://recyclinginside.com/recycling-technology/separation-and-sorting-technology/innovations-in-advanced-sorting-technologies-for-recyclable-materials/; "Mining," TOMRA, https://www.tomra.com/en/mining; "Sensor-Based Sorting Applications," TOMRA, https://www.tomra.com/en/waste-metal-recycling/applications; "Ore Sorting," Steinert, https://steinertglobal.com/us/applications/mining/ore-sorting/; *Global Sorting Equipment Market Research Report 2021* (January 2021), https://www.360researchreports.com/global-sorting-equipment-market-17148058; "Full Stream Elemental Analyzer," Energy Technologies Incorporated, https://www.energytechinc.com/fsea.php; *The Smart Next Generation PGNAA Cross-Belt Elemental Analyser* (Mackay: Real Time Instruments), https://www.tecnicasycontroles.com/gallery/AllScan_Cemento_i.pdf; "Online Timegated Raman Mineral Analysis of Keliber's Lithium Battery Minerals, Raman Spectroscopy, 7 June 2022, https://www.timegate.com/about-us/news/online-timegated-raman-mineral-analysis-of-kelibers-lithium-battery-minerals.

SDG ASSESSMENT

This market assessment also examines the interplay between technological innovation in the mid- and downstream segments of critical minerals value chains and the SDGs. A theory of change was developed, and qualitative and quantitative assessments were conducted, linking innovations to specific SDGs, with a focus on gender equality and other social outcomes. This comprehensive analysis includes data compilation, stakeholder interviews, and thematic analyses to uncover the multifaceted impacts of technological advancements on sustainable development. The assessment evaluates how technological innovations contribute to poverty reduction and other specific SDGs. It also offers insights into how these innovations can enhance social outcomes, particularly in promoting gender equality and other positive social impacts.

ASSESSMENT PHASES AND COUNTRIES OF FOCUS

Phase 1: Market Assessment of 30 Developing Countries

During Phase 1 of the market assessment, out of the 131 countries and territories outside of Europe on the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) List of Official Development Assistance (ODA) Recipients, 30 developing countries of focus were identified based on criteria including mid- and downstream critical minerals imports, policy readiness, and governance and innovation indicators. Appendix A, Section 1, details the methodology for selecting the 30 countries of focus during Phase 1 countries, and Table 2 lists the 30 countries.

TABLE 2. Countries from the DAC ODA list selected for assessment during Phase 1

Countries from DAC ODA list	Region	Score
Malaysia	ASP	4.7
India	ASP	4.7
Thailand	ASP	4.7
South Africa	Africa	4.5
Indonesia	ASP	4.5
Colombia	LAC	4.5
Dominican Republic	LAC	4.4
Türkiye	ASP	4.2
Viet Nam	ASP	4.2

TABLE 2. Countries from the DAC ODA list selected for assessment during Phase 1 (continued)

Countries from DAC ODA list	Region	Score
Brazil	LAC	4.1
Philippines	ASP	4.1
Mexico	LAC	4.1
Morocco	Africa	4.0
Argentina	LAC	4.0
Peru	LAC	4.0
Egypt	Africa	3.9
Kenya	Africa	3.9
Cambodia	ASP	3.9
Ecuador	LAC	3.9
Nigeria	Africa	3.8
Mauritius	Africa	3.6
Georgia	ASP	3.5
Jordan	ASP	3.5
Senegal	Africa	3.4
Namibia	Africa	3.4
Tunisia	Africa	3.0
Kazakhstan	ASP	3.0
Tanzania	Africa	2.8
Zambia	Africa	2.8
Bolivia	LAC	1.9

Source: Prepared by the authors based on data from various sources (see Appendix A).

During Phase 1, the enabling policy and regulatory environment of the 30 countries selected was evaluated, assessing aspects such as renewable energy frameworks, legal frameworks for mining, fiscal incentives affecting decarbonisation technologies, and circular economy regulations or frameworks that support sustainable resource management and recycling. This preliminary assessment served to rank the countries based on their innovation-friendly environments and identify those with the greatest potential for fostering technology development in the mid- and downstream segments of critical minerals value chains. Section 2 presents the results of the analysis during Phase 1.

Phase 2: Deep-Dive Market Assessment of Nine Developing Countries

For Phase 2 of the market assessment, out of the 30 Phase 1 countries, nine countries were selected for a deep dive. A comprehensive framework was used to evaluate and rank countries, based on their policy and technology readiness, the long-term financial sustainability of technological innovation, and knowledge production and sharing.

This analysis provided a comprehensive understanding of each country's technological innovation landscape, resulting in the selection of nine countries with the highest potential for technological innovation in the midstream and downstream segments of critical minerals value chains.

Appendix A, Section 2, details the methodology for selecting the nine countries of focus during Phase 2 countries, and Table 3 lists the nine countries.

Phase 2 achieved a deeper understanding of the relevant technologies and markets in the nine selected countries, based on the continued collection of quantitative and qualitative data from the review of written materials (policy documents, legal frameworks, and various reports) as well as interviews with various stakeholders from international organizations, governments, financial institutions, mining companies, industry associations, and academic and research institutions, among others.[12] Section 3 presents the results of the deep-dive analysis during Phase 2.

TABLE 3. Countries from the DAC ODA list selected for assessment during Phase 2

Countries from DAC ODA list	Region	Score
Brazil	LAC	0.707
Türkiye	ASP	0.693
India	ASP	0.665
South Africa	Africa	0.660
Indonesia	ASP	0.641
Mexico	LAC	0.605
Argentina	LAC	0.561
Zambia	Africa	0.508
Namibia	Africa	0.508

Source: Prepared by the authors based on data from various sources (See Appendix A).

12) Zoom's AI Companion generative artificial intelligence tool was used to generate transcripts and summaries of stakeholder interviews conducted throughout this market assessment.

2

Phase 1

Market Assessment of 30 Developing Countries

This section presents the results of the first phase of the market assessment—an analysis of the enabling environment of technological innovation in critical minerals value chains in 30 developing countries across Africa, ASP, and LAC, and an overview of relevant technological innovations.

This section presents the results of the first phase of the market assessment—an of the enabling environment of technological innovation in critical minerals value chains in the 30 developing countries selected (Section 2.1), and an overview of relevant technological innovations (Section 2.2).

The quantitative and qualitative data compiled and analysed were collected through desk-based research as well as stakeholder surveys and interviews. Outreach focused on stakeholders from governments, international governmental and non-governmental associations, companies, industry associations, financial institutions, and academia at global, regional, and national levels in the 30 countries.

2.1 ENABLING ENVIRONMENT OF TECHNOLOGICAL INNOVATION IN CRITICAL MINERALS VALUE CHAINS

Phase 1 of the market assessment involved an overview of the various dimensions of an enabling environment of technological innovation in the mid- and downstream segments of critical minerals value chains, including the mapping of global, regional, and national stakeholders was undertaken, and a review of key features of policy, legal, and regulatory frameworks of the 30 developing countries selected. Global, regional, and national initiatives and financial delivery mechanisms relevant to technological innovation in critical minerals value chains were also identified.

Stakeholder Mapping at Global, Regional, and National Levels

Stakeholders relevant to technological innovation in the mid-and downstream segments of critical minerals value chains span across the public and private sectors. Phase 1 focused on a preliminary mapping of global and regional stakeholders, and, to a lesser degree, national stakeholders, through a preliminary identification and categorisation of who these stakeholders are and what roles they play (see Figure 8). The mapping led to a broader understanding of the major players and their roles, facilitating a macro-level perspective on stakeholder dynamics.

Major **mining companies** are key stakeholders relevant to technological innovation, not only in the upstream segment of critical minerals value chains, but also in the mid- and downstream segments, to the extent they are vertically integrated (for example, with certain companies operating in extraction and processing, as well as in the recovery of critical minerals from tailings dams or from e-waste) and contribute to the development of technologies that may be applicable across segments of mineral value chains (for example, in metal extraction as well as processing). Accordingly, the activities, priorities, and strategies of mining companies contribute directly to the direction toward which technological innovation moves. Companies such as Anglo American, Rio Tinto, and Vale are leaders in large-scale extraction and processing, as well as in investment in sustainability and innovation in extraction as well as throughout mineral value chains. They engage in this space by advocating for policy, regulatory, and legal frameworks conducive to technological innovation; leveraging and supporting technology innovators and providers as well as academic and research institutions; and seeking to deliver sustainability co-benefits to mining-affected communities.

The role of **industry associations** is a more high-level version of the mining companies that they represent. Organizations such as ICMM—an industry association of mining companies with the objective of improving sustainable development outcomes in the mining and metals industry—provide leadership to their constituents, influencing the direction that sustainable development in mining and mineral value chains will take. Beyond setting top–down standards and guidelines, they also collaborate directly with member companies on technological innovation and sustainability initiatives.

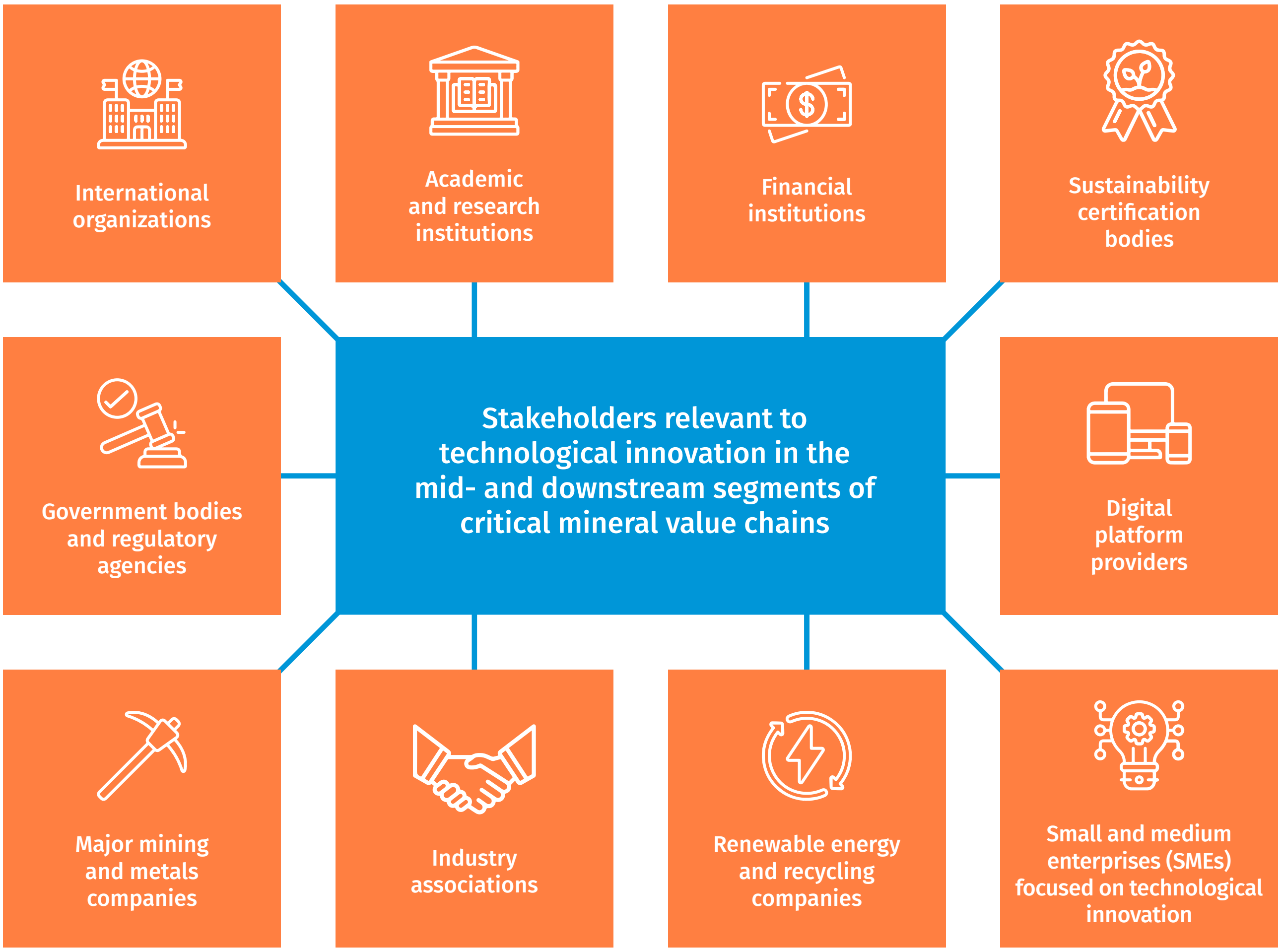


Figure 8. Landscape of stakeholders

Source: Prepared by the authors.

Looking more toward the downstream segment of mineral value chains, **renewable energy and recycling companies** are key players in technological innovation in that they support the demand-side of the transition as a source for new energy applications and provide the services of urban mining and recycling of e-waste, batteries, and other end-of-life goods containing critical minerals. Companies such as Green Eco Manufacturing (GEM) and Umicore engage by improving recycling processes.

Small and medium enterprises (SMEs) focused on technological innovation space play a supporting role to other stakeholders, by providing cutting-edge sustainable technologies for processing, recycling, and other circular economy approaches in mineral value chains. Companies such as Phoenix Tailings, Maverick Biometals, and Allonia collaborate with major corporations, research institutions, and governments to develop technological innovations.

In the same vein, **digital platform providers** give necessary support to the major drivers of technological innovation. Companies such as Circulor and BlockCycle, for example, contribute to enhance supply chain transparency and traceability using digital technologies. They improve overall accountability by integrating their platforms with supply chains.

Government bodies and regulatory agencies at national and sub-national level play a central role in developing and enforcing new and existing policies, laws, and regulations governing and encouraging critical minerals value chains, renewable energy development, technological innovation, and sustainability. They also provide support for research and development (R&D) in these fields, whether in the form of grants, incentives, or public–private partnerships.

International organizations, whether at the global or regional level, support governments as well as private sector stakeholders in developing an enabling environment for technological innovation for critical minerals. They promote international cooperation and data sharing, publish research reports, maintain publicly available databases, and provide technical assistance and capacity building for governments to improve national policy, legal, and regulatory frameworks. Relevant organizations in this space include the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).

In parallel to mandatory instruments by governments, private **sustainability certification bodies** such as the Initiative for Responsible Mining Assurance (IRMA), Fairmined, and the Responsible Jewellery Council provide standards and certification schemes for responsible practices throughout critical mineral value chains. They engage with other stakeholders by providing certification and auditing services to ensure compliance with sustainability standards.

Academic and research institutions drive innovation by conducting research on new technologies and sustainable practices, often collaborating with industry stakeholders. Globally influential examples include the University of Queensland (Australia), Imperial College London (United Kingdom), and Colorado School of Mines (United States).

Such research and innovation would not be possible without the support of **financial institutions and investors**, who fund sustainability-focused critical minerals projects. Examples such as the International Finance Corporation (IFC), BlackRock, and the European Bank for Reconstruction and Development (EBRD) provide capital for innovative clean energy technologies.

Policy, Legal, and Regulatory Frameworks

The 30 developing countries analysed during Phase 1 display a diverse spectrum of policy, legal, and regulatory frameworks governing and encouraging clean energy technological innovation in critical minerals value chains, ranging from highly advanced and well-established frameworks to more nascent and developing ones. This variation is indicative of the countries' differing levels of critical minerals resource availability, level of economic development, technological capability, and overall commitment to fostering innovation within critical minerals value chains, among other factors.

Several of the countries analysed have a high level of support, having implemented comprehensive and robust policies that encourage technological innovation, facilitate advanced critical mineral processing, support the development of domestic industries that manufacture or assemble products derived from critical minerals, and promote the adoption of circular economy principles. These policies are often characterised by substantial investments in R&D, incentives for private sector innovation and public–private partnerships, and robust policy, legal, and regulatory frameworks that support sustainable practices throughout critical minerals value chains.

Conversely, countries with a medium or low level of support tend to have less comprehensive policies. These countries are beginning to recognise the importance of fostering innovation in critical minerals but are still in the process of establishing the necessary policy and regulatory infrastructure. Even so, there is a growing trend among the 30 analysed countries to prioritise R&D and advanced processing technologies as they seek to enhance their competitiveness in the global market and expand into the mid- and downstream segments of the value chain to add value to their extracted critical minerals. Additionally, the integration of circular economy principles is increasingly being recognised as a critical component of sustainable development, even in these nascent policy frameworks.

The analysis undertaken during Phase 1 led to a classification and rating of the 30 countries according to their high, medium, or low level of support their policy, legal, and regulatory frameworks provide for technological innovation in critical minerals value chains (see Table 4):

- Countries classified as providing a **high** level of support have robust frameworks that are conducive to the rapid development and marketing of cutting-edge technologies in the mid- and downstream segments of critical minerals value chains and to the long-term financial sustainability of technological innovation projects.
- Countries classified as providing a **medium** level of support exhibit frameworks that, while supportive, may still require further development or refinement to fully harness their innovation potential in critical minerals.
- Countries classified as providing a **low** level of support are in the early stages of policy, legal, and regulatory development; their financial mechanisms and incentives for long-term financial sustainability of technological innovation projects, as well as their circular economy frameworks, may be incipient or absent.

TABLE 4. Analysis of policy, legal, and regulatory environments in the 30 Phase 1 developing countries

	Africa	ASP	LAC
High	Morocco Namibia South Africa Zambia	India Indonesia Türkiye	Argentina Brazil Mexico
Medium	Egypt Tanzania Tunisia	Georgia Kazakhstan Malaysia Philippines Thailand	Bolivia Colombia Peru
Low	Kenya Mauritius Nigeria Senegal	Cambodia Jordan Viet Nam	Dominican Republic Ecuador

Source: Prepared by the authors.

Table 5 presents a comparison of Phase 1 countries based on the scoring analysis of policy readiness across different policy areas. The policies were scored on a three-point scale, as explained above, with a score of 1 indicating low level of support, 2 indicating medium level of support, and 3 indicating high level of support. This approach offers a comparative perspective by focusing on the readiness level of specific policy areas, providing an overview of the relative strengths and gaps within various policy frameworks across Phase 1 developing countries.

TABLE 5. Phase 1 Policy Readiness Overview Matrix

Country	Mining Frameworks	Renewable Energy Targets	Environmental Protection	Circular Economy/ Recycling	Technology Innovation and R&D	Critical Minerals Processing and Refining	Assembly and Manufacturing	Waste Management
Egypt (Africa)	medium	high	medium	low	medium	medium	medium	low
Kenya (Africa)	medium	high	medium	low	medium	low	low	low
Mauritius (Africa)	low	high	medium	medium	low	low	low	medium
Morocco (Africa)	high	high	high	medium	high	high	medium	medium
Namibia (Africa)	high	high	high	low	high	high	low	medium
Nigeria (Africa)	medium	low	low	low	low	medium	low	low
Senegal (Africa)	high	medium	medium	low	low	low	low	low
South Africa (Africa)	high	high	medium	medium	high	high	high	medium
Tanzania (Africa)	medium	medium	medium	low	medium	medium	medium	medium
Tunisia (Africa)	medium	medium	medium	medium	medium	high	medium	low
Zambia (Africa)	high	medium	medium	low	high	high	medium	medium
Cambodia (ASP)	medium	low	low	low	low	low	low	low
Georgia (ASP)	low	medium	medium	high	high	low	low	medium
India (ASP)	high	high	medium	medium	high	high	high	medium
Indonesia (ASP)	high	high	medium	low	high	high	high	low

● = high ● = medium ● = low

● Africa ● ASP ● LAC

Source: Prepared by the authors

TABLE 5. Phase 1 Policy Readiness Overview Matrix (continued)

Country	Mining Frameworks	Renewable Energy Targets	Environmental Protection	Circular Economy/ Recycling	Technology Innovation and R&D	Critical Minerals Processing and Refining	Assembly and Manufacturing	Waste Management
Jordan	Medium	Medium	Medium	Low	Low	Low	Low	Medium
Kazakhstan	High	Medium	Low	Medium	Medium	Medium	Low	Medium
Malaysia	Medium	High	Medium	Medium	High	Low	High	Medium
Philippines	Medium	Medium	High	Low	Medium	Medium	High	Low
Thailand	Medium	High	Low	Low	Medium	High	High	Low
Türkiye	Medium	High	Medium	Medium	High	High	Medium	Medium
Viet Nam	Medium	High	Low	Low	Medium	Medium	High	Low
Argentina	Medium	High	High	Medium	High	High	Medium	Medium
Bolivia	Medium	High	High	Medium	High	High	Low	High
Brazil	High	Low	High	High	High	High	High	High
Colombia	High	High	Medium	Medium	High	High	Low	Medium
Dominican Republic	Medium	Medium	Low	Low	Low	Medium	Low	Low
Ecuador	Medium	Low	Medium	Medium	Medium	Medium	Low	Medium
Mexico	High	Medium	Medium	Medium	High	High	High	Medium
Peru	High	Medium	High	Low	High	High	Low	Medium

● = high ● = medium ● = low

● Africa ● ASP ● LAC

Source: Prepared by the authors

The 30 developing countries were rated according to their **policy readiness** level: 50% of countries rated high in renewable energy targets and policies for technological innovation, R&D, and critical minerals processing and refining, while 30% rated high in policies for assembly and manufacturing, and only 6.7% rated high in policies for circular economy, recycling, and waste management.

Below are summaries of the analysis of policy, legal, and regulatory frameworks applicable to the 30 countries, sorted by developing country region and alphabetically within each region. The summaries present the **rating of each country's policy readiness** and discuss key takeaways from the analysis of its overall policy environment, its policy support for technological innovation projects in critical minerals value chains, and the availability of financial sustainability of such projects. Appendix B provides a list of legal instruments and other references consulted for the preparation of the summaries. A policy tracker spreadsheet compiling over 370 policies, laws, and regulations by region and country, which served as the baseline for this analysis, is available upon request.

CONTINENTAL FRAMEWORKS

The African Continental Free Trade Area (AfCFTA) fosters technological innovations in the critical minerals value chain by integrating markets, attracting investment, and promoting infrastructure development. By creating a single market of 1.3 billion people across Africa, the AfCFTA aims to promote industrial development, support local processing, facilitate technology transfer, and attract foreign investment. The larger unified market is expected to incentivise investment in and development of technologies related to critical minerals processing and value addition.

By harmonising policies and enabling the free movement of skilled labour, AfCFTA creates a conducive environment for innovation. Its focus on sustainable practices and global collaborations brings advanced technologies and expertise to the continent, enhancing the competitiveness and technological advancement of Africa's critical minerals sector. By boosting intra-African trade and promoting digital trade, the AfCFTA can create more opportunities for collaboration and knowledge sharing in critical minerals technologies.

The draft AfCFTA Protocol on Intellectual Property Rights, if adopted, will mandate member States to adopt measures to promote access and environmentally friendly use of new and emerging technologies and utilise these emerging technologies to facilitate industrialisation, the development of regional value chains, and ultimately a just and fair energy transition.

The AfCFTA Protocol on Investment promotes and facilitates investment in sectors such as renewable energy, low-carbon technologies, and promotes policy frameworks that enable intra-regional and international transfer and deployment of climate-friendly technologies, goods, and services to build regional and continental value chains.

REGIONAL FRAMEWORKS

The Southern African Development Community (SADC) comprises 16 member states, including 5 countries in this market assessment: Mauritius, Namibia, South Africa, Tanzania, and Zambia. Several SADC instruments contribute to building a framework to support technological innovation, including in clean energy technologies for critical minerals:

- The SADC Protocol on Energy (1996) promotes cooperation in energy development and usage among member states, possibly including sharing critical minerals technologies in midstream and downstream of the value chain.
- The SADC Protocol on Mining (1997), though focused on upstream activities, can serve as a starting point to encourage and regulate partnerships in other market segments.
- The SADC Protocol on Finance and Investment (2006) aims to accelerate growth, investment, and employment in the SADC region, benefiting the critical minerals sector by creating a more favourable regional investment climate.
- The SADC Protocol on Science, Technology and Innovation (2008) aims at promoting development and harmonisation of science, technology, and innovation policies among the signatories, advocating investment in research and development, and promoting public awareness of science and technology.

EGYPT

RATING: **MEDIUM**

Overall Policy Environment: Egypt's critical minerals policy readiness shows a mixed but promising landscape. Policies in the mining value chain create a competitive environment for foreign investment, but an integration of decarbonisation interventions is still developing. Renewable energy policies are leading, driven by a 42% renewable energy target by 2035. Environmental policies are moderate, with some initiatives promoting sustainable technologies.

Policies on Technological Innovation: Development policies have been advancing, aiming to boost technological transfer and innovation in critical minerals and renewable energy sectors. Innovation policies are moderate, with an emphasis on R&D in the beneficiation and processing of critical minerals. However, comprehensive frameworks for circular economy practices and waste management are in the early stages.

Policies on Financial Mechanisms: Egypt offers various financial mechanisms and incentives for the critical minerals sector, including tax exemptions and guarantees under the Investment Law, subsidies for renewable energy projects' midstream and downstream equipment purchasing, funding support for R&D through a government environmental protection fund, and special economic zone benefits to attract foreign investment and promote innovation in the mining and renewable energy industries.

KENYA

RATING: **LOW**

Overall Policy Environment: Kenya's critical minerals policy framework aims to modernise the sector, attract foreign investment, and promote local processing and value addition. The establishment of the National Mining Corporation enhances mineral resource management, while policies supporting renewable energy encourage downstream investment. Kenya's overall framework in mining, energy, environment, development, and innovation shows a commitment to sustainability, but faces challenges in balancing local development with foreign investment attraction.

Policies on Technological Innovation: Policy mechanisms promote investments in mining and value addition, seeking to enhance R&D and promote markets for finished products derived from critical minerals. The country's beneficiation strategy mandates local processing for large foreign investments. However, the regulatory environment is still evolving. Exploitation, refining, processing, production, and selling of critical minerals requires partnership with the National Mining Corporation, reflecting the government's intention to maintain involvement in the value chain while promoting local value addition and innovation. Frameworks on decarbonisation and circular economy are still developing.

Policies on Financial Mechanisms: Kenya offers tax incentives for downstream renewable energy investments under the VAT Act, and royalty-sharing arrangements benefiting local communities and subnational governments. It emphasises local value addition and processing through the beneficiation strategy, which mandates that large investments in critical minerals extraction must include terms and conditions to localise processing and value addition.

MAURITIUS

RATING: **LOW**

Overall Policy Environment: Mauritius has established a policy and regulatory environment focused primarily on renewable energy development and environmental sustainability, rather than on the critical minerals value chain. The country's limited mineral resources have resulted in a less developed mining policy framework, with a high-level Act from 1966 serving as the primary legislation. However, Mauritius has made significant strides in renewable energy policy that aims to increase the share of renewable energy in the national energy mix, promote environmental sustainability, and foster international collaboration in the energy sector.

Policies on Technological Innovation: Mauritius shows limited policy focus on technological innovation in mid- and downstream segments of critical minerals value chains. There is little evidence of specific policies targeting critical mineral technologies, beneficiation, processing, or manufacturing of final products such as EVs and batteries. This suggests that Mauritius' policy framework for technological innovation in critical minerals value chains is still in its early stages.

Policies on Financial Mechanisms: Mauritius offers financial incentives for renewable energy deployment, including tax deductions for expenditures on fast chargers, solar energy units, green technology equipment, and tax exemptions for investments in renewable energy projects. Most of Mauritius' financial incentives are geared towards shifting to a low-carbon economy by using clean energy sources and existing renewable energy technologies.

MOROCCO

RATING: **HIGH**

Overall Policy Environment: Morocco's critical minerals legal framework emphasises responsible resource management, with tax and grant incentives designed to attract investment. The country targets 52% renewable capacity in its electricity mix by 2030. Various initiatives evidence efforts to enhance energy efficiency and reduce fossil fuel reliance. Partnerships to foster innovation and environmentally friendly projects underscore the commitment to sustainability. Various programmes support energy efficiency and renewable energy projects, fostering green industry. Despite decarbonisation efforts, Morocco needs improved environmental regulations and benefits for low-income communities.

Policies on Technological Innovation: Morocco offers tax incentives to stimulate investment in critical minerals, such as exemptions on imported equipment for large investments and reduced tax rates for companies exporting their output or supplying ores to domestic processing firms. The country's strategy emphasises R&D in minerals-related fields, promotes sustainable refining, and integrates renewables into mineral processing. The solid waste management framework promotes sustainable waste disposal and landfill construction, contributing to circularity.

Policies on Financial Mechanisms: Morocco's incentives for the critical minerals sector include tax exemptions on imported equipment for investments exceeding approx. USD 20 million, a reduced tax rate for companies exporting manufactured or supplying ores to domestic processors, and support mechanisms through the Moroccan Agency for Solar Energy (MASEN) and the Morocco Sustainable Energy Financing Facility (MorSEFF) to promote renewables and sustainability.

NAMIBIA

★★★ RATING: **HIGH**

Overall Policy Environment: Namibia has a comprehensive policy and regulatory environment that supports critical minerals value chains while promoting sustainability. It has a goal of 70% or more of renewable electricity by 2030. The legal framework facilitates energy investments, especially in renewable technologies, by removing restrictions on royalties to ensure that proceeds from upstream mining allows for private sector participation in the electricity market. The government is committed to developing local generation capacity and promoting renewables. It also requires environmental impact assessments and has a solid waste management strategy.

Policies on Technological Innovations: The Minerals Beneficiation Strategy aims to increase value-added activities and attract investments in mineral processing. Namibia's National Solid Waste Management Strategy prioritises waste minimisation and recycling and integrates circular economy principles into long-term planning. Overall, Namibia is positioning itself as a leader in sustainable mineral development and renewable energy innovation.

Policies on Financial Mechanisms: Namibia provides financial support for critical minerals through the Minerals Development Fund, which reinvests mining proceeds into the mid- and downstream segments, and tax exemptions and Special Economic Zones to promote mineral beneficiation, technological innovation, and green jobs. Collaborative initiatives, including with the EU, focus on capacity building and research in mineral processing. Renewable energy financing mechanisms, such as the Solar Revolving Fund and the National Energy Fund, support projects that enhance technological advancements.

NIGERIA

★☆☆ RATING: **LOW**

Overall Policy Environment: Nigeria has developed a policy and regulatory environment aimed at enhancing its mining and energy sectors, focusing on attracting private investment and promoting sustainable development. The government emphasises the importance of local content and technological innovation to advance the upstream mining sector and increase its contribution to the economy. Efforts to integrate renewable energy into the national grid are also underway, reflecting a commitment to harnessing the country's vast renewable resources. Despite Nigeria's significant mineral resources, the critical minerals sector is not a major engine of economic growth and currently receives little investment. The sector produces less than 0.5% of GDP, significantly less than the oil and gas sector.

Policies on Technological Innovation: In terms of technological innovation within the critical minerals value chain, Nigeria's recent policies prioritise local processing and value addition to stimulate investment in midstream and downstream activities. Recent initiatives encourage companies to develop plans for local mineral processing as a condition for obtaining new mining licences. However, official guidelines for implementing these enabling initiatives are still under development. Additionally, the country is developing policies to promote local mineral processing and value addition, including granting new mining licences exclusively to companies that present plans for in-country processing.

Policies on Financial Mechanisms: Nigeria currently only provides financial incentives to broadly attract investments in the mining and renewable energy sectors. These incentives aim to build local technical and managerial skills necessary for future industry needs. These incentives include tax exemptions on imported mining equipment and favourable feed-in tariffs for electricity generated from renewable sources.

REGION: AFRICA

SENEGAL

RATING: LOW

Overall Policy Environment: Senegal has implemented measures to support renewable energy development and encourage the adoption of clean energy technologies in mineral value chains. Most of these initiatives are part of the Emerging Senegal Plan, which focuses on economic diversification and sustainable growth. The creation of the Senegal Mining Company demonstrates the government's commitment to increased involvement in critical minerals value chains. Senegal has implemented policies to promote local hiring, improve social infrastructure, and facilitate knowledge transfer along the value chain, which currently focuses on upstream activities.

Policies on Technological Innovation: Senegal has introduced provisions to incentivise investment in advanced technologies for more efficient mineral processing. While Senegal aspires to advance down the critical minerals value chain, the country is currently focused on developing and expanding upstream activities. Specific policies for R&D in critical minerals, circular economy practices, and waste management are still emerging. The government's initiatives to promote value-added activities and foster knowledge transfer through training programmes, along with policies that encourage technological innovation and local value addition via production sharing agreements, demonstrate a long-term commitment to developing these segments of the value chain.

Policies on Financial Mechanisms: Senegal offers financial incentives for the critical minerals sector, focusing mainly on upstream operations. These incentives include VAT exemptions for renewable energy equipment along the critical minerals value chain, customs duty exemptions on imported equipment and materials for mining operations, and reduced royalty rates for local mineral processing.

SOUTH AFRICA

RATING: HIGH

Overall Policy Environment: South Africa has a robust policy and regulatory environment to leverage its critical minerals, particularly in nickel and manganese processing. The national strategy emphasises the critical minerals sector's role in driving economic growth and sustainable development. There is also significant effort towards creating equitable access to employment opportunities and achieving other SDGs. Policies on investments in renewable energy projects support the integration of sustainable practices in the critical minerals sector.

Policies on Technological Innovation: In the mid- and downstream segments, South Africa has initiatives to promote local processing and manufacturing of mineral commodities, supporting R&D in mineral processing and beneficiation, and fostering innovation through strategic frameworks and development plans. The country has also engaged in international partnerships to bolster its technological know-how. Collaborations with countries like Japan and the United Kingdom focus on technology transfer and expertise sharing, further strengthening South Africa's local mineral beneficiation and processing capabilities. Policies and laws on recycling and waste management in the critical minerals sector are still under development.

Policies on Financial Mechanisms: South Africa has implemented tax benefits within 11 Special Economic Zones, lower corporate income tax rates, duty deferment, and VAT exemptions for companies in critical minerals processing and in the manufacturing and assembly of products derived from critical minerals. The country leverages support from the Industrial Development Corporation (IDC) and various initiatives outlined in the Beneficiation Strategy and National Development Plan 2030 to foster local processing, technological advancement, and sustainable practices in mining value chains.

TANZANIA

RATING: **MEDIUM**

Overall Policy Environment: Tanzania has established an enabling policy and regulatory environment for its mining and energy sectors, with a focus on sustainable resource management and local economic benefits. The mining laws emphasise value addition within Tanzania, encourage local participation, and ensure fair compensation for the nation's mineral resources. Additionally, Tanzania has developed programmes to expand access to modern energy services and promote the use of renewable energy technologies.

Policies on Technological Innovation: Tanzania has also implemented regulations to drive technological innovation and local value addition along the entire value chain, including mandates for in-country processing and beneficiation before export. The country's local content regulations aim to increase the participation of Tanzanian individuals and companies in the value chain, with provisions for technology transfer programmes and reporting requirements. Tanzania has also been exploring circular economy policies recently, especially with regard to solid waste management laws. However, there is room for more comprehensive policies, particularly regarding e-waste management and circular economy practices in the critical minerals sector.

Policies on Financial Mechanisms: Tanzania provides tax exemptions on imported renewable energy equipment and reduced royalty rates for local mineral processing. The Finance Bills also introduced tax exemptions for strategic investments approved by the National Investment Steering Committee, further incentivizing technological innovation. Additionally, programmes like the Scaling up Renewable Energy Programme (SREP) and the Tanzanian Energy Development Access Programme (TEDAP) provide financial support for renewable energy innovations.

TUNISIA

RATING: **MEDIUM**

Overall Policy Environment: Tunisia has a comprehensive policy and regulatory environment to support mining, renewable energy development, energy efficiency, and technological innovation. It targets 30% renewable electricity production by 2030. Laws and initiatives set ambitious targets for renewables deployment and energy conservation. These policies collectively create a robust framework that promotes sustainable development and innovation across the energy sector.

Policies on Technological Innovation: Tunisia has several policies to incentivise R&D and the adoption of advanced technologies. Key laws, such as the Decree on rules of selling renewable electricity to the Tunisian Company of Electricity and Gas (STEG), create a robust framework to promote energy efficiency and incentivise downstream technological improvements. While solid waste management remains a challenge for policymakers in Tunisia, policy initiatives centred on circular economy and recycling have been picking up in recent years.

Policies on Financial Mechanisms: Tunisia offers ample tax incentives towards technology and high value-added products, R&D, innovation, and sustainable practices. Recent tax incentive laws suspend value-added tax for investments in renewables and minerals-related energy investments. These measures aim to foster innovation in technologies for renewables and sustainable processing of critical minerals. There are also tax exemptions for imported renewable energy equipment, premiums for efficiency projects, tax benefits for regional development and R&D through the Investment Laws, and financial support from the Energy Efficiency Fund (FNME) to drive technological innovation and sustainability in the mid- and downstream critical minerals segments.

REGION: AFRICA

ZAMBIA

★ ★ ★
RATING: **HIGH**

Overall Policy Environment: Zambia has an enabling policy and regulatory environment that supports its mining and energy sectors, focusing on economic development and local value addition. The framework is designed to attract domestic and foreign investment and enhance the efficiency and sustainability of resource management. Complementary initiatives promote investment along the value chain, including mining and mineral processing, and outline long-term development goals aimed at economic diversification and industrialisation. Environmental sustainability is supported by policies promoting the adoption of renewable energy technologies and efficient practices in mineral processing activities.

Policies on Technological Innovation: Zambia promotes local beneficiation and processing to enhance value addition. Among African countries within the scope of this market assessment, Zambia has the largest number of mentions of "mineral processing" licences and facilities in its major minerals law, signalling its leading level of policy readiness regarding mid- and downstream critical minerals technologies. The country is also engaging in initiatives to promote renewables, which is crucial for the processing of critical minerals. Zambia's commitment to solid waste management further underlines its readiness to contribute to a circular economy approach within the critical minerals sector.

Policies on Financial Mechanisms: Zambia imposes higher taxes on raw materials exports and imports of processed products to promote local midstream value addition. Tax exemptions for renewable energy equipment are geared toward attracting foreign and domestic investments downstream. Zambia benefits from initiatives focused on technological innovation, local capacity expansion, and sustainable development through partnerships with the EU and the World Bank.

CAMBODIA

RATING: **LOW**

Overall Policy Environment: Cambodia has several laws in place to regulate mining operations and set environmental protection measures and waste management policies. The latest policy on mineral resources set a vision for critical minerals to drive economic growth for the country, including through the development of the renewable energy power sector and zero-emission transportation sector. Targets on transport electrification (40% LDVs to be EVs by 2050) and share of solar PV domestic energy capacity (17.9% by 2030) aim at encouraging the development of midstream and downstream segments of the critical minerals sector in the country.

Policies on Technological Innovation: There are open discussions to implement a regulation on the country's position regarding the domestic processing of critical minerals, the use of raw materials in domestic industries, and related technological innovation. There is also limited documented implementation of downstream circular economy practices beyond a battery waste collection pilot and an e-waste management regulation prohibiting the import of waste.

Policies on Financial Mechanisms: Cambodia has limited financial mechanisms in place to drive the development of the critical minerals sector. The national minerals policy emphasises the importance of establishing a fund dedicated to mine rehabilitation. It also encourages industrial mining companies to create funds to support local communities, financed through royalties and a portion of corporate profits tied to mineral production. At the midstream level, Cambodia is advancing its energy sector transition by utilising concessional and grant financing facilities to scale up renewable energy initiatives.

GEORGIA

RATING: **MEDIUM**

Overall Policy Environment: Georgia has a national mining code to govern the entire critical minerals value chain, alongside environmental protection frameworks and a myriad of waste management policies. The country has set ambitious renewable energy and transport electrification targets and aims to enhance the reliability and capacity of the power transmission network. These targets include achieving a 35% share of renewable energy by 2030 and a majority of BEV, PHEV, and fuel cell LDV category sales by 2050.

Policies on Technological Innovation: In 2019, the government launched a strategy that encourages investors to process mined minerals domestically and views research and development as strategically important for the country's sustainable development. This is supported by a broad spectrum of laws regulating science, technology, and innovation. The country has implemented comprehensive policies addressing waste management, with a focus on end-of-life vehicles, used batteries, and e-waste, targeting an 80% e-waste collection rate by 2030.

Policies on Financial Mechanisms: Georgia fosters innovation and R&D projects through co-financing grants and startup support programmes, backed by loans and grants from the European Union and the World Bank. The country's green climate fund provides technical and investment support for infrastructure projects in transport, industry, energy, and waste management. Additionally, Georgia is collaborating with the World Bank to develop an innovative ecosystem. At the SME level, the state-run "Produce in Georgia" programme supported entrepreneurs in producing energy-efficient technologies. Georgia currently lacks specific funding targets for energy and climate change in its policy framework, as most projects are financed by international partners.

INDIA

★ ★ ★
RATING: **HIGH**

Overall Policy Environment: Mineral value chains play an important role in India's pursuit of growing its manufacturing sector. Thirty minerals have been identified as critical, and national policy requires activities across the minerals value chain to be undertaken within a Sustainable Development Framework. The country has ambitious decarbonisation goals for the power and transport sectors, aiming for 50% of non-fossil fuel–based installed power capacity by 2030 and for EVs to comprise 30% of new vehicle sales by 2030.

Policies on Technological Innovation: The government is working on a policy to drive domestic mineral processing and recovery, including efforts to import mineral supplies and secure international technology collaborations. Domestic manufacturers receive support to build capacity through production-linked schemes, where the extent of local value addition increases selection odds and speeds up approvals. EV policies encourage domestic value addition and manufacturing capacity. India has policies on e-waste management, extended producer responsibility, and e-waste recycling targets.

Policies on Financial Mechanisms: India offers production-linked incentives to advance R&D, processing, and manufacturing in critical minerals value chains, including for vehicles, electronics, advanced chemistry cell batteries, and renewable energy components such as high-efficiency solar PV modules. Several Indian states support EV industry development through consumer demand, industry incentives, and infrastructure support, including capital subsidies and tax exemptions. India is furthering international cooperation with Australia and the United States to promote investment in critical minerals projects and high-impact research in manufacturing and emerging technologies.

INDONESIA

★ ★ ★
RATING: **HIGH**

Overall Policy Environment: Progressive amendments in Indonesia's mining laws aim to stimulate downstream industrialisation and enhance sustainable resource management practices. Following Indonesia's bans on unprocessed mineral exports and regulation for domestic mineral processing and refining, the country identified critical minerals based on exposure to supply chain disruption and limited substitution availability. Indonesia has steadily advanced its midstream processing capabilities and set ambitious targets for EV battery production, aiming to rank among the top three global producers by 2027.

Policies on Technological Innovation: Indonesia's export bans on unprocessed minerals are designed to strengthen domestic midstream processing capabilities. Simultaneously, financial incentives that promote the use of local components are accelerating industrialisation within the country. Local content requirements for EV development companies, which range from 40% to 70%, have recently been postponed from 2023 to 2027. Indonesia is also lagging on international partnerships to encourage investment, R&D, and collaboration in building downstream supply chains. While Indonesia does not have mineral recovery–specific policies in place, there are several waste management regulations in place.

Policies on Financial Mechanisms: Indonesia's targets and broader domestic industrialisation goals are supported by a growing set of financial mechanisms, including tax incentives for R&D initiatives and lowering the cost of EVs that include a share of domestic components. Indonesia is also prioritising the development of special economic zones to attract foreign investment and stimulate industrial activity through a series of corporate income tax allowances and exemptions.

JORDAN

RATING: **LOW**

Overall Policy Environment: Jordan has adopted various laws to develop its natural resources while ensuring environmental protection and responsible waste management. The national mining strategy pushes forward the country's broader vision for economic modernisation and goal to transform Jordan into a mining state by 2033, given its wide portfolio of mineral resources, including strategic critical minerals. Through select renewable energy laws, Jordan is starting to create an enabling environment for achieving national strategy targets.

Policies on Technological Innovation: While the country is aiming to attract international investment to the sector, there are limited policies supporting the development of localised critical minerals processing, industrialisation, recovery, circularity, or technology innovation.

Policies on Financial Mechanisms: Jordan's financial mechanisms across critical minerals value chain sectors include industry development funding from the World Bank (IBRD) to promote investment and exports in the manufacturing sector. In line with goals to expand renewable energy adoption, project developers can access grants for research and technical collaboration, as well as mechanisms to ease credit access. These support mechanisms require local content in material inputs across development stages. The country also promotes industrial scientific R&D through a dedicated national fund to link universities and research institutions to industry needs and provide access to grants.

KAZAKHSTAN

RATING: **MEDIUM**

Overall Policy Environment: Kazakhstan's legislation regulating the mining sector is complemented by environmental codes and targets to increase the share of renewables to 15% by 2030. The country fosters a supportive policy environment for industrial development across the automotive sector, through several incentives. Latest mining code updates and policies aim to attract investment in research and innovation across mineral value chains, often under local content conditions.

Policies on Technological Innovation: Kazakhstan's development plans centre on sustainable growth and focus on exporting higher-value manufactured products. Kazakhstan recognises the benefits of international partnerships (e.g., with the EU) on critical minerals and battery value chains. Such partnerships involve collaboration to modernise technologies, build capacity, and share knowledge to add value across processing, manufacturing, and recycling. Kazakhstan has broad circular economy policies, including waste management (including e-waste) across all lifecycle stages and extended producer responsibility.

Policies on Financial Mechanisms: Kazakhstan provides government financing across priority technological areas, including clean technologies, through innovation grants, business incubation, and technology transfer. The government collaborates with manufacturing consortia to prioritise projects for funding. Automakers benefit from R&D financing, production incentives for eco-friendly vehicles, and disposal programs. Kazakhstan is also enhancing international collaboration with countries like France to jointly develop and fund critical minerals projects across the value chain.

MALAYSIA

RATING: **MEDIUM**

Overall Policy Environment: Malaysia has prioritised environmental protection in the minerals sector, integrating it into the country's development agenda. Through a series of sequential five-year national development plans, the country has established policies designed to build capacity, attract investment, and forge international partnerships. Malaysia's ambitious green technology targets include achieving 100% electrification of private vehicles and 40% of public vehicles by 2030, reaching 70% of renewable energy by 2050, and reaching a battery storage capacity of 500 MW by 2030. These targets underscore the expanding importance of the mid- and downstream sectors in Malaysia's critical mineral value chains, supported by enabling policies and tax incentives for local industries.

Policies on Technological Innovation: The country's most recent development plan includes mineral policy reform plans and projects to innovate and commercialise processed mineral products. This includes building R&D&C&I (research, development, commercialisation, and innovation) capabilities. It also promotes downstream activities, by building recycling capabilities and implementing circular economy strategies.

Policies on Financial Mechanisms: To advance its mineral industry, Malaysia has allocated MYR 87.2 million (approx. USD 18.6 million) for sustainable development indicators, innovation, and the commercialisation of mineral products. Strategic funds have also been launched to boost domestic investment in manufacturing, encourage the acquisition of new technologies, and modernise production plants, driving over MYR 837 million (approx. USD 185 million) in matching grants for more than 180 projects. Additionally, Malaysia offers Energy Audit Conditional Grants to promote energy efficiency in industrial and commercial sectors, along with tax incentives to support the local EV industry.

PHILIPPINES

RATING: **MEDIUM**

Overall Policy Environment: National mining laws govern operations and mineral resource development in the country. These are accompanied by an extensive range of environmental laws covering water, waste, and clean air, among other environmental protection considerations. The Philippines has set ambitious clean energy targets, aiming for 35% renewable generation by 2030 and transport electrification with 850,000 EVs by 2040.

Policies on Technological Innovation: The Philippines has published national development industrialisation plans to enhance focus on value-adding activities and develop strategic downstream industries for critical minerals. In support of realising these plans, specific mid- and downstream industry policies offer incentives such as tax exemptions or competitive bidding for the recovery of valuable metals in mine waste and tailings. The Philippines has yet to issue regulations on dismantling e-waste and extended producer responsibility.

Policies on Financial Mechanisms: The Philippines encourages investment in the EV manufacturing sector, including R&D, battery manufacturing, assembly, and waste treatment through global partnerships (e.g. U.S. Critical Minerals Partnership) and, in the form of domestic tax exemptions, special corporate tax, enhanced deductions, and duty exemptions. Renewable energy manufacturers benefit from a range of tax incentives, including income tax holidays and zero-rated VAT on transactions with local suppliers. To further support the broader minerals sector, the government has mandated that a portion of mining operation costs be allocated to community and technology development projects. Additionally, a proposed fund aimed at stimulating research, development, and deployment of sustainable mining technologies is currently under discussion.

THAILAND

RATING: **MEDIUM**

Overall Policy Environment: Thailand's mineral act governing the sector is centred on achieving positive economic, social, and environmental outcomes for the country. Multiphase development plans are focused on accelerating the deployment of clean energy and transportation technologies to meet national targets, which include achieving a 50% share of renewable energy in power generation and ensuring that 30% of EVs are locally manufactured by 2030.

Policies on Technological Innovation: Thailand has a mature enabling policy environment to stimulate investment in low-carbon technologies, emerging R&D fields, and industrial projects across the mid- and downstream segments of critical minerals value chains. The government is leveraging the development of the Eastern Economic Corridor (EEC) to bolster the manufacturing sector, focusing on batteries and EVs. Thailand's downstream e-waste management remains inadequate with pending regulations, processes, and infrastructure for commercial recycling and disposal of certain e-waste categories, including batteries.

Policies on Financial Mechanisms: The Thai government has set up funds and plans to stimulate investment in the development of clean energy technologies in the critical minerals value chain, including large-scale industrial projects. This is activated through funds, increased debt financing availability, tax reductions, and other incentive packages. Thailand currently offers financial support through corporate income tax exemptions to battery cell manufacturers for EV and energy storage applications. Substantial corporate discounts and tax deductions available for purchasing domestically manufactured vehicles also boost the local EV manufacturing sector.

TÜRKIYE

RATING: **HIGH**

Overall Policy Environment: Türkiye's mining law and national development plans position the supply security of critical minerals as a core objective for the sector. Türkiye's policies are focused on creating a localised critical minerals supply chain, from investing in research to developing production infrastructure. The country has also joined leading global coalitions and committed to achieving 100% zero-emission vehicle sales by 2040. Additionally, Türkiye aims to boost its already substantial renewable energy generation capacity, targeting 65% by 2035.

Policies on Technological Innovation: In line with Türkiye's focus on mineral security, the country has set plans to enhance domestic manufacturing, recycling, and recovery industries for critical minerals. Türkiye puts great emphasis on R&D particularly for rare earth elements, where national research agencies advise the ministry on policy and technology development. Recent e-waste regulations set more stringent producer requirements and aim to strengthen the country's circular economy and waste management capabilities.

Policies on Financial Mechanisms: Türkiye has unveiled USD 30 billion in incentive packages to support high-tech industries, focusing on boosting the domestic EV sector and developing regional battery production capabilities. Grants are also planned to support solar cell and wind energy component manufacturing facilities. Additionally, the country has secured USD 1 billion in loans and grants from the World Bank to expand its solar energy sector and pilot a battery storage programme. In previous years, Türkiye's Growth and Innovation Fund, backed by the European Investment Fund, provided equity investments in innovative and technology-focused sectors.

REGION: ASP

VIET NAM

★★★
RATING: LOW

Overall Policy Environment: Viet Nam has been progressively updating mining and environmental protection laws governing the critical minerals sector. National mineral resources strategies aim to secure investment in mineral projects across the value chain. Viet Nam's decarbonisation targets are among the most ambitious in the region, aiming for 67.5% to 71.5% renewable energy generation and 100% electrified transport by 2050.

Policies on Technological Innovation: Viet Nam's minerals strategy emphasises the role of scientific and technological research. The goal is to expand collaboration and develop processing industrial parks with advanced technologies suited to individual minerals. With growing global interest in building resilient and secure technology supply chains, Viet Nam is working with international partners to promote domestic manufacturing of products derived from critical minerals and industry development via innovation funds. The country aims to modernise the mining and mineral processing industry, incorporating a circular economy model.

Policies on Financial Mechanisms: Given Viet Nam's limited domestic renewables market, the country aims to attract foreign investment through tax incentives to grow local manufacturing and assembly, and has bolstered its solar sector through high feed-in tariffs. Furthermore, Viet Nam is partnering with the United States in developing its semiconductor ecosystem via international technology security and innovation funding. On the global stage, current financing pledged through the Just Energy Transition Partnership (JETP) international green fund of USD 15.5 billion is likely to fall short of supporting the country's transition needs across expanding network infrastructure, piloting battery storage systems, and deploying renewable energy projects.

ARGENTINA

★★★ RATING: **HIGH**

Overall Policy Environment: Argentina's robust mining framework, along with environmental protection laws, requires environmental impact assessments for all mining activities and mandates responsible parties to mitigate or restore environmental damage. Argentina substantially promotes the use of renewable energy in industrial processes. Strategic plans in the mining sector underscore the integration of sustainability, community development, and transparent management, reinforcing the state's commitment to sustainable development.

Policies on Technological Innovation: Argentina's policy landscape strongly supports technological innovation in the mid- and downstream segments of critical minerals value chains. The country's focus is on industrialising lithium, incorporating advanced R&D in collaboration with universities, research centres, and institutions. Additionally, the legal framework actively promotes recycling and circular economy initiatives, providing subsidies and grants for recycling facilities and projects incorporating recycled materials.

Policies on Financial Mechanisms: Argentina's general mining framework offers tax benefits to incentivise mining projects and processing plants. Additionally, the government offers support to companies working on their national goal to industrialise the lithium value chain through grants, subsidies, and R&D tax credits for the development of lithium-ion battery manufacturing plants. The country also proposes tax exemptions and low-interest loans to boost processing technologies and substantially promotes the use of renewable energy in industrial processes with tax incentives to support sustainability in the critical minerals value chain. Additionally, funds are made available through various international partnerships, including the EU–Argentina Partnership on Sustainable Raw Materials Value Chains.

BOLIVIA

★★☆ RATING: **MEDIUM**

Overall Policy Environment: Bolivia's mining legal framework establishes a comprehensive regulatory environment that mandates compliance with stringent environmental and social standards for all mining activities of the value chain. The country's development plan underscores the importance of adding value to Bolivia's mineral resources through processing and industrialisation, advocating for technological advancements and the transition from traditional extractive mining to value-added mining.

Policies on Technological Innovation: Bolivia's policy framework fosters technological innovation in the mid- and downstream segments of critical minerals value chains, particularly for lithium. The state-owned company, Yacimientos de Litio Bolivianos (YLB), oversees the entire lithium value chain, from prospecting to commercialisation, with a strong focus on processing and refining projects and the development of manufacturing plants for lithium-based products such as EV batteries. Robust regulations on solid waste management emphasise recycling and circular economy principles, particularly for electronic and industrial waste, ensuring critical minerals recycling and recovery.

Policies on Financial Mechanisms: Tax incentives in Bolivia encourage investments in R&D and public-private partnerships for advanced mineral processing technologies. Through YLB, the state allocates an annual budget of approximately USD 120 million for processing and refining projects, as well as the development of manufacturing plants for lithium-based products, encouraging investment in innovative technologies for these segments of the lithium value chain. Bolivian laws also promote public-private partnerships, encouraging private investments in processing technologies and manufacturing facilities.

BRAZIL

★ ★ ★
RATING: **HIGH**

Overall Policy Environment: Brazil has a comprehensive legal and regulatory framework for mining value chains, backed by a robust institutional framework that enforces stringent environmental standards across mineral value chains, including processing plants. Mining policies focus on sustainable development, competitiveness, and the integration of mineral production with energy transition technologies, reflecting the government's commitment to prioritising strategic critical mineral production.

Policies on Technological Innovation: Brazil's policy framework strongly supports technological innovation within the mid- and downstream segments of critical minerals value chains. Policies facilitate unrestricted foreign trade of lithium, enhancing Brazil's global market competitiveness. A policy to support environmental permitting mandates states to ensure the timely completion of priority projects. In the national interest, the policy even allows for bypassing certain regulatory processes. The government fosters a circular economy by providing incentives for recycling technologies and mandating reverse logistics systems for e-waste.

Policies on Financial Mechanisms: Brazil offers significant financial incentives to support an innovative environment in critical minerals value chains. General tax incentives for R&D and infrastructure investment are available through governmental funds and programs. Substantial tax incentives promote investment in advanced mineral processing technologies. Tax rebates are available for the export of technologically advanced goods derived from critical minerals to promote cutting-edge technologies. Governmental funds and programs are set, with additional tax benefits and subsidies, promoting investment in the local production of EV batteries and components and recycling technologies.

COLOMBIA

★ ★ ★
RATING: **MEDIUM**

Overall Policy Environment: Colombia's regulatory landscape for mineral value chains is robust, promoting sustainable and environmentally responsible practices, integrating renewable energy, and fostering technological innovation. The National Development Plan and supporting policies emphasise sustainable mining, technological innovation, and critical minerals. Since 2014, Colombia has supported the integration of renewables into its energy mix, positioning the country as a leader in the region, with ambitious targets and significant progress.

Policies on Technological Innovation: Colombia strongly supports technological innovation in the mid- and downstream segments of critical minerals value chains by emphasising research, traceability, and fair marketing of critical minerals, with a focus on good practice standards and financing for small-scale miners. The draft new mining law seeks to bolster mineral processing and manufacturing by proposing the creation of a state-owned company to manage the value chain from exploration to commercialisation. The focus on the circular economy, promoting effective waste management and recycling, and the integration of renewable energy technologies underscore the commitment to sustainability and innovation.

Policies on Financial Mechanisms: The government offers tax incentives and grants for R&D in critical minerals processing and manufacturing, provided through national funds and institutions supporting R&D projects focused on critical minerals and renewable energy. Public–private partnerships are encouraged to leverage private sector expertise and investment in advanced processing technologies and manufacturing facilities for critical minerals. These financial incentives are part of a broader strategy to support the sector, encouraging technological innovation.

DOMINICAN REPUBLIC

★★★ RATING: LOW

Overall Policy Environment: The Dominican Republic's mining legal framework primarily focuses on upstream activities but also includes some regulations and support for mid- and downstream processes. It emphasises environmental protection and sustainable development by mandating environmental impact assessments and waste management regulations. Additionally, the integration of renewable energy into industrial processes is promoted, indirectly benefiting the minerals sector.

Policies on Technological Innovation: Technological innovation in the mid- and downstream segments of the critical minerals value chain is currently supported by a few regulations, such as expedited permitting for the adoption of advanced, sustainable technologies in these processes. Current discussions on a new mining law aim to introduce specific and robust regulations for critical minerals, emphasise technological advancements, and offer tax deductions for R&D in mineral processing technologies. However, explicit policies on critical minerals recycling and circular economy practices are currently lacking.

Policies on Financial Mechanisms: The Dominican Republic supports mid- and downstream processes through some financial incentives. These include tax incentives, exemptions, and reductions for companies engaged in mineral processing and manufacturing activities. Companies adopting sustainable technologies also receive tax benefits. More broadly, the legal framework promotes innovation within the industrial sector by supporting R&D and SMEs and providing tax incentives.

ECUADOR

★★★ RATING: LOW

Overall Policy Environment: Ecuador's policy framework for mining activities is comprehensive and interconnected, recognising mining as a public utility sector. The framework mandates advanced technologies and best practices to minimise environmental impact, requiring environmental management plans, environmental impact assessments, environmental licences, and compliance monitoring. It also encourages the use of clean technologies and renewable energy through various incentives. The country's Development Plan emphasises sustainable economic development, a transition to a circular economy, and improved resource efficiency, promoting recycling and sustainable mining through R&D and public–private partnerships.

Policies on Technological Innovation: Ecuador's policies incipiently support technological innovation in the mid- and downstream segments of critical minerals value chains, focusing on sustainability and innovation. These policies also emphasise circular economy practices and recycling of critical mineral waste by setting stringent regulatory requirements and targets for recovery and reuse. Ministerial agreements further support hazardous waste management and extended producer responsibility schemes for electronic waste, fostering an environment conducive to technological innovation in refining, manufacturing, and developing final products.

Policies on Financial Mechanisms: Ecuador promotes technological innovation in mineral processing and manufacturing through financial incentives, including tax breaks, subsidies, and grants. These incentives are designed to support future development of advanced technologies, the transition to a circular economy, and the use of renewable energy.

MEXICO

★★★
RATING: **HIGH**

Overall Policy Environment: Mexico's regulatory landscape for the mining sector is shaped by comprehensive laws and reforms that govern all aspects of mining activities, from exploration to processing. This framework is designed to promote sustainable development and environmental protection while incentivising infrastructure investments. Renewable energy and clean technologies are promoted through financial support mechanisms that foster innovation and efficiency in energy production and use. Environmental protection is reinforced by strict guidelines for managing mining tailings.

Policies on Technological Innovation: Mexico has implemented comprehensive policies and reforms to advance technological innovation in the mid- and downstream segments of critical minerals value chains. The nationalisation of the lithium industry and the establishment of the state-owned entity Lithium for Mexico aims to strategically control and develop lithium resources. These reforms prohibit exclusive private capital in lithium value chains and promote public–private partnerships to establish lithium processing facilities and EV battery plants. Emphasising advanced processing methods and refining techniques, these initiatives position Mexico as a leader in lithium-related products and technological innovation.

Policies on Financial Mechanisms: The regulatory framework offers tax incentives for infrastructure investments and provides financial support mechanisms to foster innovation and efficiency in energy production and use, including renewable energy and clean technologies. Complementary policies provide tax credits and subsidies for renewable energy component manufacturing and incentives for recycling and circular economy practices, further enhancing the overall capacity across the value chain.

PERU

★★☆
RATING: **MEDIUM**

Overall Policy Environment: Peru's legislative and regulatory framework for critical minerals provides a comprehensive foundation for sustainable development, environmental management, and technological innovation in mineral value chains. Laws emphasise stringent environmental standards and the importance of environmental impact assessments. The country's framework also supports the integration of advanced technologies and innovation across various sectors, including critical minerals. Additionally, the promotion of renewable energy investments indirectly boosts the demand for critical minerals.

Policies on Technological Innovation: Peru's policy framework strongly supports technological innovation in the mid- and downstream segments of critical minerals value chains. This framework encourages R&D in advanced processing techniques, adding value to raw critical minerals, and innovative ways to incorporate them into tech industry components. Specific initiatives designate lithium exploration, processing, and industrialisation as a national priority, mandating regulatory measures to develop a national battery industry and a recycling process, with a draft proposal for a National Lithium Battery Plant involving public-private partnerships. The focus on circular economy principles further emphasises sustainable waste management and recycling practices across the sector.

Policies on Financial Mechanisms: Peru's framework provides tax incentives for companies investing in R&D, particularly in sectors involving critical minerals and technological innovation.

Initiatives at Global, Regional, and National Level

The analysis of initiatives identified and evaluated ongoing and emerging collaborative efforts aimed at developing, deploying, and scaling up technological innovations in the mid- and downstream segments of critical minerals value chains that help overcome challenges in these segments, improve their efficiency, and contribute to the SDGs, notably climate action and clean energy goals.

Phase 1 focused on mapping global and regional initiatives, and, to a lesser degree, national ones, to provide an understanding of the landscape of relevant initiatives, such as partnerships, collaborations, and consortia including public and private stakeholders within critical minerals value chains, and programmes by international organizations and governments.

Initiatives were mapped by type, key technologies and stakeholders involved, and geographic focus, with the objective of assisting innovation-driven stakeholders in identifying gaps and opportunities in the landscape. While some initiatives identified may involve a financing component, mechanisms to support technology development primarily through financing are noted separately.

Table 6 summarises the global and regional initiatives analysed during Phase 1. The following paragraphs provide additional information on these global and regional initiatives, as well as highlighting notable examples of national initiatives identified among countries that were not selected for the deep-dive analysis—Colombia and Morocco. National initiatives identified in the nine deep-dive countries are included in Section 3 of this report, which presents the findings of Phase 2.

TABLE 6. Landscape of initiatives (Phase 1)

Initiative	Type	Key technologies involved	Key stakeholders involved	Geographic focus
World Economic Forum's UpLink	Platform for innovators to present their solutions to global challenges	• Waste management systems • Greenhouse gas emission reduction innovations • Resource efficiency technologies	• Startups • Academic institutions • Industry	• Global
Prospect Innovation	Accelerator for technological innovation in the mining sector	• Energy generation and storage • Recycling and recovery • Robotics, mobility, and hardware • Data capture, analytics, and AI • Carbon capture • Synthetic Biology	• Research institutions • Mining companies • Venture capital firms	• Americas • ASP • Europe
Global Battery Alliance (GBA)	Public–private partnership that promotes sustainable battery value chains	• Battery recycling • Tracking methods for batteries in the value chain ("Battery Passport")	• Government • Civil society • Industry	• Africa • Asia • Europe

TABLE 6. Landscape of initiatives (Phase 1) (continued)

Initiative	Type	Key technologies involved	Key stakeholders involved	Geographic focus
World Bank Group's Climate Smart Mining (CSM) Initiative	Initiative to provide guidance and technical support on decarbonisation and sustainability in mineral value chains in developing countries	• Critical minerals recycling • Reusing and repurposing EOL materials	• Government • International organizations • Local communities	• Developing countries
Activate.org	Fellowship that supports entrepreneurial scientists and engineers in developing technologies for global challenges	• Broad; supports original ideas of its fellows	• Academia • Government • Corporations • Philanthropic foundations	• United States

Source: Prepared by the authors.

Global and Regional Initiatives

The World Economic Forum's (WEF) **UpLink** is a platform where innovators can present their solutions to global challenges. It provides crowdsourcing solutions for global challenges, including sustainable practices in mineral value chains. These include resource efficiency technologies, waste management systems, and greenhouse gas emissions reduction innovations. With a global focus, UpLink partners with startups, industry leaders, and academic institutions.[13]

Prospect Innovation has a more narrow focus on accelerating technological innovation to address challenges in mineral value chains. Among its areas of focus are technologies for energy generation and storage, recycling and recovery, and sustainability and carbon capture. It also prioritises digitalisation, implementing digital technologies to optimise processes in mining value chains. The Americas, Europe, and Asia are their focus regions, and they collaborate with academic and research institutions, mining companies, heavy industry, and venture capital firms, among other stakeholders, to fund startups and implement new technologies.[14]

The **Global Battery Alliance** (GBA) focuses specifically on promoting a sustainable and responsible battery value chain. It looks to implement technology related to battery recycling and carbon footprint reduction in the battery value chain. Focusing on Africa, Asia, and Europe, GBA collaborates with governments, civil society, and industry players to implement sustainable practices and ensure compliance with human rights as well as with social, health, and environmental standards.[15] The GBA's Critical Minerals Advisory Group (CMAG), launched in 2022, provides a platform for engagement of public and private stakeholders on sustainable value chains of battery minerals; in June 2024, CMAG called on policymakers to increase cooperation and data harmonisation and transparency.[16]

13) "Home," Uplink, World Economic Forum, https://uplink.weforum.org/uplink/s.

14) "About," Prospect Innovation, Prospect Innovation, https://prospectinnovation.com.

15) "About GBA," Global Battery Alliance, Global Battery Alliance, https://www.globalbattery.org.

16) "Critical Minerals," Global Battery Alliance, https://www.globalbattery.org/critical-minerals; Global Battery Alliance, *The Global Battery Alliance's Call to Action: Policymakers to Bridge the Cooperation Gap in Critical Battery Minerals with Harmonised Data and Transparency* (Brussels, GBA, June 2024), https://www.globalbattery.org/media/publications/gba-cmag-communique-final-june24.pdf.

The World Bank Group's **Climate-Smart Mining (CSM) Initiative**, launched in 2019 with a target of investing USD 50 million over five years, provides guidance, analysis, and capacity building to developing countries to decarbonise and minimise the environmental impact of critical mineral value chains, and to increase their sustainable development benefits for developing country populations, working across critical minerals extraction, processing, and recycling. The CSM framework, created in collaboration with key stakeholders from government, industry, and civil society, serves as a guide to help developing countries adopt climate-smart strategies through four key pillars: decarbonisation, resilience, circular economy, and market opportunities. The initiative's circular economy pillar, particularly relevant to the mid- and downstream segments, seeks to support the policies, technologies, and other conditions necessary to unlock critical minerals recycling, repurposing, and reuse. CSM also partners with organizations like the United Nations Environment Programme (UNEP) and the United Nations Development Programme (UNDP) to leverage expertise and resources.[17]

Lastly, **Activate.org** takes an R&D approach, supporting scientists and engineers in developing transformative technologies to address global challenges, including sustainable mining and resource management. Their focus is primarily the United States, with potential global implications as technologies are scaled and adopted internationally. The initiative collaborates with universities and national labs to support early-stage research, partners with corporations to provide funding for innovative technologies, and works with governments to align initiatives with policy goals.[18]

National Initiatives in Phase 1 Countries

In **Colombia,** the Copper Innovation Hub aims to foster collaboration and innovation for a safe energy transition, share good practices, and engage with governments to promote socially responsible and environmentally friendly copper extraction and processing. Headquartered in Colombia, the Hub researches copper and supports the transition to clean energy by integrating the use of Colombian copper ore, local copper transformation capabilities, and economic and social value with local and international applications. The hub represents a collaboration between ten companies from Colombia as well as Australia, Chile, Peru, Sweden, and New Zealand.[19]

In **Morocco**, the Tatwir Green Growth Programme is a key public–private partnership which aims to foster the development of new green industry sectors and reduce industrial carbon emissions by supporting micro, small, and medium-sized enterprises (MSMEs) focusing on energy efficiency projects.[20] In addition, the Morocco Sustainable Energy Financing Facility (MorSEFF)—a partnership between Morocco, the European Union, and several European financial institutions—provides technical assistance as well as financing for energy efficiency and renewable energy projects. This initiative supports sustainable, local processing of critical minerals in Morocco.[21]

Financial Delivery Mechanisms at Global, Regional, and National Level

The analysis of financial delivery mechanisms identified and categorised various funding sources and support mechanisms relevant to facilitating the development, deployment, and scaling up of technological innovations in the mid- and downstream segments of critical minerals value chains.

Phase 1 focused on mapping global and regional mechanisms, and, to a lesser degree, national

17) "Climate-Smart Mining Initiative," World Bank Group, World Bank Group, https://www.worldbank.org/en/programs/climate-smart-mining; World Bank, "New World Bank Fund to Support Climate-Smart Mining for Energy Transition," press release (1 May 2019), https://www.worldbank.org/en/news/press-release/2019/05/01/new-world-bank-fund-to-support-climate-smart-mining-for-energy-transition.

18) "The Path to Science Entrepreneurship," Activate, Activate, https://www.activate.org.

19) "Us," Copper Innovation Hub, Copper Innovation Hub, https://hubinnovaciondelcobre.co.

20) Morocco Ministry of Industry and Trade, "Industrial Recovery Plan: Launch of the 'Tatwir Green Growth' Program to Support the Decarbonization of Industrial SMEs," news release, 26 January 2021, https://www.mcinet.gov.ma/fr/actualites/plan-de-relance-industrielle-lancement-du-programme-tatwir-croissance-verte-pour-lappui.

21) "Morocco—Sustainable Energy Financing Facility (MorSEFF)," DAI, DAI Global, https://www.dai.com/our-work/projects/morocco-sustainable-energy-financing-facility-morseff.

ones, to provide a high-level understanding of the landscape of relevant financial delivery mechanisms. The preliminary mapping categorised them according to the predominant public or private nature of their funding source, to help guide stakeholders in identifying financing opportunities and gaps and evaluating the potential roles of various financing sources and models in supporting technological innovation.

Table 7 summarises the preliminary identification and categorisation of sources, and the following paragraphs describe and exemplify the sources identified as relevant during Phase 1. Additional information and insights on global, regional, and national financial delivery mechanisms in the nine deep-dive countries are included in Section 2 of this report, which presents the findings of Phase 2.

TABLE 7. Landscape of financial delivery mechanisms (Phase 1)

Public Sources	Private Sources
• Multilateral Development Banks (MDBs)	• Venture Capital
• Multilateral Climate Finance Funds	• Corporate Venture Capital
• National Development Banks	• Private Equity
• Bilateral Development Agencies	• Accelerators and Incubators
• Government Grants and Subsidies	• Private Banks
• Sovereign Wealth Funds (SWFs)	• Impact Investment Funds

Source: Prepared by the authors.

Under the **public** sources preliminarily identified in Phase 1, development finance institutions feature prominently as providers of financial resources that enable and de-risk private investment, whether financing private entities in certain cases, whether indirectly through onlending of grants and concessional finance provided to governments. They also offer necessary policy support and technical assistance for governments, geared toward promoting technological innovation throughout mining value chains in developing countries.

Examples of potentially relevant Multilateral Development Banks (MDBs) in this space include the International Bank for Reconstruction and Development (IBRD) and the International Finance Corporation (IFC) under the global umbrella of the World Bank Group; the New Development Bank (NDB), with relevance for several of the 30 selected developing countries; as well as regional MDBs such as the African Development Bank (AfDB) for Africa, the Asian Development Bank (ADB) and the Asian Infrastructure Investment Bank (AIIB) for ASP, and the Inter-American Development Bank (IDB) for LAC.

Bilateral development agencies of donor countries and groups in the Global North (such as those maintained by Japan, Germany, the United Kingdom, and the United States) have the potential to play a similar role in supporting policy development and technological innovation projects in developing countries. Innovations that seek to decarbonise mining value chains may also attract funding from multilateral climate finance funds, such as the Green Climate Fund (GFC) and the Global Environment Facility (GEF).

Considering national-level sources, public funding can be obtained from national development banks that support technological innovation, such as the Brazilian Development Bank (BNDES), as well as from national or subnational innovation grants and subsidies focused on or conditioned to decarbonisatio or broader sustainability objectives. Certain Sovereign Wealth Funds (SWFs) that support clean energy technologies and industrial development may also be considered potentially relevant sources.

Under the **private** sources preliminarily identified in Phase 1, various mechanisms can have a complementary role in financing innovation, both for early-stage startups and more established companies in critical mineral value chains.

Early-stage companies in developing countries can seek to obtain resources to invest in innovation and commercialisation from accelerators and incubators as well as venture capital (VC). Notable examples of accelerators and incubators include Prospect Innovation's Accelerator Program[22] and Techstars Sustainability Accelerator,[23] both of which support sustainability-focused startups by providing funding as well as mentoring and networking opportunities.

Larger companies in the mining, renewable energy, battery storage, or technology sectors may leverage corporate venture capital to invest in technological innovation. Private equity also tends to be a more promising source for more established companies to commercialise or scale innovations. Private banks may also be useful sources, particularly for more established companies and in partnership with public financial institutions. Finally, impact investment funds that focus on sustainability innovations may also be accessible to clean energy and other decarbonisation technologies in critical minerals value chains.

Section 3 of this report, which presents the findings of Phase 2, builds on this categorisation of sources as public and private and on the listed institutional types and mechanisms, providing additional information into specific delivery mechanisms that have been effective in practice, based on further research and stakeholder interviews.

2.2 TECHNOLOGICAL INNOVATION IN CRITICAL MINERALS VALUE CHAINS: INNOVATORS, TECHNOLOGIES, AND PROJECTS

The analysis of the landscape of innovators, technologies, and projects identified and analysed the most relevant later-stage demonstration innovations (TRL 6–7) in the mid- and downstream segments of critical minerals value chains globally. Recognising that technologies at TRL 8–9 in developed countries may be relevant at lower TRLs in developing countries, innovations at that maturity level were also considered, to the extent that they could be transferred to developing countries. Projects that advance sustainable practices, process efficiencies, and recycling technologies were targeted in the analysis, given their potential to serve as benchmarks for innovation in critical minerals value chains.

Phase 1 focused on collecting data for an initial mapping of innovators and their technologies and projects, based on technology trends, patent databases, academic research, and the authors' experience and expertise in the field. Table 8 presents the resulting preliminary list, which showcases the relevant innovators, technologies, and projects identified in Phase 1; indicates their TRL level and geographic origin and focus; and notes their actual or potential activities in developing countries.

Additional details on the preliminarily identified projects listed above and on other projects identified in, or with relevance for, the nine deep-dive countries are contained in Section 3 of this report, which presents the findings of Phase 2, including the project pipeline—a strategic portfolio showcasing innovative clean energy technology projects in the mid- and downstream segments of critical minerals value chains, and assessing their status, viability, sustainability, and scalability in developing countries.

22) "About," Prospect Innovation, Prospect Innovation, https://prospectinnovation.com.

23) "Techstarts Sustainability Accelerator," The Nature Conservancy, https://www.nature.org/en-us/about-us/who-we-are/how-we-work/technology-and-innovation/techstars-sustainability-accelerator.

TABLE 8. Landscape of Innovators, Technologies, and Projects (Phase 1)				
Company	Technology Name	Technology Description	Country	TRL
Umicore	Battery Recycling Program	Advanced technologies in battery recycling, catalysis, energy, and surface technologies, and precious metals refining.	Belgium, potential to collaborate with developing countries	9
Livent Lithium	LIOVIX® Production	Development and scaling of LIOVIX, a lithium product enhancing battery output and lifespan.	Argentina, replicable in developing countries	9
Green Eco Manufacturing (GEM)	Urban Mining and Recycling Projects	Recycling of waste batteries, electronic waste, and strategic resources into valuable materials.	Indonesia, South Africa, replicable in developing countries	8–9
American Battery Technology Company	(Various Projects)	Developing technology for recycling lithium-ion batteries and extracting battery metals such as lithium, cobalt, nickel, and manganese from primary and secondary sources.	United States, potential to collaborate with developing countries	8–9
Neometals Ltd.	(Various Projects)	Recycling lithium-ion batteries to recover valuable materials such as lithium, nickel, cobalt, and vanadium; recovering vanadium from steel slag.	Australia, partnered with companies in Malaysia and Indonesia	8–9
Electra Battery Materials	Ontario Refinery	Operating a refinery to produce cobalt sulphate for the EV market. The project also includes recycling cobalt from battery materials. Integration of recycling processes with primary refining operations to maximise resource utilisation.	Canada, projects in Democratic Republic of Congo	8–9
Rare Earth Salts (RES)	(No specific name)	Developing proprietary technology for the recycling and refining of REEs from end-of-life products and industrial waste. The focus is on producing high-purity REEs for use in clean energy technologies.	United States, potential projects in developing countries	8–9
Lithium Americas Corp. (Argentina, United States)	(No specific name)	Developing lithium production projects with a focus on sustainable extraction methods and minimising environmental impact. The Cauchari-Olaroz project utilises solar evaporation for lithium extraction from brine.	Argentina, United States, extraction techniques can serve as a model for other developing countries	8–9
Maverick Biometals	Bioextraction Initiative	Development of bioextraction technology using enzymes to break down ores and extract metals such as lithium, nickel, and cobalt.	United States, potential for technology transfer to developing countries	7–8

TABLE 8. Landscape of Innovators, Technologies, and Projects (Phase 1) (continued)				
Company	**Technology Name**	**Technology Description**	**Country**	**TRL**
Allonia	Sustainable Mining Solutions	Cutting-edge bioleaching and hydrometallurgical technologies that enhance resource efficiency and minimise waste.	United States, exploring potential engagement with companies in Latin America and Africa	**6–7**
Genomines	Hyperaccumulator Plant Project	Utilising synthetic biology to enhance plants' ability to extract metals from soil and mining tailings, thus remediating the land.	France, potential projects with developing countries	**6**
Phoenix Tailings	CO_2 GONE Process	A zero-waste technology that uses CO_2 to extract nickel and magnesium from iron-rich ores.	United States, potential for implementation in developing countries.	**5–6**

Source: Prepared by the authors.

3

Phase 2

Deep-Dive Market Assessment of Nine Developing Countries

This section presents the results of Phase 2—a deep-dive into the enabling environment and selected technological innovations in critical minerals value chains in nine developing countries across Africa (Namibia, South Africa, and Zambia), ASP (India, Indonesia, and Türkiye), and LAC (Argentina, Brazil, and Mexico).

This section presents the results of Phase 2 of the market assessment—a deep-dive analysis of the enabling environment for technological innovation in critical minerals value chains in the nine developing countries selected (see Appendix A), along with more detailed information on relevant technological innovations identified throughout the assessment.

During Phase 2, the collection, compilation, and analysis of quantitative and qualitative data continued to be carried out through desk-based research, surveys, and in particular, interviews with a range of stakeholders from governments, international governmental and non-governmental organizations, companies, industry associations, financial institutions, and academia at global, regional, and national levels, focusing on the nine countries (see Appendix C). The survey questions and interview protocols used to collect data from stakeholders are available upon request.

Phase 2 of the market assessment continued in greater detail the work undertaken in Phase 1, leading to more comprehensive landscapes of and interactions among stakeholders; policy, legal, and regulatory frameworks; initiatives; and financial delivery mechanisms relevant to technological innovation in the mid- and downstream segments of critical minerals value chains, as well as further information on relevant innovators, technologies, and projects.

Findings about these landscapes that are relevant across the three developing country regions are presented in Section 3.1, followed by sections focused on each of the three developing country regions with findings relevant to the nine deep-dive countries selected: Namibia, South Africa, and Zambia in Africa (Section 3.2); India, Indonesia, and Türkiye in ASP (Section 3.3); and Argentina, Brazil, and Mexico in LAC (Section 3.4). Section 2.5 assesses potential impacts of technological innovation projects on the achievement of the SDGs. Interspersed throughout the analysis of innovators, technologies, and projects, as well as throughout the SDG assessment (Section 3.5), case studies are presented of successful technology implementations in developing countries, highlighting the challenges, solutions, and impacts on relevant SDGs. Appendix D presents the project pipeline, compiling all relevant projects identified throughout Phases 1 and 2. It includes projects in developing countries as well as projects in developed countries that have the potential to be transferred to developing countries at a lower TRL.

3.1 CROSS-CUTTING FINDINGS OF GLOBAL RELEVANCE

Though focused on refining and deepening the information relevant to (and within) the nine deep-dive countries and their respective developing country regions, Phase 2 also resulted in cross-cutting insights of relevance to technological innovation in critical minerals value chains within as well as beyond the regions and countries of focus in this market assessment. This section presents findings on key global stakeholders; policy, legal, and regulatory frameworks; initiatives; and financial delivery mechanisms; as well as on innovators, technologies, and projects identified beyond the nine deep-dive countries and three regions.

Stakeholders at Global Level

Building on the preliminary mapping of stakeholders carried out during Phase 1 (see Section 2.1), the analysis during Phase 2 provided more details on the mandate, activities, and contributions of globally relevant stakeholders in fostering technological innovation in the mid- and downstream segments of critical minerals value chains (Figure 9).

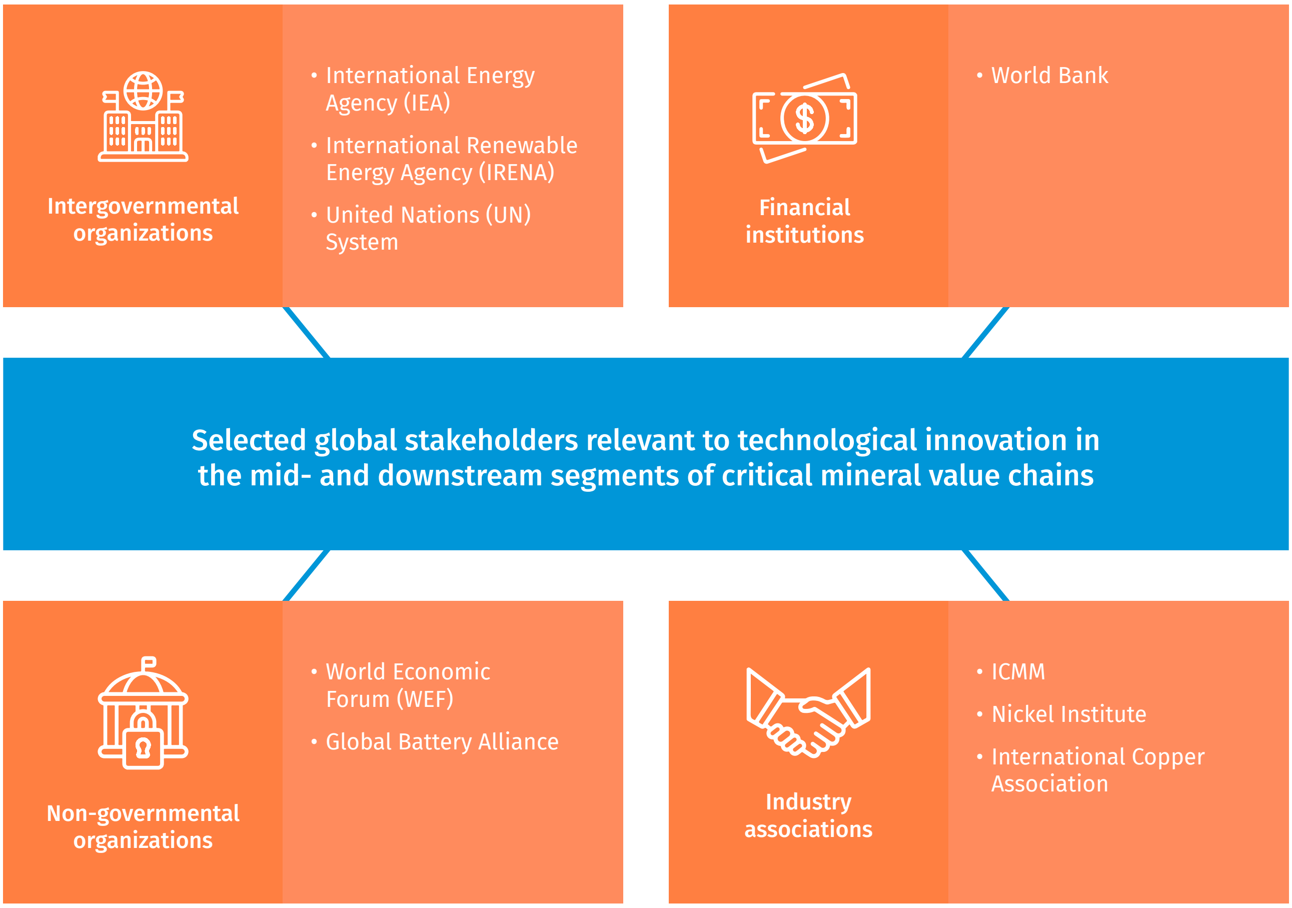


Figure 9. Selected global stakeholders (Phase 2)

Source: Prepared by the authors.

The **International Energy Agency (IEA)** has been instrumental in highlighting the importance of critical minerals for the global energy transition, particularly for renewable technologies like batteries, wind turbines, and EVs. The Agency has published multiple reports relevant to the critical minerals sector—offering insights into industry developments, supply chain vulnerabilities, forecasts for key energy transition minerals, and recommendations for policymakers and industry stakeholders for sustainable sourcing—to guide policies that ensure stable and responsible access to the critical minerals and foster urban mining and recycling.[24] To support these reports, the IEA has also developed tools like the Critical Minerals Data Explorer to allow users to interactively explore projections on critical minerals, and the Critical Minerals Policy Tracker that monitors policies on critical minerals in over 35 countries.[25]

24) See relevant IEA publications:
IEA, *Critical Minerals Market Review 2023* (Paris: IEA, July 2023), https://www.iea.org/reports/critical-minerals-market-review-2023; IEA, *Global Critical Minerals Outlook 2024* (Paris: IEA, May 2024), https://www.iea.org/reports/global-critical-minerals-outlook-2024; IEA, *Sustainable and Responsible Critical Minerals Supply Chains* (Paris: IEA, December 2023), https://www.iea.org/reports/sustainable-and-responsible-critical-mineral-supply-chains; IEA, *The Role of Critical Minerals in Clean Energy Transitions* (Paris: IEA, May 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

25) See relevant IEA resources:
IEA, *Critical Minerals Data Explorer* (Paris: IEA, Last Updated May 2024), https://www.iea.org/data-and-statistics/data-tools/critical-minerals-data-explorer; IEA, *Critical Minerals Policy Tracker* (Paris: IEA, Last Updated December 2023), https://www.iea.org/data-and-statistics/data-tools/critical-minerals-policy-tracker; IEA, *Recycling of Critical Minerals: Strategies to Scale up Recycling and Urban Mining – A World Energy Outlook Special Report* (Paris, IEA, November 2024), https://www.iea.org/reports/recycling-of-critical-minerals.

The **International Renewable Energy Agency (IRENA)** contributes to technological innovation in critical minerals value chains by providing a platform for international cooperation in the renewable energy sector, conducting research and analysis relevant to critical minerals value chains, promoting technology development and transfer, and offering technical assistance and policy advice to governments.[26] Recent IRENA analysis has focused on understanding the critical minerals requirements of the global transition to renewable energy systems, supply-demand projections and dynamics, and the potential for technological innovation to reduce demand for critical minerals. Forthcoming work includes publications on critical minerals for EV batteries, a methodology to rank critical minerals lists, and on the importance of data availability for better governance and decision-making on critical minerals.[27]

Several bodies within the **United Nations (UN)** system play an instrumental role in the mid- and downstream segments of critical minerals value chains and can help foster technological innovation in developing countries. The **UN Industrial Development Organization (UNIDO)** is highly active in the critical minerals landscape, hosting panel discussions,[28] establishing coalitions (such as the Global Alliance for Responsible and Green Minerals),[29] and funding proposals for innovation in relevant sectors.[30] Both the **UN Environment Programme (UNEP)** and the **UN Development Programme (UNDP)** support their member states in achieving the SDGs, focusing on environmental policy (UNEP) and poverty reduction and economic development (UNDP).[31] The **UN Secretary-General's Panel on Critical Energy Transition Minerals**—in which UNEP and the **UN Conference on Trade and Development (UNCTAD)**[32] also play a role—published Guiding Principles on Critical Energy Transition Minerals, providing guidance and recommendations for governments, the private sector, civil society, and other stakeholders, highlighting the need for ramped-up technological innovation and circular economy approaches in critical minerals value chains.[33] Increased collaboration and enhanced coordination throughout the UN system can support technological innovation and expansion toward the mid- and downstream segments of critical minerals value chains, particularly in resource-rich developing countries that have historically been more narrowly involved in upstream mining activities.

The **World Bank Group**, through the world's largest Multilateral Development Bank (MDB), the International Bank for Reconstruction and Development (IBRD), provides developing country governments with loans and grants for development projects,[34] which may involve technological innovations in the mid- and downstream segments of critical minerals value chains.

---

26) "International Renewable Energy Agency," IRENA, https://www.irena.org.

27) IRENA, interview by the authors, 26 August 2024. See relevant IRENA publications: Dolf Gielen, *Critical Minerals for the Energy Transition* (Abu Dhabi: IRENA, November 2021), https://www.irena.org/Technical-Papers/Critical-Materials-For-The-Energy-Transition; Dolf Gielen and Martina Lyons, *Critical Materials for the Energy Transition: Lithium* (Abu Dhabi: IRENA, January 2022), https://www.irena.org/Technical-Papers/Critical-Materials-For-The-Energy-Transition-Lithium; IRENA, *Geopolitics of the Energy Transition: Critical Materials* (Abu Dhabi: IRENA, July 2023), https://www.irena.org/Publications/2023/Jul/Geopolitics-of-the-Energy-Transition-Critical-Materials; Dolf Gielen and Martina Lyons, *Critical Materials for the Energy Transition: Rare Earth Elements* (Abu Dhabi: IRENA, May 2022), https://www.irena.org/Technical-Papers/Critical-Materials-For-The-Energy-Transition-Rare-Earth-elements; IRENA, *World Energy Transitions Outlook 2022*, Chapter 7: Critical Materials (Abu Dhabi: IRENA, May 2022), https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022#page-7; IRENA, *The Energy Transition in Africa: Opportunities for International Collaboration with a Focus on the G7* (Abu Dhabi: IRENA, April 2024), https://www.irena.org/Publications/2024/Apr/The-energy-transition-in-Africa-Opportunities-for-international-collaboration-with-a-focus-on-the-G7.

28) "Accelerating the Green Transition: Critical Minerals, Metals Production and a Fair Future for All," UNIDO, 28 November 2023, https://www.unido.org/general-conference-20/side-events/responsible-mining-green-transition-and-fair-future-all.

29) UNIDO, "UNIDO Announces Launch of Global Alliance for Responsible and Green Minerals in Cooperation with Saudi Arabia," news release, 10 January 2024, https://www.unido.org/news/unido-publishes-first-global-call-proposals-accelerate-demonstrate-a2d-facility.

30) "Accelerating the Green Transition: Critical Minerals, Metals Production and a Fair Future for All," UNIDO, 28 November 2023, https://www.unido.org/general-conference-20/side-events/responsible-mining-green-transition-and-fair-future-all; UNIDO, "UNIDO Announces Launch of Global Alliance for Responsible and Green Minerals in Cooperation with Saudi Arabia," news release, 10 January 2024, https://www.unido.org/news/unido-publishes-first-global-call-proposals-accelerate-demonstrate-a2d-facility; UNIDO, "UNIDO Publishes the First Global Call-For-Proposals of the Accelerate-to-Demonstrate (A2D) Facility," news release, 8 July 2024, https://www.unido.org/news/unido-publishes-first-global-call-proposals-accelerate-demonstrate-a2d-facility.

31) "About the United Nations Environment Programme," UNEP, https://www.unep.org/who-we-are/about-us. "About Us," UNEP, https://www.undp.org/about-us.

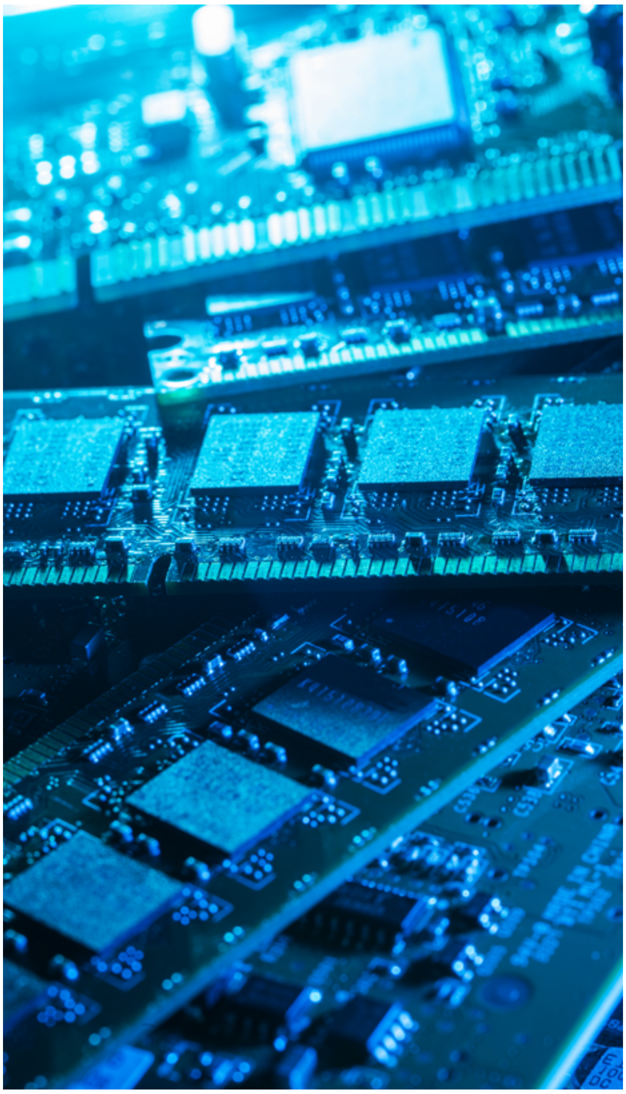
32) "Critical Minerals," UNCTAD, https://unctad.org/topic/commodities/critical-minerals.

33) "The UN Secretary-General's Panel on Critical Energy Transition Minerals," United Nations, https://www.un.org/en/climatechange/critical-minerals; United Nations, *UN Secretary-General's Panel on Critical Energy Transition Minerals, Resourcing the Energy Transition: Principles to Guide Critical Energy Transition Minerals Towards Equity and Justice* (New York: United Nations, 11 September 2024), https://www.un.org/en/climatechange/critical-minerals; Martin Dietrich Brauch, Perrine Toledano, and Lisa Sachs, "Before—and Beyond—the UN Guiding Principles on Critical Energy Transition Minerals," CCSI (blog), 18 September 2024, https://ccsi.columbia.edu/news/before-beyond-un-guiding-principles-critical-energy-transition-minerals.

34) "International Bank for Reconstruction and Development," World Bank Group, https://www.worldbank.org/en/who-we-are/ibrd.

The private-sector arm of the World Bank Group—the International Finance Corporation (IFC)[35]—conducts a global mapping of opportunities for investments in critical minerals value chains and provides financing and advisory services for private sector companies in critical mineral processing, refining, and manufacturing. In addition to financial resources, the World Bank provides technical assistance, capacity building, research and data support, and policy advice to developing country governments. Its mandate, resources, and activities—including, notably, its Climate-Smart Mining initiative[36] and its Resilient and Inclusive Supply-Chain Enhancement (RISE) programme[37]—enable the World Bank to play a fundamental role in supporting developing country governments to build necessary legal and physical infrastructure, facilitate technology transfer and innovation, and enhance local value addition and industrialisation along critical mineral value chains.[38]

The **World Economic Forum (WEF)** facilitates multi-stakeholder dialogue, raises awareness of the importance of critical minerals for the energy transition, and promotes sustainable practices in mining and resource management. The WEF also actively contributes to discussions around policies that promote equitable access to critical minerals. Its initiatives such as the Sustainable Mining Challenge[39] and the Mining and Metals Blockchain Initiative[40] accelerate innovative technologies and solutions for the critical minerals supply chain. The WEF also contributes to the critical minerals sector by publishing data reports that discuss action points relevant to the security, sustainability, availability, and circularity of critical minerals for the energy transition.[41]



35) "International Finance Corporation," World Bank Group, https://www.ifc.org.

36) "Climate-Smart Mining Initiative," World Bank Group, https://www.worldbank.org/en/programs/climate-smart-mining.

37) "Resilient and Inclusive Supply-Chain Enhancement (RISE)," World Bank Group, https://www.worldbank.org/en/programs/egps/brief/resilient-and-inclusive-supply-chain-enhancement.

38) World Bank Group, interview by the authors, 16 September 2024.

39) "Sustainable Mining Challenge", UpLink - World Economic Forum, https://uplink.weforum.org/uplink/s/uplink-issue/a00TE000001FQLNYA4/sustainable-mining-challenge.

40) "How blockchain is helping mining companies reduce carbon emissions", World Economic Forum (10 September 2024), https://www.weforum.org/impact/the-responsible-sourcing-of-raw-materials.

41) See relevant WEF publications:
Michel Van Hoey and Jörgen Sandström, *Investing in innovation will secure vital critical minerals for the energy transition – here's where to start* (Geneva: WEF, June 2024), https://www.weforum.org/agenda/2024/06/why-investing-in-innovation-is-essential-to-securing-critical-minerals; Nick Pickens and Julian Kettle, *Why recycling metal is an opportunity too good to waste* (Geneva: WEF, April 2024), https://www.weforum.org/agenda/2024/04/why-recycling-metal-is-an-opportunity-too-good-to-waste; Benedikt Sobotka, *Why partnerships are critical to accelerating energy transition* (Geneva: WEF, November 2023), https://www.weforum.org/agenda/2023/11/why-partnerships-are-critical-to-accelerating-energy-transition; Espen Mehlum and Michel Van Hoey, *Securing critical minerals for energy transition requires collective action* (Geneva: WEF, February 2024), https://www.weforum.org/agenda/2024/02/securing-critical-minerals-energy-transition-collective-action.

The **Global Battery Alliance (GBA)** is a cross-sectoral collaboration among stakeholders to promote human rights and sustainability in battery value chains. The GBA launched a Critical Minerals Advisory Group (CMAG) in 2022, which hosts a politically impartial platform for engagement between the private and public sectors.[42] Their mission is to circumnavigate bottlenecks within the circular economy of critical minerals.[43] With that said, out of the "170 leading international organizations, NGOs, industry actors, academics and multiple governments" that make up the alliance, only a single organization is based in one of the nine Phase 2 countries.[44] Only recently—in October 2024—have the first three governments joined the Alliance: Germany, Serbia, and, notably, Zambia.[45]

ICMM (formerly the International Council on Mining and Metals) is an industry association of mining and metals companies. Many of its member companies have significant critical minerals operations in the nine Phase 2 countries, notably Brazil, Indonesia, and South Africa. Though the focus of ICMM's activities tends to be on upstream mineral extraction since most of its members sell their commodities before the processing stage, the association also contributes to enhancing sustainability in the mid- and downstream segments of mineral value chains, to the extent that some of its members are vertically integrated or enter into joint ventures across mineral extraction and processing. Notable examples of such members are Anglo American, Freeport, Glencore, and Sumitomo.[46] As regards its work on technological innovation for sustainability in the mid- and downstream segments, ICMM has fostered knowledge production and collaboration on circular economy approaches.[47] It has commissioned independent research on technology, policy, and finance conditions as well as reforms needed to enable global circularity in critical minerals value chains of solar panels and wind turbines.[48] ICMM's *Tools for Circularity* aims to support companies in mineral value chains to improve their circular performance, foster business opportunities, and enhance sustainability outcomes.[49]

The **Nickel Institute** is an industry association that connects its member companies to sources of funding and capacity building opportunities, giving them valuable insight into the current state of the market for nickel. Technical guides, case studies, position papers, and reports[50] often have a sustainability focus, and recently centreed on Indonesia.[51] Most of its member companies are based in developed countries, but some of them conduct operations in developing countries relevant to this assessment, such as Brazil and Indonesia. Though these operations are mainly focused on extraction, the association could play an increasing role mid- and downstream.[52]

The **International Copper Association (ICA)** provides a collective voice for the copper industry on subjects of circularity, while also presenting individual case studies to foster innovation.[53] The industry association has a strong presence in India and Mexico and is looking to branch into Indonesia as well.[54] Their member countries are traditionally focused on primary extraction of

42) "Our Work: Critical Minerals," Global Battery Alliance, https://www.globalbattery.org/critical-minerals.

43) Global Battery Alliance, *The Global Battery Alliance's Call To Action: Policymakers to Bridge the Cooperation Gap in Critical Battery Minerals with Harmonised Data and Transparency* (Brussels: Global Battery Alliance, June 2024), 13, https://www.globalbattery.org/media/publications/gba-cmag-communique-final-june24.

44) "Supporters," Global Battery Alliance, https://www.globalbattery.org/about/members.

45) Federal Ministry for Economic Cooperation and Development, "More Than 15 Agreements for a Sustainable Future," press release, 8 October 2024, https://www.bmz.de/en/news/press-releases/hsc-more-than-15-agreements-for-a-sustainable-future-230740.

46) ICMM, interview by the authors, 26 September 2024.

47) "Innovation for Sustainability," ICMM, https://www.icmm.com/en-gb/our-work/innovation-for-sustainability; "Circular Economy," ICMM, https://www.icmm.com/circular-economy.

48) Perrine Toledano, Martin Dietrich Brauch, and Jack Arnold, *Circularity in Mineral and Renewable Energy Value Chains: Overview of Technology, Policy, and Finance Aspects. Executive Summary* (New York: CCSI, October 2023), https://ccsi.columbia.edu/circular-economy-mining-energy.

49) ICMM, *Tools for Circularity* (London: ICMM, October 2024), https://www.icmm.com/en-gb/guidance/innovation/2024/tools-for-circularity.

50) "Library," Nickel Institute, https://nickelinstitute.org/en/library.

51) Nickel Institute, *ESG Requirements for Indonesian Nickel and Cobalt Producers* (Toronto: Nickel Institute, May 2024), https://nickelinstitute.org/en/library/meetingworkshop-report/topical-webinar-esg-requirements-for-indonesian-nickel-and-cobalt-producers.

52) Nickel Institute, interview by the authors, 28 August 2024.

53) "Member Best Practices," International Copper Association, https://internationalcopper.org/spotlight/member-best-practices.

54) International Copper Association, interview by the authors, 5 September 2024.

copper, but the ICA nevertheless plays an important role in the broader discussion of this project, including through initiatives to improve energy efficiency, in partnership with UNEP.[55]

Finally, any mapping of globally relevant stakeholders in the ecosystem of technological innovation in critical minerals value chains would be incomplete without mentioning the **People's Republic of China**. Though not among the countries of focus during either Phase 1 or Phase 2 of this assessment, China's public and private stakeholders exert dominance in the global markets in the mid- and downstream segments. China accounts for more than 50% of the global share of the processing capacity for cobalt, graphite, lithium, manganese, and REEs, and nearly 40% of the global processing capacity of cobalt and lithium.[56] China is also a dominant player downstream—for example, in battery manufacturing, it accounts for almost 90% of installed manufacturing capacity for cathode active materials and more than 97% for anode active materials.[57] Several of the interviewed stakeholders noted that the bulk of the critical minerals extracted in their countries of operation are sent to China for processing and that Chinese investments in the up- and midstream segments are present in many of their countries of operation, often in partnership with local companies in both segments.[58] Accordingly, China and the technological innovations it develops in these segments are globally relevant. The developing countries of focus in this assessment may seek collaboration with Chinese entities (through joint ventures or other partnerships) and opportunities for technology transfer; they also need to be aware of the risks, costs, and challenges of attempting to catch up and compete with technological innovations from China's established market.

55) "The Mission," Mission Efficiency, https://missionefficiency.org.

56) UNCTAD, *Digital Economy Report 2024: Shaping an Environmentally Sustainable and Inclusive Digital Future* (New York: United Nations, 10 July 2024), https://unctad.org/publication/digital-economy-report-2024.

57) IEA, *Global EV Outlook 2024* (Paris: IEA, 2024), https://www.iea.org/reports/global-ev-outlook-2024.

58) ICA, interview by the authors, 5 September 2024; IRENA, interview by the authors, 26 August 2024; World Bank Group, interview by the authors, 16 September 2024; IEA, interview by the authors, 6 September 2024.

Policy, Legal, and Regulatory Frameworks at Global Level

Complementing the analysis of policy, legal, and regulatory frameworks discussed in the region-focused sections that follow, this section presents selected international legal frameworks and instruments that are globally relevant to technological innovation in critical minerals value chains. Worthy of note in this context are the existing international regimes governing climate change, intellectual property, trade, and transboundary movements of hazardous wastes, as well as the role of existing and emerging soft law frameworks in promoting international cooperation.

Both key international legal texts under the **international climate change regime**—the UN Framework Convention on Climate Change (UNFCCC)[59] and the Paris Agreement,[60] to which all deep-dive countries are parties—stress the importance of research, development, application, and diffusion (including transfer) of decarbonisation technologies, and provide for mechanisms of promotion, cooperation, and technical and financial support to developing countries in this regard. In 2010, the UNFCCC Conference of the Parties (COP) created the Technology Mechanism to facilitate technology development and transfer.[61] Its Technology Executive Committee provides policy recommendations, and its implementation body—the Climate Technology Centre and Network—provides technical assistance to developing countries, increases access to information and knowledge on climate technologies, and fosters stakeholder collaboration through regional and sectoral networks of experts.[62]

The World Intellectual Property Organization (WIPO) administers several treaties within the **international intellectual property** regime. Notably, the Patent Cooperation Treaty (PCT) assists patent applicants in seeking international protection, supports patent offices in granting decisions, and facilitates public access to technical information related to patents.[63] Other WIPO-administered treaties include the Patent Law Treaty on harmonisation and streamlining of patent applications, the Hague Agreement governing the international registration of industrial designs, the 1967 Stockholm Act revising the Paris Convention on industrial property, and the Strasbourg Agreement establishing the International Patent Classification.[64]

Under the **international trade regime**, the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), to which all Phase 2 countries are parties, aims to protect and enforce intellectual property rights as a way to promote technological innovation, dissemination, and transfer. While developing country governments could, in theory, use TRIPS flexibilities such as compulsory licensing to expand access to green technologies such as those relevant to decarbonising critical minerals value chains,[65] it is unclear whether the limited tools provided under the Agreement would be most effective for that purpose.[66] WTO reform and further negotiations on issues of relevance to developing countries, such as those proposed by the African Group of 44 countries to the WTO Working Group on Trade and Transfer of Technology (WGTTT), may be necessary to develop appropriate mechanisms for technology transfers under the trade regime.[67]

The **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal** aims to protect human health and the environment from the adverse effects of

59) United Nations Framework Convention on Climate Change, opened for signature 12 June 1992, entered into force 21 March 1994 (UNFCCC), https://unfccc.int/process-and-meetings/the-convention/history-of-the-convention/convention-documents.

60) Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC), Adoption of the Paris Agreement, UN Doc. FCCC/CP/2015/L..9/Rev.1 (12 December 2015) (Paris Agreement), https://undocs.org/en/FCCC/CP/2015/L.9/Rev.1.

61) UNFCCC COP, The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, Decision 1/CP.16, UN Doc. FCCC/CP/2010/7/Add.1 (15 March 2011), https://undocs.org/FCCC/CP/2010/7/Add.1.

62) "Technology Mechanism," UNFCCC, https://unfccc.int/ttclear/support/technology-mechanism.html.

63) Patent Cooperation Treaty, World Intellectual Property Organization, signed 19 June 1970, 1160 U.N.T.S. 231, as amended, https://www.wipo.int/documents/d/pct-system/docs-en-texts-pct.pdf.

64) "WIPO-Administered Treaties," WIPO, https://www.wipo.int/treaties/en.

65) See, e.g., World Bank, *Inclusive Green Growth: The Pathway to Sustainable Development* (Washington, DC: World Bank, 2021), http://hdl.handle.net/10986/6058.

66) Robert Fair, "Does Climate Change Justify Compulsory Licensing of Green Technology?", 6 *BYU Int'l L. & Mgmt. R.* 6(21) (2010), https://digitalcommons.law.byu.edu/ilmr/vol6/iss1/3.

67) Jan Walter and Stephen S. Kho, "Tech Transfer in the WTO—What's in It for Africa? And for the Rest of the World?", *Akin Gump*, 25 July 2023, https://www.akingump.com/en/insights/alerts/tech-transfer-in-the-wtowhats-in-it-for-africa-and-for-the-rest-of-the-world.

hazardous waste by ensuring its environmentally sound management and restricting the movement of hazardous waste from developed countries to emerging markets and developing economies. A 2022 amendment created a new classification for hazardous and non-hazardous e-waste that aims to develop an accountable global e-waste system.[68] Continued efforts and negotiations under the framework of the Basel Convention are perceived as necessary, in light of the evolving ecosystem of the mid- and downstream segments of critical minerals value chains, to ease the cross-border movement of mineral inputs for processing, battery production, and end-of-life recycling—while at the same time safeguarding human health and the environment.[69]

As highlighted by several interviewed stakeholders,[70] beyond existing treaty regimes and their potential reforms, intergovernmental negotiations and platforms at a multilateral level are essential in promoting **international cooperation** in areas including policy development and analysis; institutional capacity and experience sharing; financing and de-risking of investments; R&D collaboration; data transparency and sharing; and technology transfer throughout critical minerals value chains.

Initiatives at Global Level

Expanding the analysis undertaken during Phase 1 (Section 2.1), additional global-level initiatives were identified and evaluated during Phase 2. This section highlights collaborative efforts (including partnerships, collaborations, consortia, and programs by international organizations) aimed at developing, deploying, and scaling up technological innovations geared toward addressing challenges, advancing energy efficiency, reducing emissions, and contributing to the SDGs in critical minerals value chains. Mechanisms that primarily focus on financing are covered separately.

Among the initiatives led by international organizations, the **IEA's Critical Minerals Policy Tracker**[71] is worthy of

68) Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, Basel, signed 22 March 1989, entered into force 5 May 1992, as amended, https://www.basel.int/theconvention/overview/textoftheconvention/tabid/1275/default.aspx.

69) Perrine Toledano, Martin Dietrich Brauch, Zheqi Li, Luciana Vazquez, and Jack Arnold, *Circularity in Mineral and Renewable Energy Value Chains: Overview of Technology, Policy, and Finance Aspects* (New York: CCSI, October 2023), https://ccsi.columbia.edu/circular-economy-mining-energy.

70) IRENA, interview by the authors, 26 August 2024; IDB, interview by the authors, 16 September 2024.

71) "Critical Minerals Policy Tracker," IEA, https://www.iea.org/data-and-statistics/data-tools/critical-minerals-policy-tracker.

mention as an online, interactive policy monitoring initiative that includes over 35 countries and 450 policies. It offers a valuable overview of evolving mineral supply chain governance and can be useful to a range of value chain stakeholders in understanding and navigating policy frameworks globally.

In 2022, **IRENA** launched its **Collaborative Framework on Critical Materials for the Energy Transition**, a platform for governments to promote dialogue, collaborate and exchange information about policies and activities, increase transparency, and identify and address energy transition challenges related to critical minerals—including regarding technological innovation, material substitution, and processing capacity improvement and expansion.[72] Interviewed IRENA stakeholders noted that the platform is open to all IRENA member states, even if not all participate. The platform has served for countries to share information about their policy developments, technical assistance needs, and development goals. For example, one developing country expressed its interest in and requested support in expanding from critical mineral extraction into processing and battery manufacturing.[73]

Within the UN system, additional initiatives may be spearheaded by the **UN Secretary-General's Panel on Critical Energy Transition Minerals** in the wake of the publication of its Guiding Principles on Critical Energy Transition Minerals. Several principles—notably Principles 2, 4, and 7—stress the importance of innovation in the design of products and services, material and energy efficiency improvements, and increased circularity; the need for equitable opportunities for developing countries to harness technological innovation and increase local content, processing, and value addition; and the fundamental role of multilateral cooperation in improving technology transfer, R&D, and investment in science and technology. The actionable recommendations advanced by the Panel include establishing "a High-Level Expert Advisory Group to facilitate a multi-stakeholder dialogue on 'Accelerating Critical Energy Transition Minerals Value Addition Towards Equity' (ACTIVATE)" and launching a process to implement "material efficiency and circularity approaches along the entire life cycle of critical energy transition minerals."[74] Should the UN Secretary-General or the Panel take steps to implement these recommendations, they are likely to unfold into globally relevant initiatives for technological innovation in the mid- and downstream segments of critical minerals value chains.

In addition to the CSM initiative analysed in Phase 1 (see Section 1.1.3), the World Bank Group also established the **Resilient and Inclusive Supply-Chain Enhancement (RISE) Partnership**, operational since February 2024. The twin goals of the initiative are fostering an enabling environment for clean energy products in low- and middle-income countries, and supporting global decarbonisation goals and other SDGs by strengthening supply chains. RISE prioritises conducting analysis, providing technical assistance, and supporting capacity building and skills development in developing countries. It will also facilitate investment through information platforms, and establish collaborative multistakeholder partnerships comprising governments, investors, MDBs, and industry associations. Given that RISE is explicitly designed to "unlock investment opportunities in the midstream and downstream supply chains of clean energy products, conducive to sustainable economic growth, job creation, and infrastructure improvement in developing countries,"[75] It can be considered one of the most relevant emerging initiatives at the global level for innovative clean energy technologies for critical minerals in developing countries.[76] Currently focused on Eastern and Southern African countries, RISE is also planning to kickstart activities in countries in LAC and Central Asia and in India.[77]

72) "Critical Materials," IRENA, https://www.irena.org/How-we-work/Collaborative-frameworks/Critical-materials.

73) IRENA, interview by the authors, 26 August 2024.

74) United Nations, *Resourcing the Energy Transition*.

75) "Resilient and Inclusive Supply-Chain Enhancement (RISE)," World Bank Group, https://www.worldbank.org/en/programs/egps/brief/resilient-and-inclusive-supply-chain-enhancement; World Bank, "World Bank and Japan Sign Administration Arrangement on RISE to Boost Investments in Supply Chains of Clean Energy," press release, 23 February 2024, https://www.worldbank.org/en/news/press-release/2024/02/23/world-bank-and-japan-sign-administration-arrangement-on-rise-to-boost-investments-in-supply-chains-of-clean-energy.

76) Paulo de Sá, interview by the authors, 3 October 2024.

77) World Bank, *The Rise Partnership: Securing the Green Energy Transition Is an Opportunity To Support Africa's Development, Update note for G7 Finance Ministers and Central Bank Governors* (Washington D.C., World Bank, May 2024), https://www.g7italy.it/wp-content/uploads/Annex-IV.-Update-note-on-the-Rise-Partnership_G7-FMCBG-23-25-May-2024-Stresa.pdf.

The World Bank Group also convened the **Energy Storage Partnership (ESP)**, hosted by the Bank's Energy Sector Management Assistance Programme (ESMAP). ESP involves governments, research institutions and laboratories, development agencies, and philanthropic institutions from around the world. Its objectives are to promote international cooperation and training on energy storage solutions in developing countries and to close the gender gap by supporting leadership and mentoring for women. Among the areas of international cooperation fostered by the ESP are policy and regulatory development, technology R&D and demonstration, enabling communications and energy infrastructure, capacity building, and circular economy and end-of-life management.[78]

The WEF's **Securing Minerals for the Energy Transition (SMET)** initiative is a global, multistakeholder platform that fosters coordinated action in critical minerals for the energy transition. Its primary objectives are facilitating policy dialogue between public and private sectors to inform policy development, guide businesses, and resolve regulatory challenges in securing minerals for energy needs. The platform also aims to identify investment requirements across critical minerals value chains and mobilise capital to address the supply-demand gap. Additionally, SMET promotes innovation by engaging the private sector in identifying new technologies and systematic advancements alongside strategies for scaling these innovations. To achieve these goals, SMET builds on strategic collaborations with leading international organizations, leverages expert knowledge, and involves a diverse range of stakeholders along the minerals supply chain. Achievements to date include contributions from academic institutions, international organizations, and private sector entities toward developing the "Securing Minerals for the Energy Transition" risk management approach. This initiative has identified 30 risks arising from the supply-demand imbalance in critical minerals for the energy transition, formulated 25 strategies to mitigate these risks, and prioritised 10 high-impact strategies for implementation.[79]

Another WEF initiative is its **UpLink Innovation Ecosystem**, a technology-driven open innovation platform that surfaces early-stage entrepreneurs and enables an innovation ecosystem to drive positive systemic change for sustainability. This platform advances progress on the SDGs by uniting innovators, investors, experts, and partner organizations. To do so, UpLink launches innovation challenges per industry, sector, or specific need. For each innovation challenge, UpLink identifies a group of winners recognised as Top Innovators, Top Investors, and Challenge Innovators. Selected winners are invited to become part of the UpLink Innovation Ecosystem and supported in scaling up their innovations.[80]
As part of these innovation challenges, in April 2024, UpLink launched the **Sustainable Mining Challenge**,[81] with the goal of accelerating innovative technologies for energy efficient mining of minerals and metals. The Challenge included 141 submissions of technological innovations throughout mineral value chains, featuring projects on innovative technology for recovery of minerals from tailings, automated characterisation of metal ores, and processing optimisation, among other innovations. The 13 winners, announced in September 2024,[82] included startups from Australia, Canada, Chile, France, and the United States, all focusing on technological advancements in the up-, mid-, and downstream segments of critical minerals value chains. However, none of these winners currently operates in Phase 1 or 2 countries.

Financial Delivery Mechanisms at Global Level

Building on the categorisation of financial delivery mechanisms conducted during Phase 1 and presented in Section 2.1, this section presents an overview of the

78) "Energy Storage Partnership (ESP) | Program Profile | ESMAP," Energy Sector Management Assistance Program (ESMAP), https://www.esmap.org/ESMAP_Energy_Storage_Partnership_ESP_Program_Profile.

79) "Securing Minerals for the Energy Transition," World Economic Forum, https://initiatives.weforum.org/smet/home.

80) "About," UpLink, https://uplink.weforum.org/uplink/s/about.

81) "Sustainable Mining Challenge," UpLink, World Economic Forum, https://uplink.weforum.org/uplink/s/uplink-issue/a00TE000001FQLNYA4/sustainable-mining-challenge.

82) "Total Winners," UpLink, https://uplink.weforum.org/uplink/s/uplink-contribution/Uplink_Contribution__c/Default?custom___Contribution_PrimaryChallenge=Sustainable%20Mining%20Challenge&activeTab=Discover&activeGrid=Winners.

findings of Phase 2 concerning global-level delivery mechanisms identified as potentially or practically effective in facilitating the development, deployment, and scaling up of technological innovations in the mid- and downstream segments of critical minerals value chains. This section focuses on qualitative data to provide a contextual understanding and detailed perspectives on the challenges and opportunities within the funding ecosystem.

UNIDO's **Accelerate-to-Demonstrate (A2D) Facility** is a global mechanism to accelerate the commercialisation and scale-up of innovative clean energy technologies currently in the prototype or demonstration phase in developing countries, contributing to achieving the SDGs. The Facility provides grant funding for the implementation of catalytic demonstration projects in critical minerals, among other areas. Its initial funding was provided by the UK Government's Department of Energy Security & Net Zero (DESNZ), with an initial commitment of GBP 65 million as part of the country's climate finance commitment. Organizations established in all ODA-eligible countries—and therefore in any developing country covered by this market assessment—are eligible to apply. A2D's first call for proposals occurred between July and August 2024.[83]

While the **World Bank Group** does not have a specific mechanism to fund technological innovation projects in the mid- and downstream segments of critical minerals value chains. However, its USD 1 billion **Accelerating Battery Storage for Development programme** launched in September 2018 aims to increase battery storage investment in low- and middle-income countries, by investing in solar PV and storage plants, stand-alone grid batteries, and mini-grids.[84] Furthermore, private sector entities developing technological innovation projects in the mid- and downstream segments may benefit indirectly from grants and loans provided by the IBRD to developing country governments (through on-lending to the private sector) or directly from loans provided by the IFC to private sector entities. Interviewed World Bank Group stakeholders noted that the Group works in all developing country regions, but that the Bank does not have a specific focus on funding for technological innovation projects. They also confirmed that figures for bank-wide funding available or disbursed for such projects are not readily available or easily accessible.[85]

The range of projects financed by the World Bank varies across developing countries and their policy priorities, with most developing countries focusing on mineral extraction and basic processing and fewer seeking to invest in battery, automotive, and other downstream industries. Interviewed stakeholders noted that the aspirations of developing country governments, notably in sub-Saharan Africa, are often far ahead of and disconnected from the realities of their countries in terms of production capabilities, technology absorption, and level of development more broadly. For example, they noted the expectation that the Democratic Republic of Congo and Zambia could jointly develop a battery processing facility, and the existence of third-party feasibility studies for such project; however, in the stakeholders' analysis, such plans appear far-fetched in light of challenges regarding power and water supply, logistics networks, and skills development in both countries. In this context, they noted that it is more realistic to move step by step—from extraction to processing to downstream. They also highlighted that the World Bank's role in often incipient critical minerals value chains in developing countries precedes the financing of specific projects, and instead entails analytical work and value chain studies to understand the realities of each developing country and the feasibility of their participation in these value chains.[86]

Interviewed World Bank stakeholders disagreed amongst themselves as to whether relevant technological breakthroughs in the mid- and downstream processes are occurring in developing countries. Some observed that no such breakthroughs have been observed in the mineral processing space, but that there are pockets of emerging homegrown technologies in developing countries, such as processing pure graphite for battery production, specifically in cathode material and cell manufacturing; others, however, stated that innovation is typically not homegrown, but comes from developed countries. Stakeholders noted that the going assumption in projects financed in developing countries is that the technology itself will come through technology transfer, and that in

83) "Accelerate-to-Demonstrate (A2D) Facility," United Nations Industrial Development Organization (UNIDO), UNIDO, https://a2dfacility.unido.org/web.

84) "Accelerating Battery Storage for Development," World Bank Group, https://www.worldbank.org/en/topic/energy/brief/battery-storage-program-brief.

85) World Bank Group, interview by the authors, 16 September 2024.

86) World Bank Group, interview by the authors, 16 September 2024.

this context efforts and financing are typically geared not to develop technologies within developing countries, but to matchmaking between the providers of existing technologies abroad and the mid- and downstream companies operating in developing countries. The IFC is attempting to matchmake technology transfers, but does not yet have case studies to showcase.[87]

Noting that the mid- and downstream segments of critical minerals value chains are at very early stages in many of the developing countries the World Bank works with, the interviewed stakeholders shared numerous challenges to finance technological innovation in these segments. Notable challenges include identifying bankable projects, developing credible offtake arrangements, building capacity and skills, securing reliable electricity supply, implementing technology transfer, resolving logistical challenges and bottlenecks (particularly in countries that have mineral resources but may not be near consumer markets), and mitigating environmental and social risks (for example, deforestation and community resettlement). They suggested long-term policy and legal frameworks, offtake agreements, and special economic zones as key to addressing these challenges, supporting developing countries to foster technological innovation and to gradually increase their involvement in value addition.[88]

Horizon Europe is an EU funding programme for research and innovation running from 2021 to 2027 with available funds for EUR 95.5 billion.[89] The programme aims to facilitate collaboration and foster research and innovation to tackle global challenges by dispersing knowledge and technologies. “Climate, Energy and Mobility” is one of Horizon Europe’s clusters. This cluster “aims to fight climate change by better understanding its causes, evolution, risks, impacts, and opportunities, and by making the energy and transport sectors more climate and environment-friendly, more efficient and competitive, smarter, safer, and more resilient.”[90] This cluster offers opportunities to researchers and innovators from all over the world and encompasses research and innovation activities within the critical raw materials value chain. Among the nine deep-dive countries, entities established in six of them (Argentina, Indonesia, Namibia, South Africa, Türkiye, and Zambia) are eligible to apply.[91]

The **Minerals Security Partnership (MSP)** is an initiative among various partner countries (Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, the Republic of Korea, Norway, Sweden, Türkiye, the United Kingdom, and the United States) and the EU. Besides diplomatic and other forms of support, the MSP provides financing for projects throughout the critical minerals value chains—including primary extraction, secondary recovery, processing and refining, and recycling—including for projects located in developing countries. While the comprehensive list of the 32 MSP-supported projects is not publicly available, the initiative has reported that it is supporting projects in mid- and downstream activities in various developing countries. The Partnership explicitly focuses on fostering state-of-the art technological innovation in line with sustainability and circular economy principles. MSP-supported projects are required to adhere to environmental and social sustainability and governance standards outlined in the partner countries’ “Principles for Responsible Critical Mineral Supply Chains.”[92] In September 2024, MSP partner countries established the MSP Finance Network, aimed at promoting cooperation, information exchange, and co-financing. The network comprises numerous development finance institutions (DFIs) and export credit agencies (ECAs) from the partner countries.[93]

---

87) World Bank Group, interview by the authors, 16 September 2024.

88) World Bank Group, interview by the authors, 16 September 2024.

89) “Horizon Europe,” European Commission, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

90) “Cluster 5: Climate, Energy and Mobility,” Horizon Europe, European Commission, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-5-climate-energy-and-mobility_en.

91) European Union, *Horizon Europe* (European Union, September 2022), https://research-and-innovation.ec.europa.eu/document/download/f3e10727-68a4-42de-8474-7e0d4c445b76_en?filename=Why%20and%20how%20to%20participate%20to%20Horizon%20Europe%20for%20international%20researchers.pdf.

92) Minerals Security Partnership (MSP), *Principles for Responsible Critical Mineral Supply Chains* (Washington D.C.: U.S. Department of State, 2023), https://www.state.gov/wp-content/uploads/2023/02/MSP-Principles-for-Responsible-Critical-Mineral-Supply-Chains-Accessible.pdf.

93) “Minerals Security Partnership,” United States Department of State, https://www.state.gov/minerals-security-partnership. U.S. Department of the State, Office of the Spokesperson, “Joint Statement of the Minerals Security Partnership Principals’ Meeting 2024,” media note, 27 September 2024, https://www.state.gov/joint-statement-of-the-minerals-security-partnership-principals-meeting-2024; U.S. Department of the State, Office of the Spokesperson, “Joint Statement on Establishment of the Minerals Security Partnership Finance Network,” media note, 23 September 2024, https://www.state.gov/joint-statement-on-establishment-of-the-minerals-security-partnership-finance-network; Jasper Wauters and Nikolas Hertel, “Critical Minerals Supply Chains: The Minerals Security Partnership and Trade-Related Challenges,” *White and Case* (blog), 17 October 2024, https://www.whitecase.com/insight-our-thinking/critical-minerals-supply-chains-minerals-security-partnership-and-trade.

Innovators, Technologies, and Projects at Global Level

This section presents findings on selected innovators, their technological innovations, and implementation projects—at varying degrees of maturity—identified and analysed outside the nine deep-dive countries and three regions within the scope of this market assessment.

Though operating out of the geographic scope of the analysis, the interviewed stakeholders are directly or indirectly involved in mid- and downstream activities in the nine Phase 2 countries. The information collected through stakeholder interviews provide the baseline for the analysis that follows, with additional references cited. Appendix C lists the names, affiliations, and stakeholder groups of those interviewed.

Based on the stakeholder interviews, the key takeaway was that, despite certain commonalities across critical mineral value chains, there were unique characteristics of the processes depending on the country or region of operation, originating from geological constraints. To the extent that these innovators are involved in the mid- and downstream segments of critical minerals value chains in developing countries, these activities are rather fragmented, and the operations tend to be connected with upstream activities that take place in the same developing countries. Accordingly, there is potential for more developing country participation in the mid- and downstream segments and further innovations directly related to these segments.

The development and implementation of technological innovation in general and more specifically in the mid- and downstream segments of critical mineral value chains in developing countries are often in the early stages and evolving. A major incentive for companies operating within these countries to invest in innovation and R&D activities is the possibility to expand and improve their market share.

One of the characteristics of the mining and metallurgy industry is that the majority of the R&D occurs in developed countries, and technologies are later transferred and implemented in developing countries, where local companies adapt these technologies to their own contexts, in some cases incorporating marginal improvements.[94] Two major motives for this rather characteristic behaviour in this industry are the significant cost of R&D activities and the extremely lengthy innovation process with uncertainties related to material complexity. However, major companies and other stakeholders in the mid-and downstream segments have developed a unique strategy to tackle these issues, which is to do the major parts of the innovation and R&D work in developed countries and transfer the know-how to the developing countries for further fine-tuning to match the material complexity of the origin.

Moreover, other challenges related to mid- and downstream operations seem to be a major barrier for companies and startups to participate in this market. For instance, in developed countries, the environmental and geopolitical concerns as well as government support incentivise startups and innovators to focus more on these segments; however, in many cases, these incentives are not offered or are weak in developing countries. In such circumstances, the uncertainties associated with these segments heavily discourage major investments in innovation and R&D. Further, the projected revenue especially from the mid- and downstream processes of critical minerals may be relatively low, due to either the inherent low concentration of value metals or the complex composition in the feedstock that can be utilised or the low volume of feedstock available. Moreover, transportation costs of feedstock and consumables (e.g. chemicals used in processing) are often significant and can be a bottleneck for processing. There are also regulatory issues with transporting hazardous materials across international borders, and sometimes even within the country; for example, black mass, hazardous chemicals used in hydrometallurgical processes, etc. Inadequate or lacking local talent and available education resources seem to be other issues that warrant attention.

While large companies carefully handpick the projects worthy of allocating their resources after significant feasibility studies, technological innovation in the mid- and downstream segments is a golden opportunity for startups in this space if they can receive adequate support. The speed and agility at which startups operate leads to a better turnaround of technological innovations that can be commercialised with the support of large multinational companies, by optimising their resources and channelling their focus on the specific technologies and problem statements local to the region of operations.

Given the substantial capital investment required to develop and scale technological innovations in critical minerals value chains, coupled with the early-stage nature of most emerging technologies—being led by developed countries—many developing countries primarily focus on observing which technologies prove effective before committing to their implementation. Despite recognizing the potential benefits of these innovations, they have yet to initiate widespread adoption due to limited financial resources, capacity constraints, and the high risks associated with technologies that remain to prove commercially viable. The complexities involved in transferring and scaling

94) World Economic Forum (WEF), interview by the authors, 27 August 2024; IEA, interview by the authors, 6 September 2024.

such technologies—particularly in resource-intensive sectors like critical minerals—underscore the need for tailored support mechanisms that can bridge the financial and technological gaps faced by emerging markets and developing economies.[95]

Given the foregoing challenges, it is in the interest of this report to interview a number of global companies from developed countries with a presence, market share, or interest in one or more developing countries. The following sections provide a general overview of the activities of selected companies in these segments. Due to the competitive nature of innovation and R&D in these companies, it is neither possible nor objective to share any specific details of the ongoing research activities. Consequently, additional information was gathered on these companies from multiple resources, connections, and expert opinions throughout the industry and the community.

Austin Elements

Austin Elements Inc., a U.S.-based company, focuses on the production of high-purity battery materials including metal salts and precursors from recycled batteries, such as lithium-iron-phosphate (LFP) and nickel-cobalt-manganese (NCM), using a proprietary low-carbon and energy efficient energy process. The company's technology can also recover other valuable materials, including critical minerals, from manufacturing scrap and ceramic glass.[96]

Based on the interview, the company's battery recycling technology is assessed to be at TRL 5–6 (with some exceptions). The company continues to develop its processes to achieve higher TRL with the goal of moving toward a circular economy by establishing a robust recycling route for batteries and black mass in the U.S. and minimising or eliminating export of spent batteries or black mass. To achieve this goal, the company recognizes the importance of technology development and adoption in all countries, especially in developing countries.[97]

According to the stakeholder, Austin Elements is interested in establishing lithium and black mass processing facilities in developing countries like Argentina, DRC, Indonesia, Mexico, Nigeria, and Zimbabwe due to their lithium reserves. However, the challenges related to the availability of reagents and chemicals in some regional markets were also highlighted. This observation coincides well with that of other lithium-ion battery (LIB) recycling stakeholders and experts interviewed throughout this study.[98]

Another point brought up by the stakeholder are the supply chain considerations, recycling potential, and the need for technology transfer, particularly from developed to developing countries. They also emphasised the need for easy-to-operate recycling processes that do not require advanced knowledge or professional education.[99]

Ecometales

EcoMetales Limited,[100] a subsidiary of Codelco Technologies Limited, Chile, is engaged in the mid- and downstream segments of critical minerals value chains, primarily focusing on developing and implementing innovative technologies for critical mineral recovery from secondary sources and abatement of environmental issues. The company currently has two operations[101] based on a patented technology: leaching of flue dust from the smelters to recover copper values and removal of hazardous arsenic from leach solutions through oxidation, pH adjustment and precipitating with ferric sulphate to form scorodite, which is a stable waste mineral, thus mitigating health risks associated with hazardous waste (see Figure 10).

95) WEF, interview by the authors, 27 August 2024.

96) "Austin Elements," Austin Elements, http://www.austinelements.com.

97) Austin Elements, interview by the authors, 12 September 2024.

98) Austin Elements, interview by the authors, 12 September 2024.

99) Austin Elements, interview by the authors, 12 September 2024.

100) "Ecometales," Ecometales, https://www.ecometales.cl.

101) "Operations and Projects", Ecometales, https://www.ecometales.cl/ecometales/site/edic/base/port/operaciones_y_proyectos.html.

Interviewed stakeholders report that since 2017 the company has processed over 545,000 tonnes of dust and recovered 108,000 tonnes of copper.[102] It also has a few projects under development. In alignment with the SDGs, Ecometales emphasises responsible waste management, water conservation, and innovative applications for copper smelter slag, such as using it in cement production to lower environmental impacts. These efforts underline the company's commitment to promoting sustainable practices.[103]

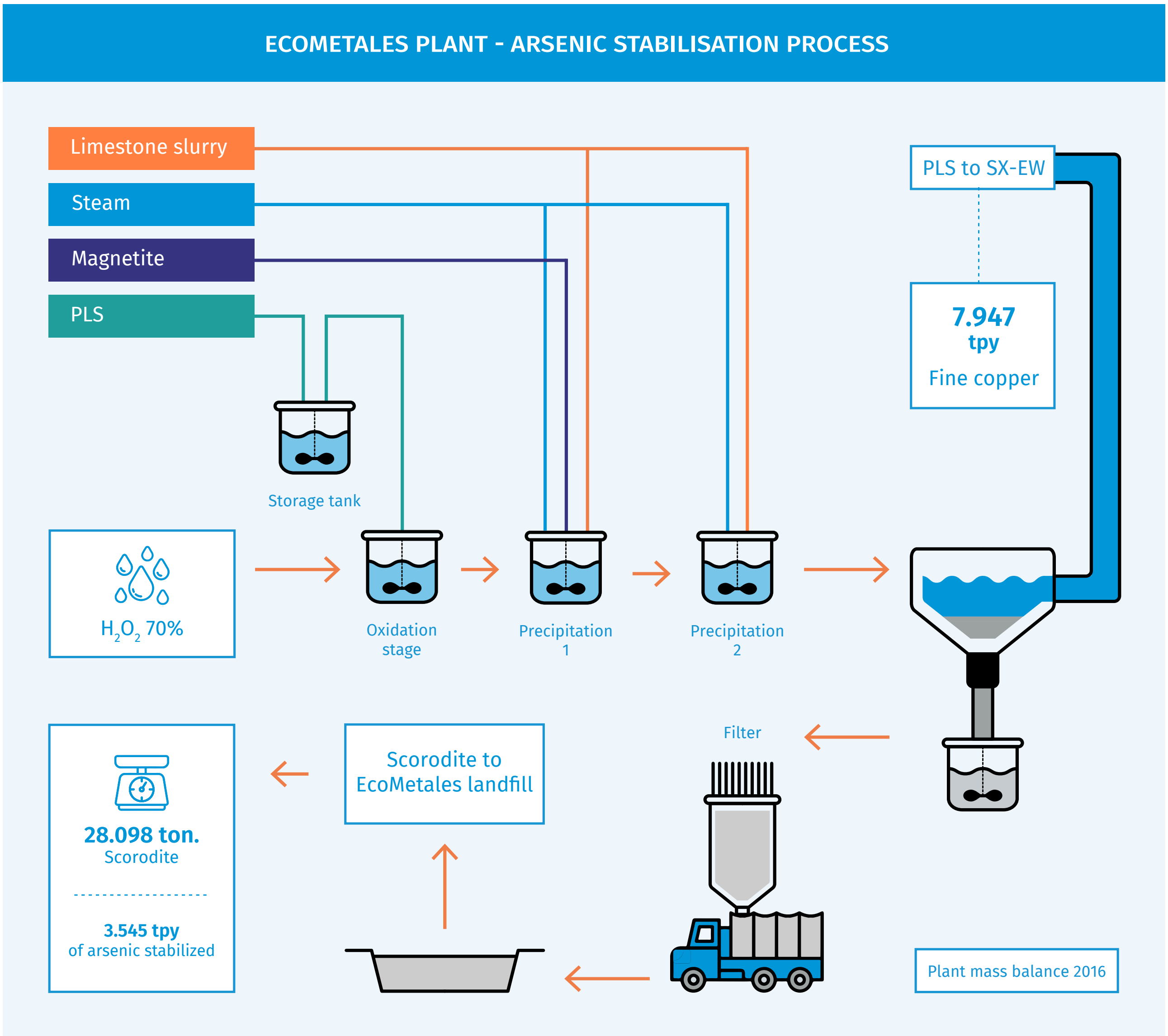


Figure 10. Ecometales plant. Arsenic stabilisation process.

Source: Ecometales.[104]

102) Ecometales, interview by the authors, 6 September 2024.

103) Ivan Valenzuela, "Towards a Sustainable Mining Industry: The Experience of Ecometales" (2017), https://ecometales.cl/ecometales/site/docs/20191113/20191113121329/presentacion_ecometales.pdf.

104) Ecometales, *Stabilization of Deleterious Elements and Circular Economy* (Santiago: Ecometales, April 2022), https://www.ecometales.cl/ecometales/site/docs/20220414/20220414093131/20220407_presentacion_seminario_as_ecl_202204.pdf.

Genomines

Genomines, based in France, is developing phytomining—a sustainable plant-based extraction technology—for the recovery of critical minerals from secondary sources, primarily focused on nickel recovery using hyperaccumulator plants.[105] Interviewed stakeholders indicated that the company is in the technology implementation stage and that results have been very promising, especially the performance of the engineered plants in hyperaccumulation of nickel. The company is now developing and optimising extraction of nickel from plant biomass with techniques such as thermal processing and bioleaching, while also generating other valuable byproducts. Although nickel is the company's primary target, it is also considering future expansion into REEs, copper, and cadmium recovery, making Genomines a key player in the future of green technologies for critical minerals value chains.[106]

According to the company's downstream processing team, Genomines has established operations in Brazil, where its phytomining technology has shown promising results, and in South Africa, among others. Moving forward, Genomines plans to expand into additional countries with the necessary infrastructure and technical skills. The company is strategically selecting

105) "Genomines," Mining Metal with Plants, https://www.genomines.com; "Sustainable Mining Challenge," https://uplink.weforum.org/uplink/s/uplink-issue/a00TE000001FQLNYA4/sustainable-mining-challenge.

106) Genomines, interview by the authors, 1 October 2024.

its expansion markets based on factors like regulatory environments, R&D investment, and availability of resources. This international approach positions Genomines to address the growing global demand for sustainable metal extraction from secondary sources.[107]

Magmatic Bio

Magmatic Bio is an Austrian-based company that specialises in developing engineered proteins for the recovery of lithium and other critical minerals.[108] Utilising the metal-binding protein lanmodulin (LanM), the company has developed a method for selective lithium separation from magnesium and other metals, especially from low-grade (poor quality) brines. The general concept is shown in Figure 11. The company's current focus is lithium from low-quality brines, but it plans to extend its technology to a wider range of metals and liquid streams, including those from battery recycling and mine tailings. This protein-based solution provides higher selectivity, which is sufficient to eliminate several unit operations from traditional process flow sheets, thereby improving efficiency, cost reduction, and reducing water consumption.

The company has received grants from the Austrian government, and after reaching a certain TRL it will scale up to EU-level funding. Most of the company's R&D happens in developing countries closer to the location of the secondary resources. The interviewed stakeholders from Magmatic Bio noted the general difficulty in funding large capital expenditure projects in developing countries where governance and economic stability are highly complex. Magmatic Bio is primarily focused on North America and the Lithium Triangle—Argentina, Bolivia, and Chile—for deploying its lithium recovery technology. The company sees petroleum brines as a key resource in the region. Although lithium remains the company's primary focus due to engineering challenges, Magmatic Bio's platform has the flexibility to adapt to a variety of critical minerals and other feedstocks. By tailoring its protein technology to meet the specific needs of each environment, the company aims to make a global impact, particularly in countries where critical mineral extraction from secondary sources is becoming increasingly strategic.[109]

107) Genomines, interview by the authors, 1 October 2024.

108) "Magmagic | Synthetic Biology powered Lithium," Magmatic Bio, https://www.magmatic.bio.

109) Magmatic Bio, interview by the authors, 24 September 2024.

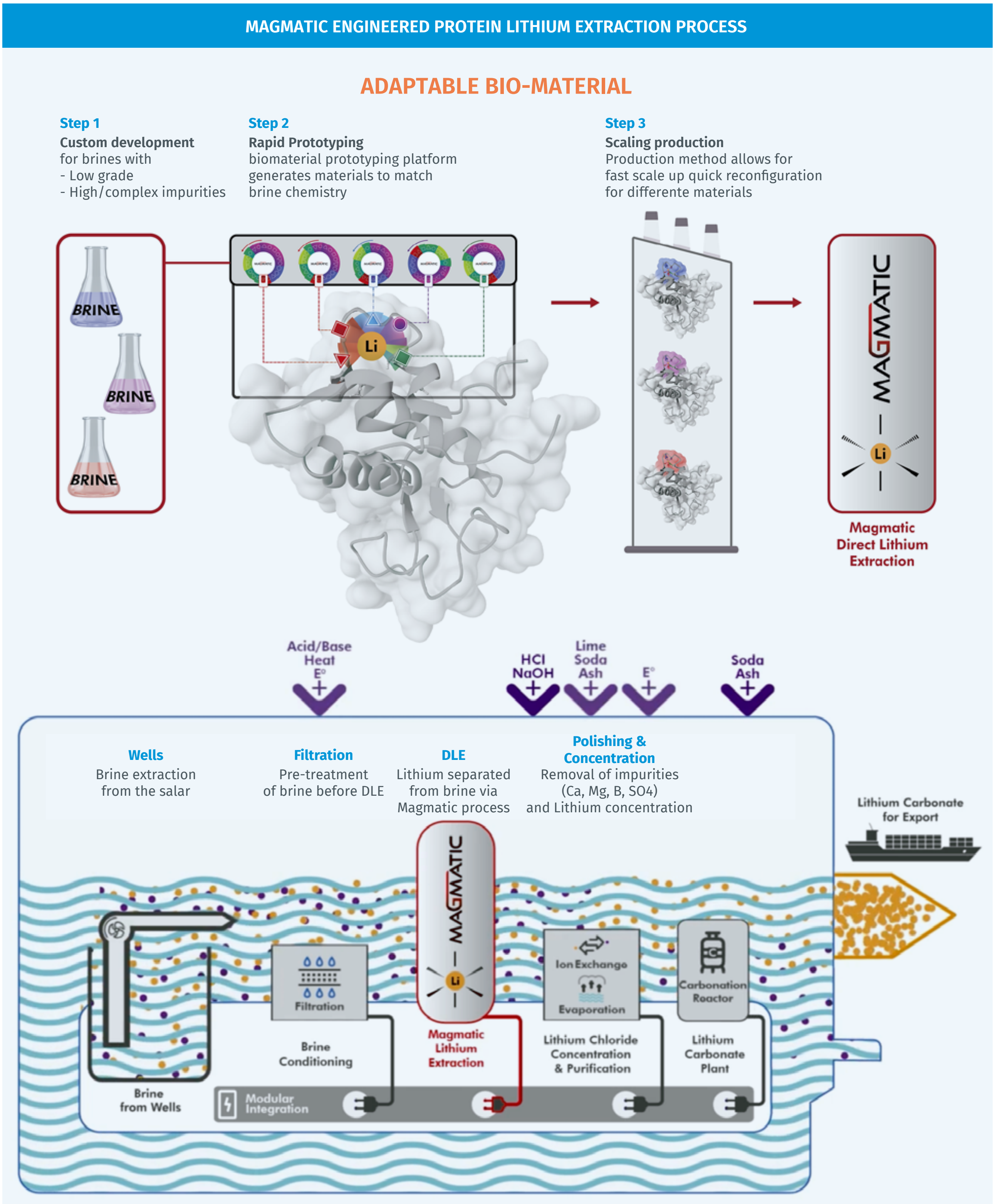


Figure 11. Magmatic engineered protein lithium extraction process

Source: Magmatic Bio's Direct Lithium Extraction process in the flow diagram of Lithium extraction from brines.[110]

110) "Lithium Production Without Mining," Magmatic Bio, https://www.magmatic.bio/s-projects-basic.

Syensqo

Syensqo (formerly known as Solvay and Cytec) is a Belgium-based company that has a long history of technology innovation, development, and leadership in mining and mineral processing chemicals. The company also promotes sustainable development, circular economy, and safer chemicals, for various up-, mid-, and downstream operations in the critical minerals value chain, including EV battery materials and other products, and is positioning itself to play a key role in the future of clean energy. The company has operations in several developed countries, such as the United Kingdom and the United States, as well as in seven Phase 2 developing countries—Argentina, Brazil, India, Indonesia, Mexico, Türkiye, and South Africa—among others. The company's global infrastructure and capabilities support technology deployment in developing countries and enabled through local workforce and collaborations with local companies and research organizations.[111]

111) "Mining Solutions & Digital Innovation for Mining | Syensqo," Syensqo, https://www.syensqo.com/en/solutions-market/resources-environment-energy/mining-solutions; Syensqo Mining Solutions, interview by the authors, 13 September 2024; SOLVAY, "SOLVAY and SYENSQO Revealed as New Company Names," news release, 16 June 2023, https://www.solvay.com/en/press-release/solvay-and-syensqo-revealed-new-company-names.

Neometals

Australia-based Neometals has developed an innovative closed-loop hydrometallurgical process to produce battery-grade salts from recycled lithium-ion batteries.[112] This technology, aimed at maximising material recovery while minimising environmental impact, has been successfully implemented in Mercedes-Benz's first battery recycling plant in Germany. Primobius, a joint venture between Neometals and SMS Group, supplied the advanced technology to this facility, enabling the recovery of key battery materials such as lithium, nickel, and cobalt.[113] These recovered materials can then be reintegrated into the production of new battery modules, supporting a sustainable circular economy for battery materials (see Figures 12 and 13).

In addition to its work in Germany, Primobius has expanded its reach through a partnership with Neo Mobility Asia, focused on establishing a battery recycling business in Thailand. This collaboration has the potential to extend Primobius's technology and recycling operations across the ASP region, further supporting regional sustainability goals and advancing responsible recycling solutions in emerging battery markets.

EV BATTERY VALUE CHAIN

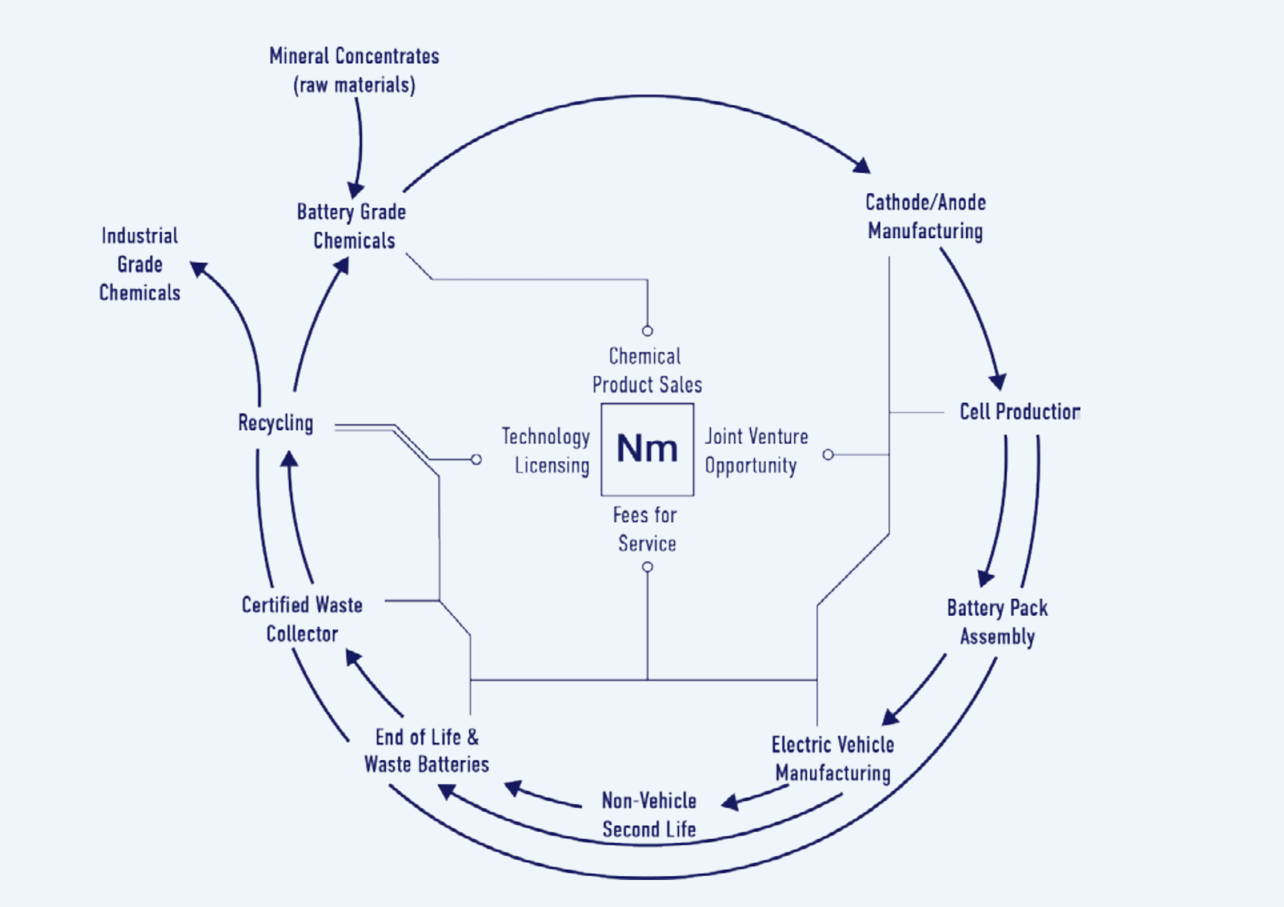


Figure 12. EV battery value chain

Source: Neometals Recycling for the Future – Value Chain.[114]

112) "Lithium-ion Battery Recycling – Neometals," Neometals, https://www.neometals.com.au/en/business-units/core-divisions/lib.

113) Primobius, "Recycling Plant Opened – Mercedes-Benz Closes Its Own Battery Loop with Primobius Technology," press release (21 October 2024, https://www.primobius.com/news-media/press-releases/detail/recycling-plant-opened-mercedes-benz-closes-its-own-battery-loop-with-primobius-technology.

114) "Battery Recycling – Neometals," Neometals, https://www.neometals.com.au/en/products-and-markets/battery-recycling.

NEOMETALS PROPRIETARY HYDROMETALLURGICAL PROCESS FOR BATTERY MATERIAL PRODUCTION FROM BLACK MASS

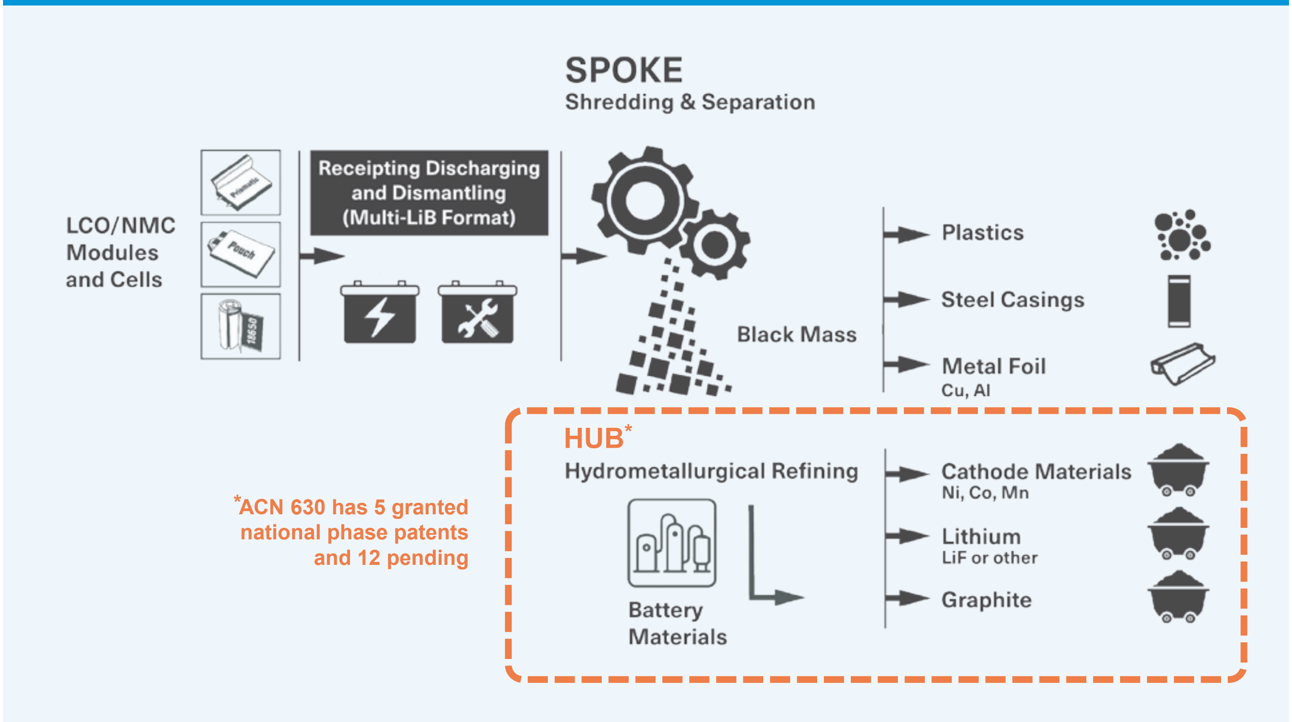


Figure 13. Neometals proprietary hydrometallurgical process for battery material production from black mass

Source: Neometals Strategy Update, August 2024.[115]

Electra Battery Materials

Electra Battery Materials, located in the Canadian province of Ontario, is building a refinery for mid and downstream processing to produce cobalt sulphate for the EV market.[116] This refinery will also host a battery recycling facility to recover nickel, cobalt, manganese, copper, and graphite. The company has secured funding and permitting for this refinery. Viability of its hydrometallurgical process was demonstrated in a plant in 2023. The modular design of its technology is suited to grow with the demand for EV market. Their future plan includes a second refinery in the Canadian province of Quebec, the creation of a battery materials park that would host a nickel sulphate plant as well as a battery precursor cathode active materials (PCAM) plant adjacent to the cobalt refinery and recycling plant, and the development of a cobalt-copper deposit in the U.S. state of Idaho.

Umicore

Umicore, based in Belgium, has significant activities and a comprehensive portfolio of technologies, both mid- and downstream, in battery materials, recycling, and critical minerals recovery, and specialty materials.[117] The company has 15 R&D sites globally. It also has a New Business Incubator (NBI) that focuses on innovation, designed to operate like a start-up, and on developing

115) Neometals, "Neometals Strategy Update," 22 August 2024, https://app.sharelinktechnologies.com/announcement/asx/80146523fa57acf5947176af6712dbc8.

116) "Projects Overview," Electra Battery Materials, https://www.electrabmc.com/projects/projects-overview.

117) "Materials for Better Life," Umicore, https://www.umicore.com/en; Umicore, "Umicore Battery Recycling: Capturing Profitable Growth and Enabling a Circular and Low-Carbon Battery Value Chain," press release (14 March 2023), https://www.umicore.com/en/newsroom/umicore-battery-recycling; "Maximizing Positive Impact on Society," Umicore, https://www.umicore.com/en/sustainability/sustainable-development-goals.

and deploying new technologies. There is significant potential for collaboration with partners in developing countries to enhance local mid- and downstream capabilities, including refining and recycling.

Allonia

Allonnia, a U.S.-based company, is developing novel engineered microbes and products for mid- and downstream bioleaching and other hydrometallurgical processing for recovery of critical minerals or the production of higher quality feedstock for further processing.[118] The company's technologies are in the advanced development and pilot stage (TRL 6–8). It has secured funding and has partnerships with several mining stakeholders for demonstration of feasibility. One outcome of its technology is reducing or eliminating the use of hazardous chemicals and harsh conditions, which could reduce the environmental footprint.

Rare Earth Salts Separations & Refining

A notable advancement from U.S.-based company Rare Earth Salts Separations & Refining[119] is its proprietary process[120] for the separation of REEs—an area notoriously complex due to the requirement of numerous separation stages, complex flow sheets, and a variety of chemicals. While specific technical details are not available, the company's process reportedly reduces the need for diverse and potentially harmful chemicals. This technology has shown potential in the production of high-purity REEs from mineral concentrates, as well as in recycling REEs from end-of-life products and industrial waste streams. Supported by the U.S. Department of Energy, the technology is now being evaluated at a commercial scale, underscoring its readiness for broad application. Additionally, there is promising potential for REE recycling and refining projects in developing countries, where such capabilities could greatly enhance local value chains.

American Battery Technology Company

U.S.-based company American Battery Technology Company has developed a proprietary closed-loop hydrometallurgical process for battery metals extraction production of high-grade battery materials from recycled lithium-ion batteries and also extraction of lithium from the claystone deposit in the U.S. state of Nevada (both up- and midstream processing) (see Figure 14). At the commercial level, the company has established a large-scale battery recycling facility, where it currently processes used batteries to recover valuable metals such as lithium, cobalt, and nickel. The company is actively expanding this facility to include black mass refining capabilities, aiming to produce battery-grade materials from the concentrated mixture of recovered metals. This expansion will enable the company to further close the loop in battery recycling, supporting a circular economy model by reintroducing high-quality recovered materials back into the battery production supply chain.[121]

118) "Sustainable Mining," Allonia, https://allonnia.com/markets/#sustainable-mining.

119) "What We Do," Rare Earth Salts, https://www.rareearthsalts.com/whatwedo; "Sustainability," Rare Earth Salts, https://www.rareearthsalts.com/ourteam-1-1; "Rare Earth Salts Announces Commercial Scale Production of Heavy & Light Rare Earth Elements Using Breakthrough Technology," Business Wire, 29 August 2023, https://www.businesswire.com/news/home/20230822581586/en/Rare-Earth-Salts-Announces-Commercial-Scale-Production-of-Heavy-Light-Rare-Earth-Elements-Using-Breakthrough-Technology.

120) Brewer, J and Lawrence, N. "Method for rare earth and actinide element recovery, extraction and separations from natural and recycled resources," Rare Earth Salts Llc. Patent Application WO2014066668A1 2014.

121) "The Future Starts Today," American Battery Technology, https://americanbatterytechnology.com/about-us.

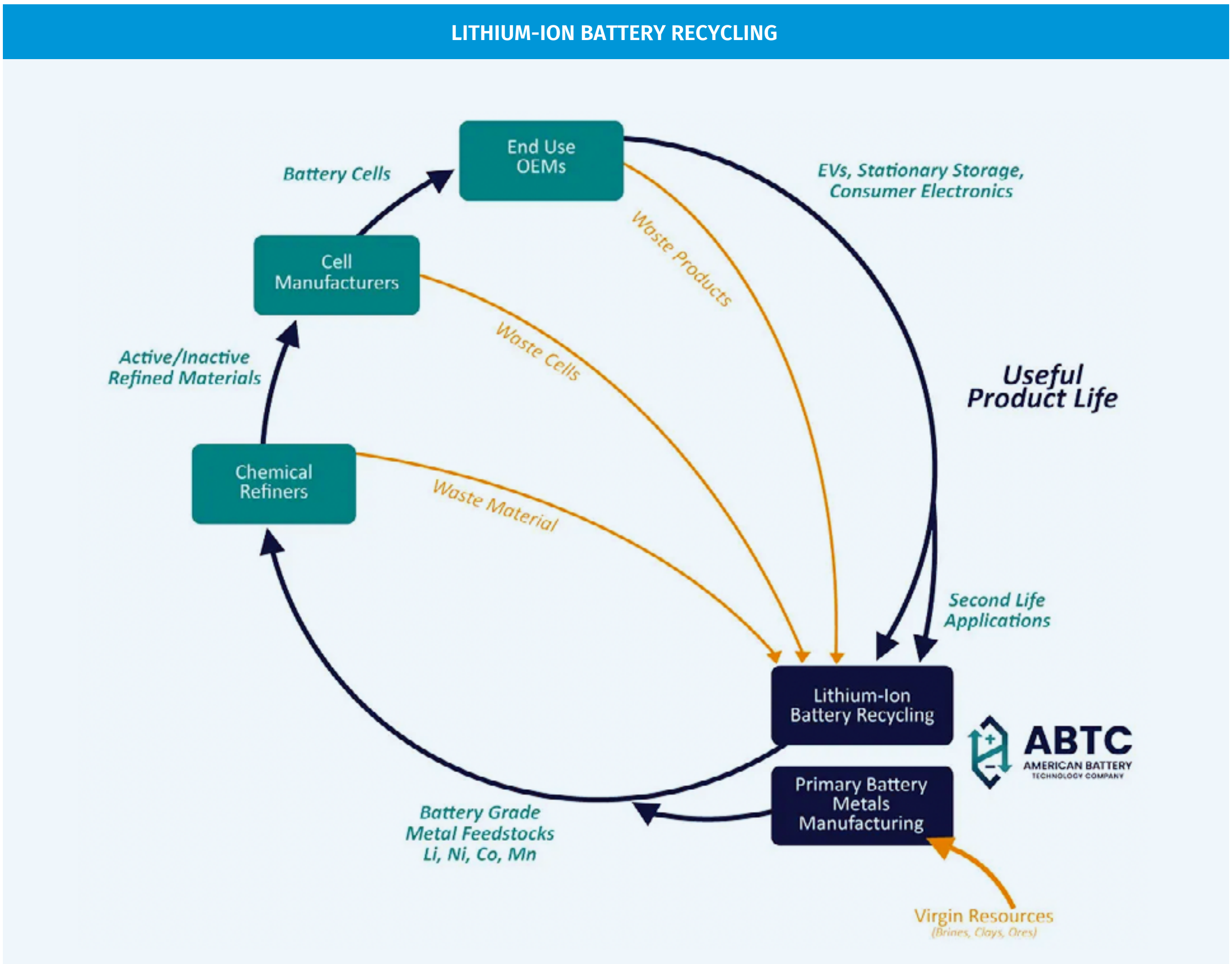


Figure 14. Lithium-ion battery recycling

Source: American Battery Technology Company, Lithium Ion Battery Recycling.[122]

Maverick Biometals

Maverick Biometals, a U.S.-based company, has introduced an innovative BioExtraction™ technology that leverages specially engineered enzymes and synthetic proteins to extract critical minerals from various feedstocks. Operating across up- and midstream processing, this approach uniquely focuses on breaking down the crystal structures of target minerals, particularly silicate minerals, under near-ambient temperature and pressure conditions. One important application of this technology is the breakdown of spodumene—a primary lithium silicate mineral—allowing for the efficient release of lithium from its matrix. This method represents an environmentally friendly alternative to the traditional acid-roasting followed by leaching, commonly employed lithium extraction from spodumene ores. Maverick is currently exploring such an approach in many applications which currently use

122) "Lithium-Ion Battery Recycling," American Battery Technology, https://americanbatterytechnology.com/solutions/lithium-ion-battery-recycling.

a combination of pyrometallurgy and hydrometallurgy. Their technology offers a significant potential for energy savings, minimal environmental impact, and high extraction of critical minerals. The company has already developed many engineered enzymes for evaluation in several applications.[123]

Lepidico

Australia-based company Lepidico operates a vertically integrated lithium production model from upstream processing to mid- and downstream operations. Upstream processing occurs in Namibia using conventional technology to produce a flotation concentrate from lepidolite and other lithium-rich micas from the Karibib open-pit, brownfield mines. This concentrate is then transported to the United Arab Emirates (UAE), where the company employs its patented, non-thermal L-Max® and LOH-Max® technologies for midstream processing to produce lithium hydroxide for battery companies. Unlike the high-temperature conversion needed for spodumene, Lepidico's processes are less energy-intensive and are designed to work efficiently with lithium micas. Production of concentrate and battery-grade lithium salt are expected to commence in 2025. Additionally, there is potential to implement their midstream processing technologies directly at the mining site in Namibia, which could further reduce transportation costs and optimise their vertically integrated model.[124]

123) "Maverick Biometals (USA) Advanced Solutions for Sustainable Mineral Processing," Maverick Biometals, https://www.maverickbiometals.com/solutions#solutions; "Revolutionising Mineral Processing with BioExtraction," Maverick Biometals, https://www.maverickbiometals.com/technology.

124) "Technologies: Leading the Next Lithium Cycle," Lepidico, https://lepidico.com/technology.

3.2 AFRICAN COUNTRIES: NAMIBIA, SOUTH AFRICA, AND ZAMBIA

Stakeholders

Using the categorisation of stakeholders developed during Phase 1 (Section 2.1), the analysis in Phase 2 focused on mapping regional and national stakeholders with actual or potential roles in fostering technological innovation in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia (Table 9). Further analysis of their roles and relationships is presented in the following sections.

TABLE 9. Selected regional and national stakeholders relevant to Namibia, South Africa, and Zambia (Phase 2)

Stakeholder	Namibia	South Africa	Zambia
Continental and regional organizations	• African Union (AU) • African Continental Free Trade Area (AfCFTA) • African Regional Intellectual Property Organisation (ARIPO) • African Natural Resources Management and Investment Centre (within the African Development Bank) • Southern African Development Community (SADC) • Southern African Power Pool (SAPP) • United Nations Economic Commission for Africa (UNECA)		
Government bodies and regulatory agencies	• Ministry of Mines and Energy • Ministry of Environment and Tourism • Ministry of Industrialisation and Trade	• Department of Trade, Industry and Competition • Companies and Intellectual Property Commission (CIPC) • Department of Mineral Resources and Energy • Centre for Public Service Innovation (CPSI) • Department of Science and Innovation • National Advisory Council on Innovation (NACI) • National Economic Development and Labour Council (Nedlac) • Technology Innovation Agency	• Ministry of Mines and Mineral Development • Ministry of Energy • Ministry of Technology and Science • Ministry of Commerce, Trade, and Industry • Ministry of Technology and Science • Ministry of Lands, Natural Resources and Environmental Protection • Ministry of Finance • Ministry of Green Economy and Environment • Industrial Development Corporation (IDC)
Industry associations	• The Chamber of Mines of Namibia	• Mining Industry Association of South Africa	• Zambia Chamber of Mines

TABLE 9. Selected regional and national stakeholders relevant to Namibia, South Africa, and Zambia (Phase 2) (continued)

Stakeholder	Namibia	South Africa	Zambia
Financial institutions	• African Development Bank (AfDB)		
	• Namibia Industrial Development Agency (NIDA) • Development Bank of Namibia (DBN) • Bank of Windhoek	• Industrial Development Corporation of South Africa (IDC) • Development Bank of South Africa (DBSA)	• Zambia Development Agency (ZDA) • Industrial Development Corporation Limited (Zambia IDC) • Citizens Economic Empowerment Commission of Zambia (CEEC)
Academic and research institutions	• Southern African Development Community Centre for Renewable Energy and Energy Efficiency (SACREEE)		
	• Namibia Energy Institute (NEI)	• Academy of Science of South Africa (ASSAf) • Data Intensive Research Initiative of South Africa (DIRISA) • Human Sciences Research Council (HSRC) of South Africa • National Research Foundation (NRF)	• Zambian Electric Mobility Innovation Alliance (ZEMIA) • Zambia Academy of Sciences (ZaAS) • Policy Monitoring and Research • Centre (PMRC) University of Zambia • Copperbelt University

Source: Prepared by the authors.

Policy, Legal, and Regulatory Frameworks

Phase 2 resulted in a deep-dive analysis of the policy, legal, and regulatory frameworks in Namibia, South Africa, and Zambia. Figure 15 presents policy highlights for the region, and the country-specific narratives that follow present key details about each country's policies, laws, and regulations governing critical minerals extraction, processing, and refining; renewable energy; environmental protection and sustainability; technological innovation & R&D; industrial assembly and manufacturing; and circular economy and waste management; among others.

Appendix B provides a list of legal instruments and other references consulted for the preparation of the narratives. A policy tracker spreadsheet compiling over 370 policies, laws, and regulations by region and country, which served as the baseline for this analysis, is available upon request.

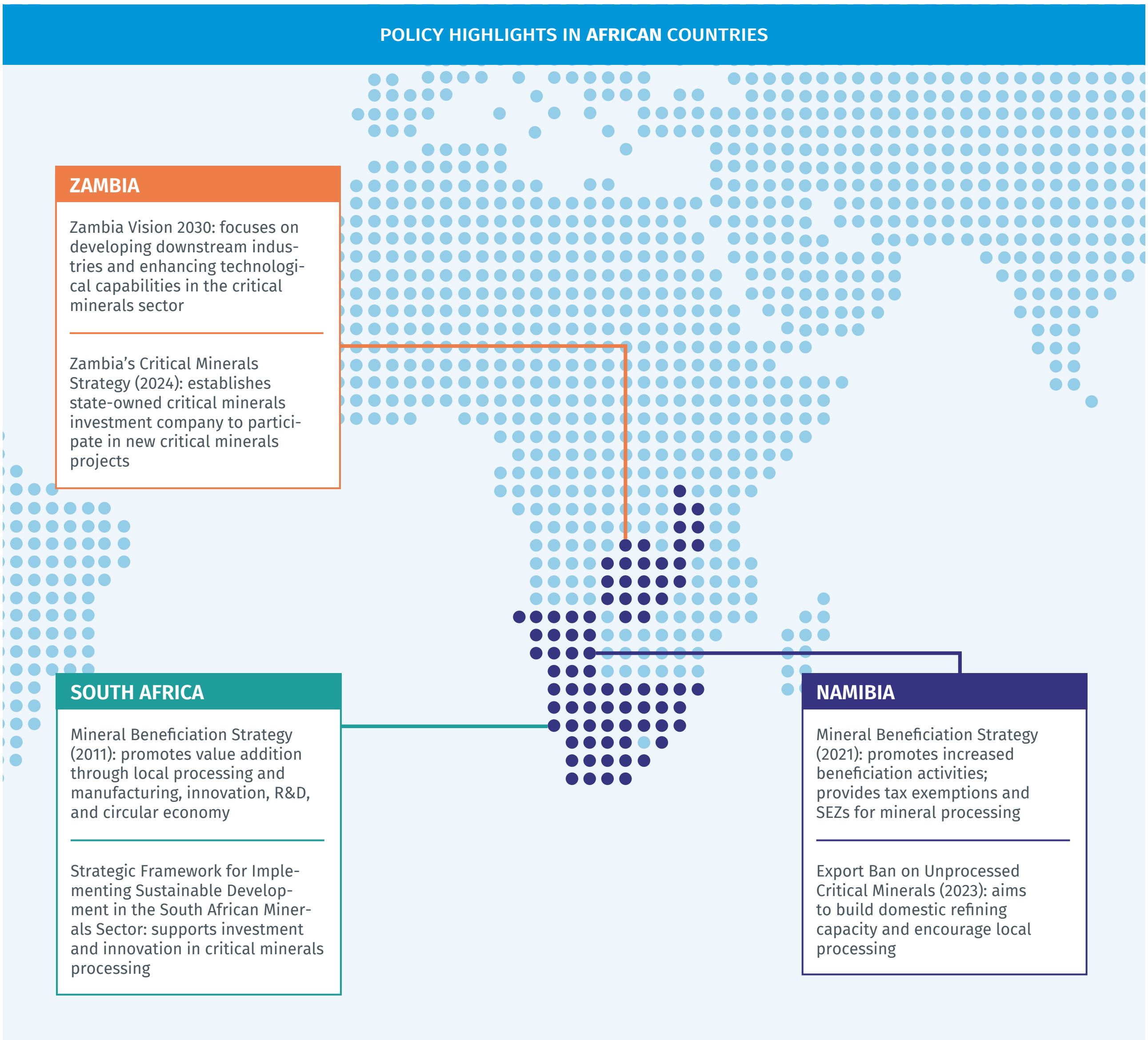


Figure 15. Policy highlights in African countries: Namibia, South Africa, and Zambia (Phase 2)

Source: Prepared by the authors.

NAMIBIA

Namibia's Minerals (Prospecting and Mining) Act 33 (1992), amended in 2008, governs the exploration and exploitation of mineral resources in the country. This regulatory framework removed restrictions on maximum rates of royalties. The Minerals Development Fund of Namibia Act 19 (1996), as amended by the State-Owned Enterprises Governance Act 2 of 2006, ensures that proceeds from mining activities are reinvested into the sector's mid- and downstream segments, supporting sustainable growth and technological advancements along the value chain.

Namibia has been implementing policies that align with the SDGs. The Energy Policy White Paper 1998, along with initiatives like the Feed-in Tariff and support for Concentrated Solar Power Technology Transfer, encourage investments in renewable energy technologies for mid- and downstream critical minerals technological improvements. The Solar Revolving Fund (SRF) and the National Energy Fund (NEF) provide mechanisms for financing renewable energy projects, supporting innovation within the energy sector. Through its National Renewable Energy Policy, Namibia has set a goal to generate 70% or more of its electricity from renewable sources by 2030, marking an ambitious target to significantly increase its reliance on clean energy sources like solar and wind power. This policy also provides a framework for private sector participation in the electricity market through public-private partnerships and enhances the country's energy security by developing local generation capacity.

Namibia also developed a three-phased Mineral Beneficiation Strategy (2021) whereby it seeks to increase the level of mineral beneficiation activities along the value chains and creates attractive opportunities for investors in mineral beneficiation—through measures such as tax exemptions and implementation of Special Economic Zones (SEZs). These efforts, in turn, aim to create sustainable jobs and alleviate poverty. In line with this, in June 2023, Namibia banned the export of unprocessed critical minerals, including cobalt, graphite, lithium, manganese, and REEs. The ban aims to improve domestic refining capacity, encourage local processing, and profit from the growing global demand for these metals. Export bans of raw materials can risk unintended consequences, such as stagnation in the mining industry, by disrupting investment and market dynamics. Therefore, such measures should be carefully evaluated to avoid undermining the sector's growth and development potential.

Namibia has also been advancing a National Solid Waste Management Strategy, which prioritises waste minimisation and recycling over treatment and disposal and integrates circular economy principles into long-term planning for several sectors, including critical minerals value chains.

SOUTH AFRICA

To capitalise on its critical minerals reserves, particularly in manganese and nickel processing, South Africa has been actively developing an enabling environment for technological innovation in midstream processing and downstream deployment of critical mineral technologies through key policies and legislative frameworks, emphasising the critical minerals sector's role in driving economic growth and development. South Africa has created 11 operating Special Economic Zones (SEZs), which offer tax incentives, such as reduced corporate income tax rate; reduced contribution to pay-as-you-earn for low-salaried employees; duty deferment; and VAT exemptions to attract foreign investment from companies working in critical mineral processing and some manufacturing companies assembling products derived from critical minerals.

The Industrial Development Corporation Act (1940) created the Industrial Development Corporation (IDC), which plays a crucial role in promoting industrial development, including in the critical minerals sector. The Mineral and Petroleum Resources Development Act (MPRDA) (2002) regulates the mining and production of critical minerals and aims to promote equitable access to decent employment opportunities among vulnerable groups, as well as stimulate economic growth. The Act also includes provisions that promote resource efficiency, mine rehabilitation, and waste minimisation. The National Environmental Management Act (NEMA) 107 of 1998 (amended by National Environmental Management Laws Amendment Act 2 of 2022) is the overarching environmental law in South Africa, providing the framework for environmental management. It emphasises sustainable development and the protection of natural resources. Mining operations must comply with NEMA and minimise waste and environmental impact.

In the renewable energy space, South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (2011) has attracted substantial investments in renewable energy projects, bolstering the energy mix that supports the processing of critical minerals.

The Beneficiation Strategy of 2011 aims to add value to South Africa's mineral resources by promoting local processing and manufacturing of mineral commodities mined in South Africa. The strategy also recognises the importance of innovation and R&D in developing new mineral processing and beneficiation technologies. The Strategy also aligns with circular economy principles by promoting resource efficiency, local supply chain development, and reducing waste by encouraging secondary processing. The National Development Plan (NDP) 2030 emphasises the role of mineral resources in driving economic growth and development, outlining strategies to enhance the mining sector's contribution to the economy, particularly in critical minerals necessary for renewable energy technologies. The Income Tax Act 58 (1962) provides tax incentives for companies that reduce energy consumption and improve energy efficiency in their operations, including those in mineral processing and manufacturing. Companies can claim tax deductions based on verified energy savings, encouraging them to adopt more efficient technologies and processes.

To support innovation in this sector, South Africa has implemented the Strategic Framework for Implementing Sustainable Development in the South African Minerals Sector, specifically designed to promote sustainable development and create a conducive environment for investment and innovation in critical minerals. The Department of Science and Innovation (DSI) has also been instrumental in promoting research and development in critical mineral processing and refining technologies through various initiatives outlined in the department's Decadal Plan. Additionally, the Mining Charter aims to promote transformation in the mining sector, including the critical minerals sector, by encouraging investment in technology and innovation to improve efficiency and sustainability.

The Waste Act, 2008 (Act No. 59 of 2008) is focused on managing waste in an environmentally responsible manner. It includes provisions for waste minimisation, reuse, recycling, and recovery. The law requires industries, including mining, to develop and implement waste management plans. A 2020 Amendment to this Act introduced the concept of extended producer responsibility (EPR), which requires companies to take responsibility for the entire lifecycle of their products, including post-consumer waste management. For critical minerals, EPR could support recycling initiatives and material recovery. The National Waste Management Strategy (2020) complements the Waste Act and sets out specific targets for waste reduction, recycling, and reuse across sectors, including mining. It promotes the circular economy by encouraging industries to minimise waste and use secondary raw materials. Moreover, the Second-Hand Goods Act (2009) has some provisions that regulate the recycling and reuse of scrap controlled metals.

ZAMBIA

The Mines and Minerals Development Act (Act No. 11 of 2015), which replaced the previous Mining Act No. 7 of 2008, is the overarching law governing mines and minerals–related activities in Zambia. The policy's complete revision in 2015 and subsequent annual amendments show its adaptability to midstream technological innovations. The Act outlines the regulatory requirements for mineral exploration, mining, and processing, ensuring that these activities contribute to the country's economic and sustainable development, and mandates environmental impact assessments for all mining-related operations. A 2018 amendment to this Act emphasises local value addition and beneficiation, creating a conducive legal environment for investing in mineral processing activities by providing different incentives, such as increasing tax for exporting raw materials and importing processed products, that ultimately aim for the country's industrialisation. The

Mines and Minerals Development (General) Regulations of 2016 further detail the implementation of the Act, providing guidelines for mineral processing and beneficiation activities in the country.

Complementing the mining legislation, the Zambia Development Agency Act of 2006 provides a framework for promoting investment in various sectors, including mining and mineral processing. This Act establishes the Zambia Development Agency (ZDA), tasked with fostering economic growth through investment promotion, trade facilitation, and enterprise development. The ZDA plays a crucial role in attracting foreign and domestic investments into the downstream and midstream segments of the critical minerals sector by providing incentives such as tax holidays or tax reductions for a set period, duty-free imports for equipment related to renewable energy projects, and exemption from excise duty for certain renewable energy-related products. Additionally, Zambia Vision 2030 outlines the country's long-term development goals, emphasising the importance of value addition beyond the upstream mining sector, the development of downstream industries, and improving its technological capabilities along the critical minerals value chain. This vision aligns with the national goal of economic diversification and industrialisation by 2030.

The National Climate Change Policy (2017) promotes clean energy and low-carbon technologies. The policy advocates for fiscal incentives and regulatory reforms to support renewable energy investments as part of Zambia's climate change mitigation efforts. The National Policy on Environment (2007) and the National Energy Policy (2008) address environmental sustainability and energy needs, which are crucial for the mining and processing industries. One of the key goals of the Energy Policy is to continue to promote, enhance, develop, and deploy renewable energy technologies. These policies promote the adoption of sustainable and efficient technologies, ensuring that mineral processing activities do not compromise environmental integrity.

Zambia is the African country in the scope of our market assessment with the largest number of mentions of "mineral processing" licences and facilities in its minerals law, signalling Zambia's leading level of policy readiness regarding mid- and downstream critical minerals technologies. It has also been making strides in solid waste management through the Solid Waste Regulation and Management (2018) and Environmental Management (Amendment) Act, No. 8 of 2023, which regulate managing and disposal of solid waste in different industries—including mining and industrial processing—contributing to a circular economy approach within the critical minerals sector.

In September 2024, the Ministry of Mines and Mineral Development announced Zambia's Critical Minerals Strategy. Under this new policy, Zambia plans to create a state-owned investment company to secure at least a 30% share of the production from future critical minerals projects. This initiative involves establishing a special purpose vehicle dedicated to investing in these minerals, with a framework that mandates a "production sharing mechanism" to ensure the state retains a minimum of 30% of the output from new mining ventures. Additionally, the policy will require investors in the critical minerals sector to source at least 35% of their procurement from local suppliers. As part of this approach, Zambia will also revise its policy and regulatory framework to ban or limit the export of raw materials, seeking to encourage more domestic processing—even though, as noted, such measures can hinder investment in the upstream segment.

Initiatives

In addition to the global initiatives identified during Phases 1 (Section 2.1) and 2 (Section 3.1), regional- and national-level initiatives were identified and evaluated with relevance for technological innovation in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia (see Figure 16). Mechanisms of a primarily financial nature are covered separately.

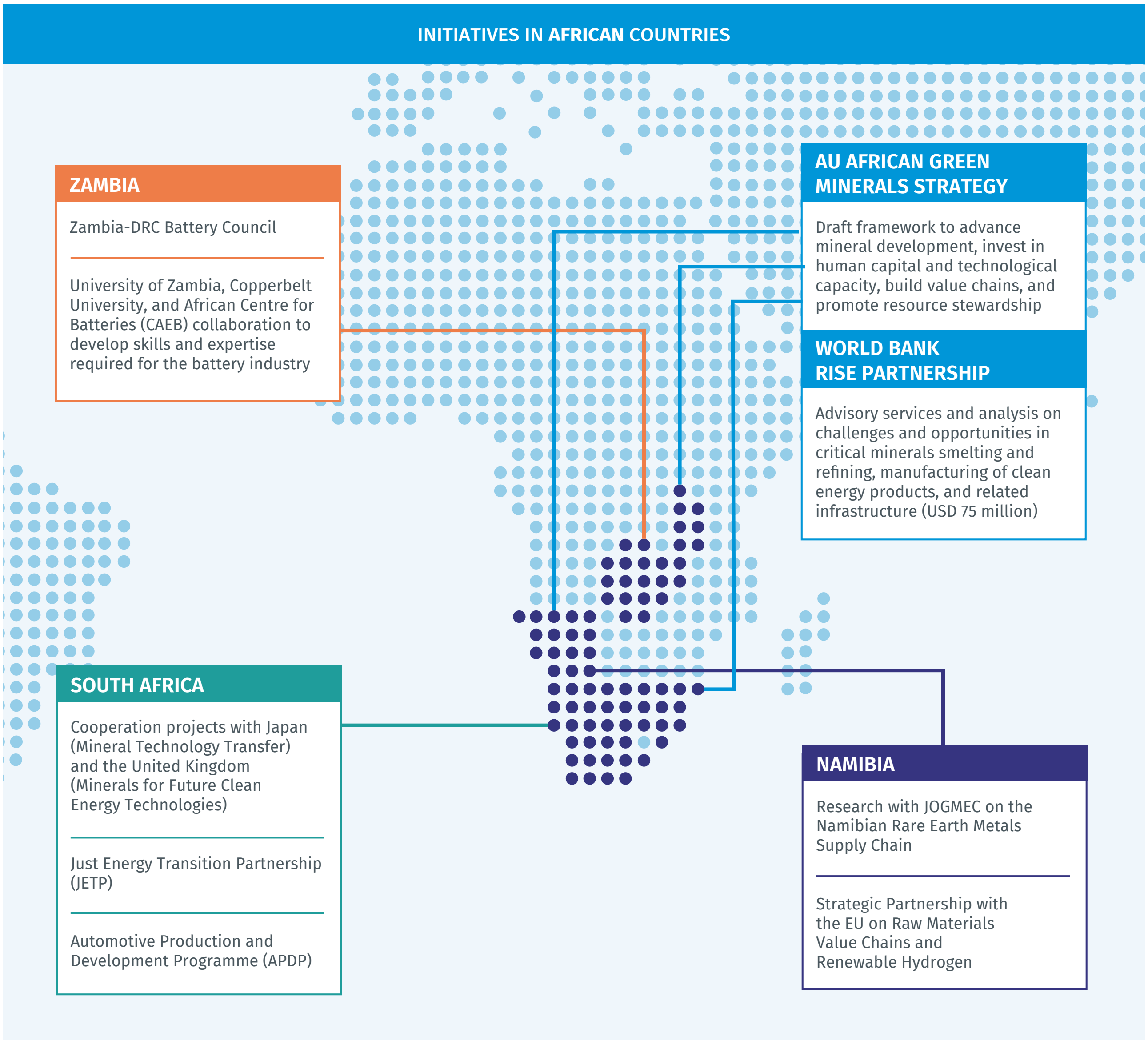


Figure 16. Selected initiatives in African countries: Namibia, South Africa, and Zambia (Phase 2)

Source: Prepared by the authors.

The **African Green Minerals Strategy (AGMS)** is a draft framework that aims to help African countries use their mineral resources in a sustainable and strategic way. Its goal is to revolutionise Africa's industrialisation based on minerals and to take advantage of the opportunities created by the transition to low-carbon economies. The AGMS is being developed by the **African Union** and other regional bodies and is built on four pillars: advancing mineral development, investing in human capital and technological capacity, building value chains, and promoting resource stewardship. The strategy aims to guide Africa in harnessing its green mineral resources strategically to drive industrialisation and strengthen the continent's position in shaping its own future, while also establishing a prominent role in the development of emerging green technologies.[125]

As part of the global **RISE Partnership** (see Section 3.1), geared toward increasing mid- and downstream value addition in critical minerals value chains, the **World Bank Group** is implementing a programme of advisory services and analytical work focused on Southern Africa from a regional lens as well as with country-specific components. The objective of the work is to identify challenges and opportunities for value addition through investment in critical minerals smelting and refining, in the manufacturing of clean energy products, and in related infrastructure. Notably, RISE includes South Africa and Zambia—along with the Democratic Republic of Congo, Mozambique, and Zimbabwe—as part of a **regional battery cluster**. (In Namibia, the Partnership's focus has been more on green hydrogen than on critical minerals value chains.) RISE's analytical work seeks to assess the potential for critical minerals output, demand, and value addition; human rights vulnerability; and logistics and energy bottlenecks. Country roadmaps outlining policy reforms and public investments are being developed based on this analysis in order to guide governments in policy development and identify their support needs; Zambia's roadmap is among the first ones underway. Several of the World Bank's preliminary findings and recommendations from its RISE work across Southern Africa are relevant to market and policy aspects of advancing technological innovation in the mid- and downstream segments:[126]

- While additional analysis is necessary to identify precise opportunities, there is untapped expansion potential for **mineral processing and scrap recycling in Southern African copper value chains**, particularly in Zambia.
- **Government subsidies** may be needed to foster innovation and R&D in mid- and downstream technologies, such as EV batteries; however, because of their risks of distorting competition and diversification, they should be transparent, limited in time, subject to monitoring, and conditioned to social and development co-benefits.
- **Local content policies focusing on technology transfers** can be effective, particularly when combined with **skills development** programmes and the facilitation of **joint ventures** between global and local actors.
- **Export restrictions on critical minerals** and **tariffs on the imports of components for producing clean energy technologies** (such as wind and solar products and EVs), though often regarded as useful measures to foster mid- and downstream development, fail to address infrastructure, skills, and investment climate constraints and can discourage upstream investment.
- **Special Economic Zones (SEZs)**, increasingly used in Africa to foster local processing and manufacturing, can be useful in unlocking knowledge and technology transfer. However, they are often costly, inadequate to address infrastructure bottlenecks, and insufficiently integrated into the surrounding economy.
- Developed countries, including notably in the G7, could provide **technical and financial assistance to facilitate technology transfer** for critical minerals value chains in Africa.

Namibia has drawn substantial interest from international organizations and from the European and Asia-Pacific regions. The Japan Organization for Metals and Energy Security (JOGMEC) has recently been in collaboration with the Ministry of Mines and Energy to further "Research on the Namibian Rare Earth Metals Supply Chain."[127] The joint statement agreed to by both parties promised to promote information sharing,

125) African Development Bank Group, *Approach Paper Towards Preparation of an African Green Minerals Strategy* (Abidjan: AfDB, December 2022), https://www.afdb.org/sites/default/files/documents/publications/approach_paper_towards_preparation_of_an_african_green_minerals_strategy.pdf.

126) World Bank Group, interview by the authors, 16 September 2024; World Bank, *The Rise Partnership: Securing the Green Energy Transition Is an Opportunity To Support Africa's Development, Update note for G7 Finance Ministers and Central Bank Governors* (Washington D.C., World Bank, May 2024), https://www.g7italy.it/wp-content/uploads/Annex-IV.-Update-note-on-the-Rise-Partnership_G7-FMCBG-23-25-May-2024-Stresa.pdf.

127) Japan Organization for Metals and Energy Security (JOGMEC), "JOGMEC Signed an agreement with African countries to secure critical minerals - Strengthening relationships with African countries through accompanying Minister Nisimura on a visit to Southern African countries," news release, 8 August 2023, https://www.jogmec.go.jp/english/news/release/news_10_00046.

technical cooperation, and the development of human resources and infrastructure.[128]

The Namibia–EU Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen (2022), backed by EUR 1 billion in investments from the EU, reinforces Namibia's commitment to attracting foreign investments that help enable technological advancement in critical mineral processing. Among the partnership's six pillars are capacity building, training, skills development, and cooperation on research and innovation along critical mineral value chains, including mineral knowledge and circularity.[129]

South Africa has specific initiatives catering to developments in mid- and downstream critical minerals value chains. The South Africa–Japan Cooperation on Mineral Technology Transfer focuses on sharing expertise to enhance South Africa's local capabilities in mineral beneficiation, showcasing the importance of technology transfer in critical minerals technology improvements.[130] Additionally, the United Kingdom–South Africa Partnership on Minerals for Future Clean Energy Technologies aims to foster investments in mining and processing, supporting the development of minerals essential for renewable technologies.[131]

The country also has initiatives for critical minerals in the context of the broader energy transition. For example, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has attracted substantial investments in renewable energy projects, bolstering the energy mix that supports the processing of critical minerals.[132] The South Africa Just Energy Transition Partnership (JETP) Investment Plan (2023–2027) introduces strategic investments from France, Germany, the United Kingdom, the United States, and the European Union to support South Africa in developing its critical minerals sector, while promoting the development of technologies for the extraction and processing of critical minerals in South Africa via technological expertise sharing.[133]

The **South African Automotive Production and Development Programme (APDP)**,[134] launched initially in 2013 and already in its Phase 2 stage, is an initiative that provides incentives for companies involved in manufacturing components that use critical minerals, such as EV batteries. Companies benefit from production rebates based on manufacturing volumes; import duty exemptions for critical components and equipment used in the production process; and tax relief and financial assistance for technology investments.

South Africa's uYilo e-mobility Programme is an initiative launched by the Technology Innovation Agency, a public organization under South Africa's Department of Science and Innovation. The programme is focused on advancing the country's electric mobility capabilities by developing key infrastructure and services. This includes establishing nationally accredited facilities for battery and materials testing, as well as initiatives for battery manufacturing, recycling, repurposing for second-life applications, and integrating vehicle-to-grid technology. The programme aims to support the growth of a comprehensive e-mobility ecosystem by addressing the entire lifecycle of batteries and promoting sustainable energy solutions.[135]

128) Japan, Ministry of Economy, Trade, and Industry (METI), *Joint Statement on Cooperation in the Mining Sector Between The Minister of Economy, Trade and Industry of Japan and The Minister of Mines and Energy of the Republic of Namibia* (Windhoek: METI, 8 August 2023), https://www.meti.go.jp/press/2023/08/20230808004/20230808004-6.

129) European Commission and Republic of Namibia, *Memorandum of Understanding on a Partnership on Sustainable Raw Materials Value Chains and Renewable Hydrogen Between the European Union Represented by the European Commission and the Republic of Namibia* (Brussels: European Commission, November 2022), https://single-market-economy.ec.europa.eu/system/files/2022-11/MoU-Namibia-batteries-hydrogen.pdf .

130) JOGMEC, "JOGMEC Signs a MOC with CGS, Republic of South Africa," news release, 13 May 2022, https://www.jogmec.go.jp/english/news/release/news_10_00003.html.

131) UK Department for Energy Security & Net Zero (UK DESNZ), *UK and South Africa Working in Partnership on Minerals for Future Clean Energy Technologies* (London: UK DESNZ, 23 November 2022), https://www.gov.uk/government/publications/uk-south-africa-joint-statement-on-partnering-on-minerals-for-future-clean-energy-technologies/uk-and-south-africa-working-in-partnership-on-minerals-for-future-clean-energy-technologies.

132) South Africa, Renewable Energy Independent Power Producer Procurement Programme (REIPPP), https://www.iea.org/policies/5393-renewable-energy-independent-power-producer-programme-reippp.

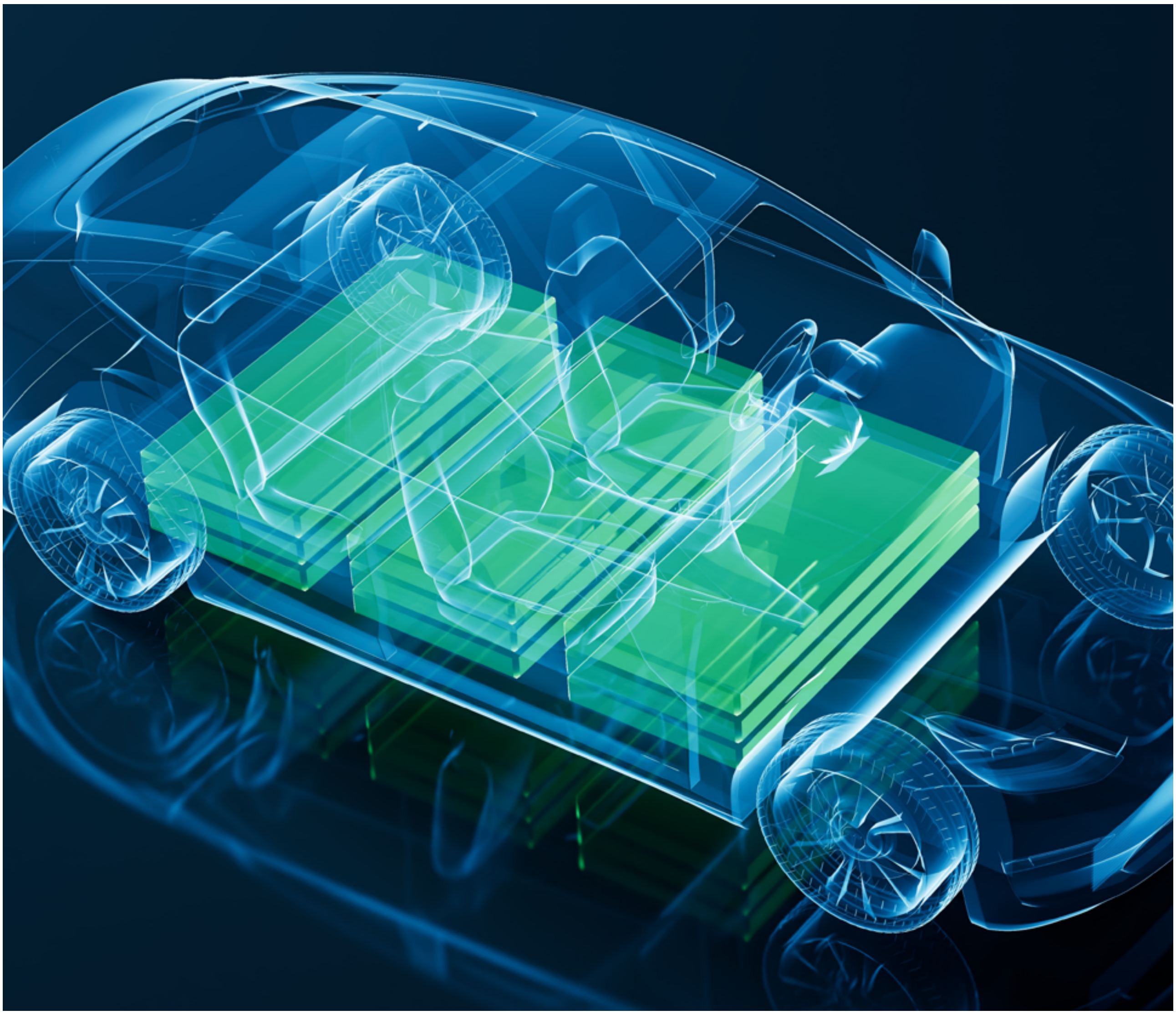
133) Presidential Climate Commission Towards a Just Transition, *Just Energy Transition Investment Plan for South Africa* (Pretoria: Presidential Climate Commission, November 2022) https://www.climatecommission.org.za/south-africas-jet-ip.

134) "Automotive Production Development Programme (APDP)," South African Revenue Service, https://www.sars.gov.za/customs-and-excise/registration-licensing-and-accreditation/automotive-production-and-development-programme-apdp.

135) "Welcome to uYilo," uYilo, https://www.uyilo.org.za.

In May 2022, **Zambia** signed a bilateral agreement with the Democratic Republic of Congo (DRC) to establish the **Zambia-DRC Battery Council**, with the goal of developing EV battery production. This initiative will be carried out across two special economic zones, creating a distinctive cross-border arrangement aimed at advancing the EV and battery industry in the region.[136]

In 2022, the **African Centre for Batteries** (CAEB) (headquartered in DRC) launched a collaboration with the **University of Zambia** and **Copperbelt University**, aiming to develop the skills and expertise required for the battery industry. Its mission is to support the growth of a competitive battery, EV, and renewable energy supply chain in Africa. To achieve this, CAEB is partnering with industry to identify research priorities and workforce needs. It is also designing Master's and PhD programmes focused on these areas to foster research and cultivate advanced human capital in the fields of energy storage, electric mobility, and sustainable technologies.[137]



136) "Zambia and DRC Sign Cooperation Agreement to Manufacture Electric Batteries," UNECA, https://www.uneca.org/stories/zambia-and-drc-sign-cooperation-agreement-to-manufacture-electric-batteries.

137) African Development Bank Group, *Approach Paper Towards Preparation of an African Green Minerals Strategy* (Abidjan: AfDB, December 2022), https://www.afdb.org/sites/default/files/documents/publications/approach_paper_towards_preparation_of_an_african_green_minerals_strategy.pdf.

Financial Delivery Mechanisms

During Phase 2, in addition to global-level mechanisms (Section 3.1), the analysis focused on regional and national mechanisms identified as potentially or practically effective in facilitating technological innovations in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia. This section focuses on qualitative data to provide a contextual understanding and detailed perspectives on the challenges and opportunities within the funding ecosystem, as well as on quantitative data, where available (see Table 10).

TABLE 10. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
Africa	Sustainable Energy Fund for Africa (SEFA) (AfDB)	Finance for governments and technical assistance grants for public and private entities	USD 95 million	SEFA 1.0: 2011–2020 SEFA 2.0: 2021–2030
	Green Investment Programme Africa (GIPA) (AfDB)	Investment in low-carbon projects by MSMEs	Not specified	2023–2033
	Youth Entrepreneurship and Innovation Multi-Donor Trust Fund (AfDB)	Technical and financial support to youth- and women-led startups and SMEs	USD 40 million	2017–2025
	Innovation & Entrepreneurship Lab (AfDB)	Incubator and financial support for startups	USD 9.5 million	2019–2025
	Africa Circular Economy Facility (ACEF) (AfDB)	Circular economy policy support for governments, business support for startups and SMEs	USD 4.3 million	2022–2026 with possibility of extension
Namibia	Namibia Industrial Development Agency (NIDA)	Financing mechanism for government-identified priorities in the industrial sector	Not specified	Not applicable
	Development Bank of Namibia (DBN)	Funding for renewable energy projects	Not specified	Not applicable
	Bank Windhoek's Sustainability Bond	Partly allocated towards renewable energy projects	USD 23.1 million	Annual; first tranche was in 2021
	Roadmap for the EU–Namibia strategic partnership on sustainable raw materials value chains and renewable hydrogen	Turning the Port of Walvis Bay into a critical minerals hub for processing and refining	USD 1.1 billion	2021–2027
South Africa	South Africa's Industrial Development Corporation's (IDC) Beneficiation Strategic Business Unit (SBU)	Funding for businesses processing critical metal products to expand their production capacity	From USD 60,000 to 60 million per business	Not applicable
	Development Bank of South Africa's (DBSA) Renewable Energy Independent Power Producer Procurement Programme (REIPPP)	Senior debt to renewable energy projects	USD 1 billion	Seventh Bid Submission Phase ended April 2024
	DBSA Climate Finance Facility (CFF)	Green bank for climate change infrastructure projects	USD 110 million	Launched 2019, 5-yr implementation period, 20-year lifespan

TABLE 10. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in Namibia, South Africa, and Zambia (continued)

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
 **South Africa**	DBSA Embedded Generation Investment Programme (EGIP)	Funding for local innovation in PV and wind energy generation, especially for Black-owned businesses	USD 200 million	Launched in 2019, no definitive end date
	DBSA Green Fund	Funding of up to USD 1.5 million for project preparation and technical support, and USD 4 million for investment	USD 63 million	Launched in 2012, no definitive end date
 **Zambia**	Strategic partnership between the EU and Zambia (Global Gateway)	Funding for projects involving local value addition and technology development in critical minerals value chains	Not specified	2023–2030
	World Bank's Scaling Solar Initiative	Advisory services, contracts, financing, and insurance, enabling governments and utilities to transparently procure affordable solar power	USD 100 million	Launched 2015; ongoing; projects take 2 years
	Citizens Economic Empowerment Commission of Zambia (CEEC)	Pursues value chain development by investing in local industry, albeit mostly in the agriculture sector	Not specified	Ongoing; est. 2006

Source: Prepared by the authors.

The **African Development Bank (AfDB)**, Africa's largest MDB, has the mandate to foster sustainable development in the continent by providing technical assistance, policy advice, and financial support to infrastructure and other development-oriented projects. Besides some analytical work of relevance to the mid- and downstream segments of critical minerals value chains,[138] the AfDB manages funds that may be leveraged to finance technological innovation in these segments. According to estimates by one survey respondent from the AfDB, the Bank lends out between USD 0.5 and 1 billion to projects to develop, deploy, and scale up technological innovations in these segments. For example:

- The **Sustainable Energy Fund for Africa (SEFA)**, through concessional finance (financing, loans, and equity instruments) for governments as well as technical assistance grants for public and private entities, seeks to unlock private sector investments to improve energy efficiency through various technologies.[139]

- The **Green Investment Programme Africa (GIPA)** provides technical assistance for project preparation as well as financing (lines of credit, SDG-based guarantees, equity, and credit enhancements) to micro, small, and

138) Jerry Ahadjie, Fred Kabanda, Charles Nyirahuku, and Freda Opoku, "Strengthening Africa's Role in the Battery and Electric Vehicle Value Chain," *Africa Economic Brief* 14, no. 7 (26 April 2023), https://www.afdb.org/fr/documents/strengthening-africas-role-battery-and-electric-vehicle-value-chain-volume-14-issue-7.

139) "Sustainable Energy Fund for Africa," AfDB, https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa.

medium-sized enterprises (MSMEs) investing in low-carbon projects.[140]

- The **Youth Entrepreneurship and Innovation Multi-Donor Trust Fund** supports entrepreneurship by equipping women- and youth-led startups and SMEs with technical assistance in project preparation as well as financial support through grants, besides supporting governments in policy and regulatory reforms geared toward job creation and skills development, particularly for women and youth.[141]

- The activities of the AfDB's **Innovation & Entrepreneurship Lab** include entrepreneurial market analysis and networking, capacity building, and knowledge sharing; notably, it also works as an incubator and provides financial support for startups.[142]

- The **Africa Circular Economy Facility (ACEF)** supports national and multinational projects by providing circular economy policy support for governments as well as business development programmes for circular economy startups and small enterprises.[143]

Namibia has the potential for multiple financial delivery avenues. The Namibia Industrial Development Agency (NIDA), although never directly financing critical minerals operations, has funded various charcoal processing plants in the past, as well as a Free Economic Zone for industry and logistics.[144] Founded in 2018, the Agency looks to align with development projects such as the 5th National Development Plan, which identifies a lack of economies of scale in the mineral processing sector as a key challenge facing the country.[145]

The Development Bank of Namibia (DBN) is also a key financial delivery mechanism that has not yet broken into the mid- and downstream sectors of critical minerals value chains. Between the Ombepo Wind Farm, Omburu Photovoltaic Park,[146] and OLC Arandis Solar Energy plant,[147] their goals to develop infrastructure as well as environmental sustainability are clear.[148] DBN also partners with Andrada Mining, a sustainability-focused upstream stakeholder for the lithium value chain.[149] Another partner of Andrada Mining is Bank Windhoek, which just issued NAD 407 million (approx. USD 23.1 million) in their September 2024 Sustainability Bond. NAD 12 million (approx. USD 0.7 million) of this bond was allocated to renewable energy.[150]

As seen in Section 3.2, Namibia's policy and regulatory frameworks are moving towards value-addition policies for the critical minerals sector. Thus, although the mid- and downstream sectors of the critical minerals value chains have not been an attractive investment area so far, large investors like NIDA, DBN, and Bank Windhoek may look to invest in the near future.

The EU, for instance, is already working on a proposal: one year after the aforementioned Namibia–EU Strategic Partnership was signed, the two parties met in Brussels to discuss an expansion of the Port of Walvis Bay into a key critical minerals hub.[151] This decision was popular with industry stakeholders such as the lithium processing company Lepidico, as it would no longer have

140) "Green Investment Programme Africa," AfDB, https://www.afdb.org/en/topics-and-sectors/initiatives-and-partnerships/green-investment-program-africa.

141) "The Youth Entrepreneurship and Innovation Multi-Donor Trust Fund," AfDB, https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/jobs-for-youth-in-africa/the-youth-entrepreneurship-and-innovation-multi-donor-trust-fund.

142) "The African Development Bank's Innovation & Entrepreneurship Lab," AfDB, https://www.afdb.org/en/documents/african-development-banks-innovation-entrepreneurship-lab.

143) "Africa Circular Economy Facility," AfDB, https://www.afdb.org/en/topics-and-sectors/topics/circular-economy/africa-circular-economy-facility-acef.

144) "NIDA Flagship Interventions 2020–2025," Namibia Industrial Development Agency (NIDA), https://www.nida.com.na/nida-flagship-interventions.

145) National Planning Commission of Namibia, *Namibia's 5th National Development Plan (NDP5)* (Windhoek: National Planning Commission, May 2017), https://www.npc.gov.na/national-plans/national-plans-ndp-5.

146) Development Bank of Namibia (DBN), *Prospectus 2021/22* (Windhoek: DBN, March 2022), 1–3, https://www.dbn.com.na/component/phocadownload/file/301-prospectus-2021-22.

147) "OLC Arandis Solar Energy," DBN, https://www.dbn.com.na/corporate-profile/showcase-projects?id=268:olc-arandis-solar-energy&catid=14.

148) "Goals of Development Finance," DBN, https://www.dbn.com.na/corporate-profile/goals-of-finance.

149) "About Us," Andrada Mining, https://www.dbn.com.na/corporate-profile/goals-of-finance.

150) Bank Windhoek, "The Bank Windhoek Sustainability Bond Completes N$407 Million Allocation," news release, 19 September 2024, https://www.bankwindhoek.com.na/Pages/News/The-Bank-Windhoek-Sustainability-Bond-completes-N$407million-allocation.aspx.

151) European Commission, "Global Gateway: EU and Namibia Agree on Next Steps of Strategic Partnership on Sustainable Raw Materials and Green Hydrogen," press release, 23 October, 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_5263.

to look to other countries like the United Arab Emirates for midstream processes of minerals mined in Namibia. The EU is currently funding an upcoming study for the costs of development, but the CEO of Namibian Ports Authority estimated that an expansion would need around USD 2.1 billion.[152]

South Africa has a vast network of financial mechanisms for green projects, especially in the downstream segment of critical minerals value chains. **South Africa's Industrial Development Corporation (IDC)** is the main national mechanism providing funding for research and innovation in critical minerals. In June 2024, its Department of Mineral Resources and Energy and IDC launched their Junior Mining Exploration Fund, which aims to allocate USD 21.8 million towards emerging companies specialising in critical minerals, albeit mostly in the upstream sector.[153] The South Africa IDC also has a Mining, Metals, and Beneficiation Strategic Business Unit (SBU) that specifically funds processing critical metal products in order to expand their production capacity.[154] The funding ranges from ZAR 1 million to ZAR 1 billion (approx. USD 60,000 to 60 million) for existing or startup businesses.[155]

In addition to the IDC, the Development Bank of South Africa (DBSA) also helps fund projects related to sustainable economic and social infrastructure.[156] One of their sectors of focus is energy, deploying programmes such as the aforementioned REIPPP, Climate Finance Facility (CFF), and Embedded Generation Investment Programme (EGIP). Through the REIPPP, DBSA provided ZAR 17.5 billion (approx. USD 1 billion) in senior debt to renewable energy projects so far, making it the bank's keynote project in the sector.[157] The CFF, endowed with USD 110 million in 2015, follows a "green bank" model, lending capital to infrastructure projects that adapt to or mitigate climate change in Southern African countries.[158] The EGIP put out a call for projects relating to PV and wind energy generation in July 2021, looking to use its USD 200 million endowment to fund local innovation, especially for the empowerment of Black-owned businesses.[159] Finally, the DBSA manages a Green Fund—initiated by the Department of Forestry, Fisheries and Environment (DFFE) with USD 63 million in 2012—that provides up to USD 1.5 million to project preparation and technical support, and up to USD 4 million for investment funding.[160]

Zambia has investment programmes in partnership with international organizations to advance technological innovation in critical minerals value chains. The strategic partnership between the EU and Zambia aims to secure strategic and critical raw materials sustainably for both parties.[161] The partnership emphasises local value addition and developing technologies value chains within both countries' critical minerals value chains. The MoU was signed as part of the European Union's Global Gateway strategy, which aims to invest EUR 300 billion in public and private green initiatives between 2021 and 2027.[162]

In addition, Zambia's Industrial Development Corporation Limited (IDC) has engaged the support of the IFC in adopting the World Bank Group's Scaling Solar initiative.[163] Scaling Solar is a transparent and inclusive

152) "EU Unveils Roadmap for Port Infrastructure Support to Namibia," *The Maritime Executive*, 29 October 2023, https://maritime-executive.com/article/eu-unveils-roadmap-for-port-infrastructure-support-to-namibia.

153) "Regional Financial Institutions Bolster African Critical Mineral Value Chain," *Energy Capital & Power*, 10 October 2024, https://energycapitalpower.com/regional-financial-institutions-bolster-african-critical-mineral-value-chain.

154) "Promoting Entrepreneurship Through Building Competitive Industries and Enterprises Based on Sound Business Principles," Industrial Development Corporation Ltd. (South Africa), https://www.idc.co.za/mining-metals.

155) "IDC Support: Metals and Mining," Career Planet, https://careerplanet.co.za/metals-and-mining.

156) "About Us," Development Bank of South Africa (DBSA), https://www.dbsa.org/about-us.

157) "Energy," DBSA, https://www.dbsa.org/sectors/energy.

158) Convergence Blended Finance, *Design Grant Case Study: Climate Finance Facility* (Toronto: Convergence, June 2019), https://www.convergence.finance/api/file.

159) "The Embedded Generation Investment Programme," DBSA, https://www.dbsa.org/embedded-generation-investment-programme.

160) "Green Fund," DBSA, https://www.dbsa.org/solutions/climate-financing/green-fund.

161) European Commission and Republic of Zambia, *Memorandum of Understanding on a Partnership on Sustainable Raw Materials Value Chains Between the European Union Represented by the European Commission and the Republic of Zambia* (Brussels: European Commission, October 2023), https://single-market-economy.ec.europa.eu/system/files/2023-11/MoU_CRM_EU-Zambia_26_10_2023_signed.

162) "Global Gateway," European Commission, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/stronger-europe-world/global-gateway_en.

163) "First Scaling Solar Project Ready for Development," Scaling Solar, World Bank Group, https://www.scalingsolar.org/first-scaling-solar-project-ready-for-development/#toggle-id-6.

approach that facilitates the development of privately owned, utility-scale solar PV projects in sub-Saharan Africa. It offers advisory services, contracts, financing, and insurance, enabling governments and utilities to transparently procure affordable solar power.[164]

Lastly, with the increase of FDI into Zambia, the government instituted a National Local Content Strategy aimed at ensuring that technology transfer and local employment come alongside foreign investment.[165] This strategy was created in partnership with the Citizens Economic Empowerment Commission of Zambia (CEEC), which pursues value chain development by investing in local industry, albeit mostly in the agriculture sector.[166] These governmental actions are in response to the vast amount of FDI Zambia receives, and will likely need to continue to scale up in order to translate foreign investment into local development.

Table 11 summarises the strengths and areas for improvement in Namibia, South Africa, and Zambia regarding their enabling environment (policy, initiatives, and financial delivery mechanisms) for technological innovation in critical minerals.

TABLE 11. Enabling environment in the deep-dive countries in Africa

	Strengths	Areas for improvement
AFRICA	• Mineral beneficiation strategies • Bilateral cooperation with developed countries (e.g. EU-Namibia Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen [USD 1.1 billion]; South Africa-UK Minerals for Future Clean Energy Technologies Partnership; partnership between Zambia and the Japan Organization for Metals and Energy Security) • Regional initiatives (e.g. African Green Minerals Strategy and DRC-Zambia Battery Council) • Industrial development agencies • Policies advancing SDGs [1 NO POVERTY] [9 INDUSTRY, INNOVATION AND INFRASTRUCTURE]	• Circular economy, recycling, and waste management policies • Power and logistics infrastructure constraints to industrial development • Government institutional capacity to build up and enforce regulatory frameworks • Policies advancing SDGs [5 GENDER EQUALITY] [12 RESPONSIBLE CONSUMPTION AND PRODUCTION]

Source: Prepared by the authors.

164) "Scaling Solar," Public-Private Partnership Resource Centre, World Bank Group, https://ppp.worldbank.org/public-private-partnership/library/scaling-solar.

165) Zambia Ministry of Commerce, Trade, and Industry (Zambia MCTI), *National Local Content Strategy 2018-2022* (Lusaka: Zambia MCTI, July 2018), https://www.zda.org.zm/wp-content/uploads/2020/09/National-Local-Content-Strategy.

166) "How CEEC Empowers You," Citizens Economic Empowerment Commission (CEEC), https://www.ceec.org.zm/how-ceec-empowers-you.

Innovators, Technologies, and Projects

This section presents findings on technological innovations in the mid- and downstream segments of critical minerals value chains throughout Africa, the innovators involved, and their projects, with a focus on the three Phase 2 countries: Namibia, South Africa, and Zambia. Data were collected through desktop-based research and stakeholder interviews. The information collected through stakeholder interviews provide the baseline for the analysis that follows, with additional references cited. Appendix C lists the names, affiliations, and stakeholder groups of those interviewed.

Amira Africa

Amira Global is a global non-profit organization with multiple offices and bases in various countries. Its Amira Africa section focuses on the full value chain in Africa and especially in South Africa. It is actively engaged in several developing countries in Africa, with a particular focus on Morocco and Zambia. In Morocco, Amira Africa is working on exceptional recycling initiatives aimed at collecting materials from diverse sources and converting them into valuable salts. In Zambia, Amira focuses on secondary resources, specifically through a pilot programme designed to extract cobalt from copper tailings and slag materials. The emphasis is on developing efficient techno-economic approaches for cobalt extraction from secondary sources, with innovative techniques such as molecular recognition technology being explored, despite their high costs.

Amira has successfully facilitated technology transfers, notably through collaborations with Australia's Curtin University, which introduced advanced instrumentation for gold monitoring and an Integrated Extraction Simulator that integrates various models used by Amira. Amira Africa's management team indicated that, while Zambia possesses capable researchers and partnerships with prominent institutions such as the Pan-African Decarbonisation Institute (PADI), discrepancies exist in the quality of research infrastructure across different African countries.[167] Amira strategically partners with universities from Australia, Canada, the United Kingdom, and the United States to leverage global resources and maximise research impact, ensuring a balanced approach that combines local capabilities with international expertise, and providing a path to transfer the technology and know-how to African countries.

Major sources of funding are from projects or private members. The Australian government also used to be an excellent sponsor of Amira Global, since their strategic interests are well aligned. However, Amira Africa's management indicated that most of the support from the Australian government aimed at primary resources and processes. Consequently, it is difficult to find funding for mid- and downstream projects, leading to a pivot toward nontraditional actors for funding opportunities such as private equity funds.

Various secondary extraction methods such as the hydrometallurgical routes are being considered to make the extraction of critical minerals from non-profitable sources more efficient and economically viable. There is a focus on technology beyond just equipment, that is, Integrated Extraction Simulator (IES) technology that integrates models to predict flowsheets and optimise routes. The overall transfer of technologies like instrumentation from Australia to African countries also enhances efficiency and innovation in Africa.

According to Amira Africa, despite the challenges of transitioning from purification to battery production, there is an emphasis on improving process control and mixing. Moving from exploration to plant commissioning in the mining industry can take a long time, depending on the regulations and laws in each country. Most funding for projects comes from private companies, especially in the mining sector. Although government funding has been received for multiple projects, securing additional support is becoming more difficult. Equity funding is being considered for major programmes, such as the Centre of Excellence in South Africa. Amira has set an ambitious goal to establish a Centre of Excellence in Mining, based in Africa. Early discussions with various agencies, academic institutions, and stakeholders have shown strong support for this initiative. While projects of this magnitude take time to materialise, Amira is receiving a high level of backing.[168]

167) "Project P1344," Amira Global, https://amira.global/projects/p1344-pan-african-decarbonisation-institute-padi.

168) "Centers of Excellence," Amira Global, https://amira.global/centers-of-excellence.

Mintek

Mintek, established in South Africa in 1934 as a national mineral research organization to support the mineral industry, is a global leader in metal and mineral innovation. Its products and services are used in 40 countries. It operates under the executive authority of South Africa's Mineral Resources and Energy department, and it is recognised as one of the world's leading technology organizations specialising in mineral processing, extractive metallurgy, and related fields.

PGMs are important critical minerals available in South Africa and Zimbabwe and play a significant role in overall Mintek activities. The majority of the R&D and studies conducted in Mintek are related to the PGM process, including up-, mid-, and downstream processes. Moreover, Mintek also works with the government to help artisanal miners.

Mintek's management indicated that most of its customers who are interested in mid- and downstream processes, including recycling, are from the EU and focus mainly on plastics. As a result, Mintek has an opportunity to provide the path for transferring the technology for this kind of activity into South Africa and other African companies. Mintek is involved with startups, projects from UNIDO and similar entities, and acceleration programmes supported by companies and government authorities.

Mintek is supporting startups at TRLs 4 and above on environmental subjects and technology developments, bringing them up to the point of revenue generation. However, according to Mintek, technology transfer from developed to developing countries is challenging. When it comes to technology and intellectual property, developed countries are often unsure about how valuable these technologies are.

On the SDG front, Mintek supports rural areas in several ways. It is an indirect mandate for Mintek to educate and lift up living conditions, helping populations in remote areas become more cognizant of environmental concerns, water recycling, and the need to tackle poverty.[169]

169) Mintek, *Impact Report 2023* (Randburg: Mintek, 2023), https://mintek.co.za/media/brochures/impact-report-2023.

Stellenbosch University

At Stellenbosch University, the focus on geometallurgy, particularly in manganese production, addresses significant challenges in the mining and metallurgical sectors of South Africa. The research principal investigator interviewed for this study is exploring the potential of low-grade manganese materials to facilitate South Africa's entry into the battery supply chain. Their ongoing work includes the development of process flow sheets, particularly hydrometallurgical techniques to produce desirable manganese sulphate from manganese tailings—a complex task given the intricacies of the production process.

Furthermore, battery recycling research was indicated as another significant project within the research group, with ongoing initiatives led by scientists and researchers. The project has recently transitioned into pilot stages following joint funding from South African and EU sources, with the South African Council for Scientific and Industrial Research (CSIR) mandated to promote battery recycling efforts within the country, in an initiative considered promising.[170] According to the interviewed scientists, although South Africa lacks a dedicated battery recycling facility, there is a growing trend of smaller companies developing containerised recycling plants. These innovations enable flexibility and low operational costs, allowing private sectors and small investors to efficiently recycle batteries on-site. However, regulatory hurdles, particularly regarding environmental assessments, are perceived to pose challenges for these ventures, as many companies struggle to meet compliance requirements due to limited resources.

170) World Bank Group, interview by the authors, 16 September 2024.

Cwenga Lib

The company Cwenga Lib represents South Africa's first lithium-ion battery recycling initiative, utilising modular technology designed for safe, efficient, and sustainable processing. Their recycling stations encompass the full recycling process, including battery disassembly, sorting, hydrometallurgical processing, and the recovery of valuable products such as lithium, cobalt, nickel, and other critical metals. At a TRL of 9, this project has recently been implemented and stands ready for commercial-scale operation, marking a significant advancement for midstream and downstream battery materials processing in the region. South Africa, already recognized as a leading producer of PGMs with established mid- and downstream infrastructure, now adds battery recycling to its portfolio of critical mineral processing capabilities. This development not only addresses the growing need for sustainable battery material supply chains but also strengthens the country's role in the circular economy for critical minerals. Its modular design allows for scalable deployment in various locations as demand increases, and positions Cwenga Lib's technology as a model in sustainable battery recycling for Southern Africa and potentially other regions.[171]

3.3 ASP COUNTRIES: INDIA, INDONESIA, AND TÜRKIYE

Stakeholders

Using the categorisation of stakeholders developed during Phase 1 (Section 2.1), the analysis in Phase 2 focused on mapping regional and national stakeholders with actual or potential roles in fostering technological innovation in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye (Table 12). Further analysis of their roles and relationships is presented in the following sections.

171) "Cwenga Technologies (Pty) Ltd.," Cwenga, https://www.cwenga.com; Cwenga, "Lithium-ion Battery Recycling with Cwenga Lib," 27 August 2024, https://www.cwenga.com/news/lithium-ion-battery-recycling-cwenga-lib.

TABLE 12. Selected regional and national stakeholders relevant to India, Indonesia, and Türkiye (Phase 2)

Stakeholder	India	Indonesia	Türkiye
Government bodies and regulatory agencies	• Ministry of Mines • Ministry of Steel • Ministry of Earth Sciences • Geological Survey of India • Ministry of Environment, Forests & Climate Change • Indian Bureau of Mines • Ministry of New and Renewable Energy • Ministry of Heavy Industries • Ministry of Science and Technology • Ministry of Commerce and Industry • Department of Industrial Policy and Promotion	• Ministry of Energy and Mineral Resources (MEMR) • Directorate General of Mineral and Coal • Ministry of Industry • Ministry of Transportation • Ministry of Research and Technology • Ministry of Investment	• Ministry of Energy and Natural Resources • Ministry of Industry and Technology • Ministry of Economy • Ministry of Environment, Urbanisation and Climate Change
Mining and metals companies	• National Aluminium Company Limited (NALCO) • Hindustan Copper Ltd. • Vedanta • Hindustan Zinc • Hindalco • Tata Steel		• PT Antam • PT Inalum • PT Krakatau Steel • PT–FI • Vale
Industry associations	• India Electronics Semiconductor Association • FICCI • CII • Confederation of Indian MSMEs in EDSM and IT (CIMEI)	• Mining Industry Indonesia (MIND ID) • Electric Mobility Ecosystem Association (AEML)	• Turkish Miners Association (TMD)
Renewable energy and recycling companies	• Ace Green Recycling	• Pertamina New & Renewable Energy • PT PLN Persero • Indonesia Battery Corporation (IBC) • Electrum	

TABLE 12. Selected regional and national stakeholders relevant to India, Indonesia, and Türkiye (Phase 2) (continued)

Stakeholder	India	Indonesia	Türkiye
Financial institutions	• Asian Development Bank (ADB) • Asian Infrastructure Investment Bank (AIIB)		
	• Invest India (public) • Indian Renewable Energy Development Agency (IREDA) (public) • Delhi Financial Corporation • Indian Institute of Technology Indore	• AC Ventures	• Industrial Development Bank of Türkiye (TKSB) • Small and Medium Enterprises Development Organization (KOGSEB) • Turkish Growth and Innovation Facility (TGIF) • Development and Investment Bank of Türkiye (TKYB)
Academic and research institutions	• Academic and research institutions	• National Research and Innovation Agency (BRIN) • Centre for Strategic and International Studies (CSIS Indonesia) • Indian Space Research Organisation (ISRO) • Central Electrochemical Research Institute (CSIR-CECRI), • Centre for Materials for Electronics Technology (CMET)	• General Directorate of Mineral Research and Exploration (MTA) • Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) • Rare Earth Elements Research Institute

Source: Prepared by the authors.

Policy, Legal, and Regulatory Frameworks

Phase 2 resulted in a deep-dive analysis of the policy, legal, and regulatory frameworks in India, Indonesia, and Türkiye. Figure 17 presents policy highlights for the region, and the country-specific narratives that follow present key details about each country's policies, laws, and regulations governing critical minerals extraction, processing, and refining; renewable energy; environmental protection and sustainability; technological innovation & R&D; industrial assembly and manufacturing; and circular economy and waste management; among others.

Appendix B provides a list of legal instruments and other references consulted for the preparation of the narratives. A policy tracker spreadsheet compiling over 370 policies, laws, and regulations by region and country, which served as the baseline for this analysis, is available upon request.

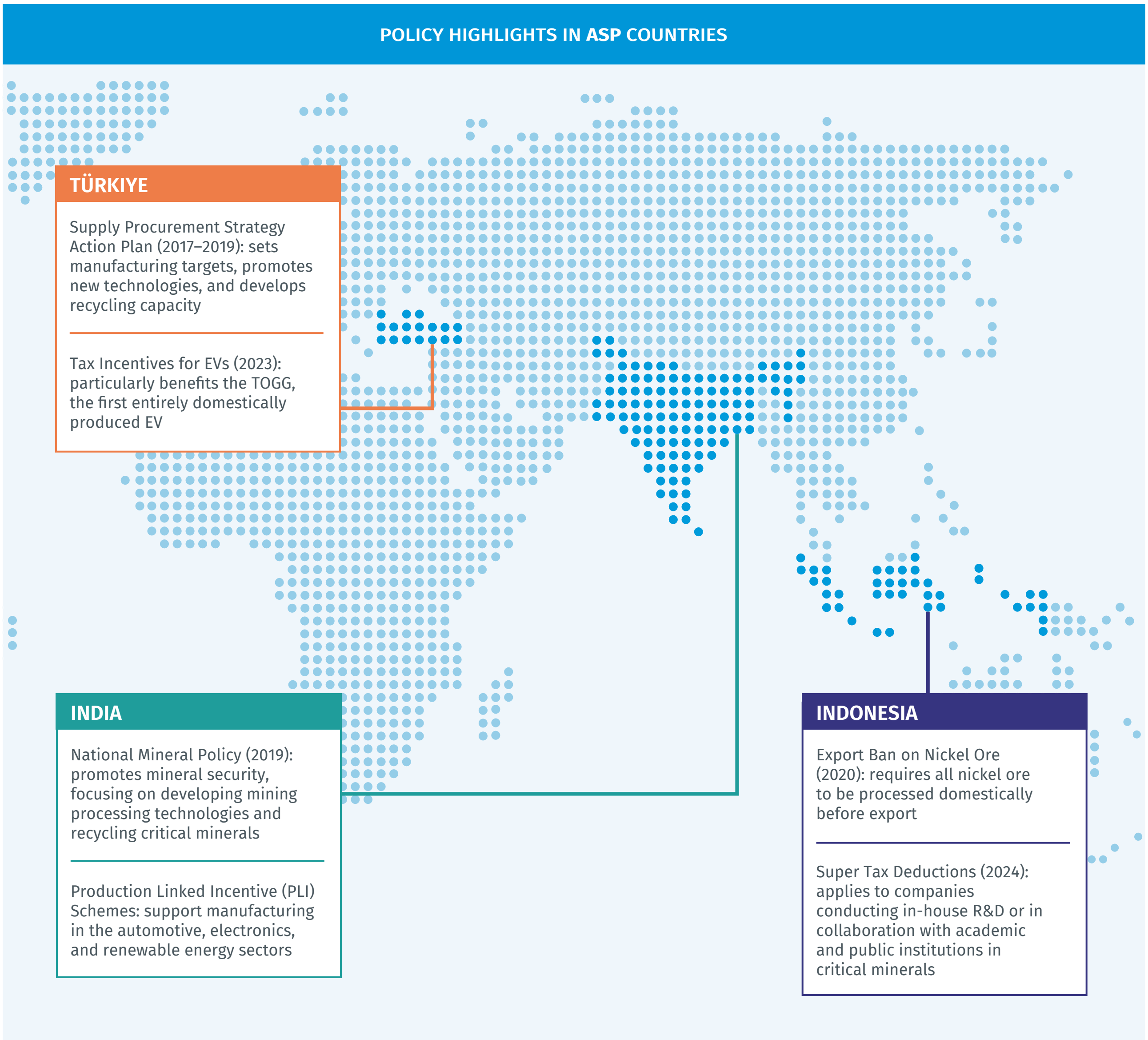


Figure 17. Policy highlights in ASP countries: India, Indonesia, and Türkiye (Phase 2)

Source: Prepared by the authors.

INDIA

India's identification of 30 strategically important critical minerals is a step towards the country's efforts towards mineral security. In line with the government's "Make in India" initiative, the National Mineral Policy (2019) highlights the role of the mining sector in growing the manufacturing share of the country's economy. This will involve the development of mining processing technologies as well as processes for the recovery of critical metals through recycling. The policy requires all activities within the mining value chain to be undertaken within a comprehensive Sustainable Development Framework to ensure environmental, economic, and social considerations are integrated into decision-making.

The Mines Ministry and related government institutes are currently working to launch a critical mineral policy to drive domestic exploration and processing of critical minerals. This includes efforts to import mineral supplies and explore international mining and technology collaborations.

On the manufacturing front, the Production Linked Incentive (PLI) Schemes announced in 2020 aim to create national manufacturing champions and 6 million new jobs across 14 key sectors. Across automotive, electronics, advanced chemistry cell batteries, and renewable energy, many sectors within the scope of this scheme will involve R&D and midstream processing and downstream manufacturing of critical minerals. For example, the PLI's National Programme on High Efficiency Solar PV Modules supported by USD 616 million over five years, enables domestic manufacturers to build capacity, rewarding higher module efficiency and local material sourcing.

In 2024, India launched a new EV policy offering a range of new incentives linked to domestic value addition, supported by new manufacturing capabilities. State-level policies across India also support EV industry development through consumer demand, industry incentives, and infrastructure support, including capital subsidies and tax exemptions. Subsidies for industrial development are linked to geographic location to encourage EV manufacturers to invest in underdeveloped regions. For instance, The Special Economic Zones (SEZ) Act of 2005 and the SEZ Rules of 2006 govern Special Economic Zones in India, which also provide incentives and infrastructure to support manufacturing activities in the downstream segment of critical minerals value chains.

Further down the value chain, India's E-Waste (Management) Rules (2022) features an Extended Producer Responsibility (EPR) regime for e-waste recycling and recycling targets for Electrical and Electronic Equipment (EEE) producers, and controls and regulates the import of e-waste for disposal. Moreover, India's Battery-Waste Management Rules (2022) mandates the collection and recycling of EV batteries, increases recovery targets and the minimum use of domestically recycled materials, and requires producers to meet these targets or make financial contributions to a public fund.

INDONESIA

Mining Law No. 3/2020, which amends the 2009 mining law, aligns with the government's mission of stimulating downstream industrialisation and strengthens policies related to environmental management in mining business activities. This was further enhanced through Indonesia's Energy Ministry Decree regarding National Planning on Mineral and Coal 2022–2027, which instituted a strategic plan to serve as a guiding framework for sustainable resource management. The plan considers key factors, such as sustainability and environmental considerations, as well as technology development and economic growth.

In 2023, the Energy Ministry released a Decree Regarding Classification of the Critical Minerals Lists, identifying critical minerals based on potential supply disruptions where substitution options are limited. This exercise follows Indonesia's bans on unprocessed mineral exports. Government Regulation (GR) No. 4 (2009) required mineral products to be processed and refined domestically. Mining companies were allowed to export ore concentrates until 2017 as long as they met commodity-specific refining requirements, paid export duties, and committed to building smelters in the country. This regulation, among many others, contributed to the prohibition of the export of nickel ore, requiring nickel to be processed domestically before export. Restrictions were initially set based on ore concentrations, however, all exports have been banned since January 2020. The goal of this policy is to strengthen domestic midstream processing capabilities and capture economic value from the commodity supply chain, creating jobs and economic development. There are currently several nickel processing plants in Indonesia, where three plants started trial production in 2021.

The electric battery and EV sectors play a significant role in developing Indonesia's mid- and downstream segments of critical minerals value chains. The country has set a goal to become a top-three global producer of EV batteries by 2027 and create a domestic EV market, as stated at the 2023 National Coordination Meeting of Regional Heads. This includes a target to produce EV batteries with a total capacity of 140 GWh annually by 2030, accounting for 4–9% of global demand. Specific production targets across various EV types have also been set. The Ministry of Industry Plan for 2020/21 set a target of 400,000 BEVs by 2025, which was later followed by a 2030 target to produce 600,000 EVs. These targets, and domestic industrialisation goals more broadly, are enabled through financial incentives schemes, such as tax incentives to reduce the cost of electric LDVs and buses that include a share of domestic components or a five-year corporate income tax holiday for IDR 10 trillion (approx. USD 647 million) investments, among others.

However, under a 2023 local content decree, Indonesia has pushed the 40% local content requirement for EV development companies to 2026, from the earlier 2023 timeframe, which also delays the local content threshold increase to 70% from 2024 to 2027.

The Indonesian government has also pledged tax incentives for special economic zones (SEZs) in Indonesia to attract foreign investment and bolster industrial activity. These include a series of tax exemptions and corporate income tax allowances.

The Ministry of Finance has been rolling out Super Tax Deductions for companies that are conducting Research and Development in-house or in collaboration with academic and public institutions. The president-elect has focused Indonesia's National Research and Innovation Agency (BRIN) on the critical minerals sector, aligning with this priority of R&D.

Indonesia's downstream activity also includes launching e-waste policies to manage and capture the value of critical minerals in waste streams. The Governmental Regulation No. 27 of 2020 on Specific Wastes Management assigns the responsibility to manage electronic waste across regional governments, electronics producers, and waste processors. Producers are also required to understand waste generation prevention measures, including technological development. Moreover, since 2021, Indonesia has banned deep-sea tailings placement and requires all high-pressure acid leach (HPAL) facilities to use tailings dams or dry stacking methods to mitigate the environmental impact of mining.

TÜRKIYE

Mining Law No. 3213 of 1985 is the primary law that governs mining activities in the country. The Eleventh Development Plan (2019–2023) outlined the overarching objective for the sector to ensure security of critical raw material supply. The plan laid out several policies on critical minerals, such as research of these minerals as well as establishing production infrastructure of mines with high economic potential and critical raw materials. This plan was followed by the Ministry of Energy and Natural Resources's Strategic Plan 2019–2023, outlining policies for the development of the critical mineral supply chain. One of the key focus areas identified included technology development and energy and natural resources localisation. The plan identified several KPIs linked to achieving R&D goals, including the completion of the project for the detection of precious minerals in waste streams of mineral enrichment facilities.

Türkiye's National Energy Plan aims to increase the share of renewable energy in electricity generation to 64.7% by 2035. To meet industrialisation ambitions, the Supply Procurement Strategy Action Plan (2017–2019) highlighted an objective to define a policy to secure supply of critical raw materials. This included future manufacturing targets and the need for new technologies. The plan also envisaged the development of a recycling industry for critical raw materials to reduce import dependency and the evaluation of domestic recovery potential.

Initially announced in 2017, Türkiye's first domestically produced vehicle, the all-electric Togg or T10X, was launched in 2023, further increasing the country's industrial and infrastructure capacity. The government has provided several tax incentives to support the launch and financial sustainability of Togg, such as a special consumption tax reduction, exemptions from VAT and a 100% tax deduction regime.

Türkiye's participation in midstream clean energy and transport development includes membership in the Accelerating to Zero Coalition, where it has pledged to work towards achieving 100% LDV sales in 2040 with zero emissions. Under the global Drive to Zero MOU, Türkiye has also set a goal for 30% zero-emission vehicle sales in medium and heavy-duty categories by 2030 and 100% by 2040.

Initiatives

In addition to the global initiatives identified during Phase 1 (Section 2.1) and Phase 2 (Section 3.1), regional- and national-level initiatives were identified and evaluated with relevance for technological innovation in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye (see Figure 18). Mechanisms of a primarily financial nature are covered separately.

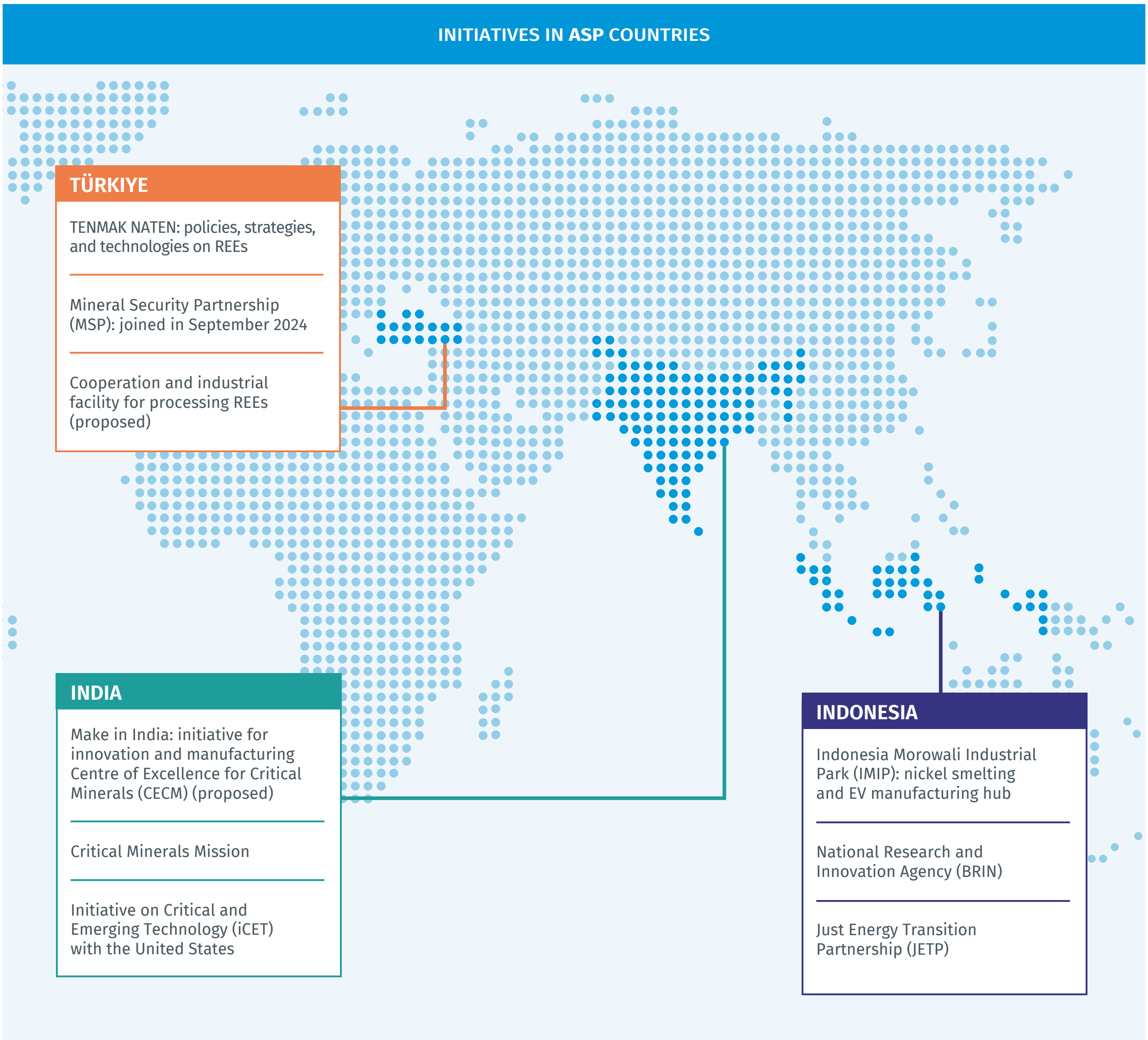


Figure 18. Selected initiatives in ASP countries: India, Indonesia, and Türkiye (Phase 2)

Source: Prepared by the authors.

The Indian government's **Make in India** initiative, launched in 2014, aims to position the country as a global manufacturing hub by promoting investment, innovation, and local skill development. Relevant to critical minerals, this initiative is focused on attracting foreign investment and fostering growth in industries such as electronics, automobile and aviation, which rely on critical minerals. The initiative encourages both domestic and foreign companies to engage in mining value chains, helping India become more self-reliant in the critical minerals supply chain and contributing to the development of downstream industries tied to these resources.[172]

The government is also considering establishing a **Centre of Excellence for Critical Minerals (CECM)** within the Ministry of Mines, which would, among other activities, support the development of the critical minerals value chain in the country.[173]

Another nascent initiative of potential relevance, announced in July 2024 by India's Finance Minister, is the proposed **Critical Minerals Mission**, geared toward producing and recycling critical minerals domestically and acquiring critical minerals assets from abroad. Its mandate includes technology development, workforce capacity building, a framework of extended producer responsibility, and a financing mechanism.[174]

Besides national-level initiatives, India is also promoting critical minerals value chains through bilateral partnerships. For example, the **United States–India initiative on Critical and Emerging Technology (iCET)**, promoting joint investment, R&D, and innovation, has expanded its scope to include critical minerals and REE refining and processing technologies.[175]

In line with the policy to prohibit nickel or exports in an attempt to promote mid- and downstream activities, the **Indonesia Morowali Industrial Park (IMIP)** was created through a joint venture between Chinese and Indonesian companies. The industrial complex began to be constructed in 2013, with an initial focus on the production of pig iron and stainless-steel. Since then, it has expanded into an integrated system of more than 50 factories, including nickel smelters and EV battery manufacturers, alongside power, port, and airport infrastructure. Highly important for the country in terms of economic growth, infrastructure development, and job creation, the industrial complex also poses notable social and environmental sustainability concerns and challenges, including water and air pollution, deforestation, and labour rights issues.[176]

Indonesia's Centre for Strategic and International Studies (CSIS Indonesia) is important to mention due to its prominence as an international and economic policy research institution in the country. Relating to critical minerals, CSIS Indonesia most recently analysed the 2022 Just Energy Transition Partnership (JETP) in a policy paper series.[177] The Centre also coordinates with BRIN and thus may have a role in the nation-wide R&D focus on critical minerals.[178]

The Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) Strategic Plan 2022–2026 defined policies for the development of critical minerals, particularly REEs. The Rare Earth Elements Research Institute (TENMAK NATEN), one of five TENMAK research institutes, supports the Ministry of Energy and Natural Resources in developing policies, strategies, and technologies on REEs.[179]

In early 2024, **Türkiye**'s energy and natural resources minister noted the country's intentions to increase cooperation for processing of REEs and to build an industrial facility to process 570,000 metric tons of REEs

---

172) India, "Make in India," https://www.mea.gov.in/Images/attach/Make_in_India_Initiative.pdf.

173) India, Ministry of Mines, *Critical Minerals for India: Report of the Committee on Identification of Critical Minerals* (New Delhi: Ministry of Mines, June 2023), https://mines.gov.in/admin/storage/app/uploads/649d4212cceb01688027666.pdf.

174) Dhanasree Jayaram & Ramu C. M., "India's Critical Minerals Strategy: Geopolitical Imperatives and Energy Transition Goals," *FIIA Briefing Paper* 386, 25 April 2024, https://www.fiia.fi/sv/publikation/indias-critical-minerals-strategy; Ankit Kumar and Arun Vishwanathan, "India's Critical Mineral Mission: Quo Vadis?" Observer Research Foundation, 21 August 2024, https://www.orfonline.org/expert-speak/india-s-critical-mineral-mission-quo-vadis; Government of India, "Budget 2024–2025: Speech of Nirmala Sitharaman, Minister of Finance," 23 July 2024, https://www.indiabudget.gov.in/doc/budget_speech.pdf.

175) White House, "Joint Fact Sheet: The United States and India Continue to Chart an Ambitious Course for the Initiative on Critical and Emerging Technology," media release, 17 June 2024, https://www.whitehouse.gov/briefing-room/statements-releases/2024/06/17/joint-fact-sheet-the-united-states-and-india-continue-to-chart-an-ambitious-course-for-the-initiative-on-critical-and-emerging-technology; White House, "FACT SHEET: United States and India Elevate Strategic Partnership with the initiative on Critical and Emerging Technology (iCET)," media release, 31 January 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/01/31/fact-sheet-united-states-and-india-elevate-strategic-partnership-with-the-initiative-on-critical-and-emerging-technology-icet.

176) Pius Ginting and Ellen Moore, "Indonesia Morowali Industrial Park (IMIP)," The People's Map of Global China, 22 November 2021, https://thepeoplesmap.net/project/indonesia-morowali-industrial-park-imip; Dwi Argo Santos, "Rise of IMIP: The Metamorphosis of Morowali's Forests into an Industrial Hub," *Jakarta Globe*, 31 January 2024, https://jakartaglobe.id/business/rise-of-imip-the-metamorphosis-of-morowalis-forests-into-an-industrial-hub; Business & Human Rights Resource Center, "Indonesia Morowali Industrial Park (IMIP)," 25 November 2021, https://www.business-humanrights.org/en/latest-news/indonesia-morowali-industrial-park-imip.

177) "About CSIS," CSIS Indonesia, https://www.csis.or.id/about-us; "Policy Paper Series: Just Energy Transition Partnership (JETP) Indonesia," CSIS Indonesia, July 2023, https://www.csis.or.id/publication/just-energy-transition-partnership-jetp-indonesia.

178) Centre for Strategic and International Studies, interview by the authors, 20 September 2024.

179) Türkiye, Turkish Energy, Nuclear and Mineral Research Agency, Strategic Plan 2022–2026, https://www.iea.org/policies/17646-turkish-energy-nuclear-and-mineral-research-agency-strategic-plan-2022-2026; "NATEN," TENMAK, https://www.tenmak.gov.tr/en/our-institutions/naten.html.

per year.[180] Türkiye's joining of the MSP initiative in September 2024 can be considered as a movement toward the increased collaboration signalled earlier in the year.[181]

Financial Delivery Mechanisms

During Phase 2, in addition to global-level mechanisms (Section 3.1), the analysis looked into regional and national mechanisms identified as potentially or practically effective in facilitating technological innovations in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye. This section focuses on qualitative data to provide a contextual understanding and detailed perspectives on the challenges and opportunities within the funding ecosystem, as well as on quantitative data, where available (see Table 13).

TABLE 13. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
ASP	Asian Development Bank (ADB) and potential facility for critical minerals value addition	Loans, grants, guarantees for downstream projects in EV battery manufacturing	Not specified	Not applicable
	Asian Infrastructure Investment Bank's (AIIB) Venture Capital (VC) Investment Programme for Green and Technology-Enabled Infrastructure	Small-scale VC funds to early-stage companies to support sustainable green technological innovation and innovative business models	USD 130 million	Est. December 2022, "three-year captive VC investment programme
India	Australia–India Strategic Research Fund (AISRF)	Grants for collaborative R&D projects, including in downstream processing, recycling, and tailings reclamation of critical minerals	Between USD 0.3 and 0.7 million	Round 15 application window: Jan–Mar 2023
	CSIR-National Institute for Interdisciplinary Science and Technology (NIIST)	Support for projects advancing critical minerals extraction and beneficiation techniques	USD 50 million	Announced Aug 2024
	Government initiatives Digital India and Startup India	Support for entrepreneurs with seed funding for research and innovation in multiple sectors, including critical minerals	Not specified	Digital India: July 2015 Startup India: January 2016
India and Türkiye	Minerals Security Partnership (MSP) Finance Network	Co-financing from development finance institutions and export credit agencies for projects in critical minerals value chains	Not specified	Announced 2022, no end date

180) Handan Kazancı, "Turkish Energy Minister Vows to Boost Rare Earth Material Cooperation," *Energy Terminal*, 9 January 2024, https://www.aa.com.tr/en/energy/general/turkish-energy-minister-vows-to-boost-rare-earth-material-cooperation/40146

181) Ragip Soylu, "Türkiye Joins Western Critical Minerals Club Amid EU–China Rivalry," *Middle East Eye*, 20 September 2024, https://www.middleeasteye.net/news/turkey-joins-western-critical-minerals-club-amid-eu-china-rivalry.

TABLE 13. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in India, Indonesia, and Türkiye (continued)

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
Indonesia	China's Belt and Road Initiative	Investments in infrastructure, including for critical minerals value chains	USD 7.3 billion	Announced 2013, could last until 2049
Türkiye	World Bank's Accelerating the Market Transition for Distributed Energy programme	Grants and loans for solar energy and battery storage projects, including by supporting SMEs to adopt new technologies	USD 1.01 billion	Launched March 2024
	Turkish Growth and Innovation Fund (TGIF), backed by an EUR 60 million commitment from the European Investment Fund (EIF)	Equity investment in innovative and technology-oriented businesses with high growth potential	USD 218 million	Est. 2016
	High Technology Investment Programme (HIT-30)	Incentives for battery production, semiconductor manufacturing, and other EV-specific technology.	USD 30 billion	2024–2030

Source: Prepared by the authors.

The **Asian Development Bank (ADB)**, Asia's largest MDB, provides loans, grants, guarantees, and other forms of financial support—besides technical and policy support—for sustainable development–oriented projects in developing country member states throughout Asia. India and Indonesia are among its largest beneficiaries; Türkiye is also an ADB member.[182] According to a survey respondent from the ADB, technological innovation in the mid- and downstream segments of critical minerals value chains is currently not one the Bank's areas of focus, and figures of funds annually invested or available for investment in projects in these segments are not available. However, they noted that some ADB-funded investments are underway, notably downstream, such as projects for manufacturing EV batteries in India. In a May 2024 publication, ADB stakeholders proposed that the ADB create a regional financial facility to provide seed funding for projects geared toward mid- and downstream value addition in critical minerals value chains, similarly to the World Bank's RISE Partnership.[183]

The **Asian Infrastructure Investment Bank (AIIB)** is an Asian MDB with the mandate to finance investments geared toward the development of physical and social infrastructure in developing countries throughout Asia, focusing on innovation and sustainable

182) Asian Development Bank (ADB), *Annual Report 2023: Accelerating Climate Action for Sustainable Development* (Manila: ADB, 2024), https://www.adb.org/multimedia/ar2023.

183) Cyn-Young Park and Anna Cassandra Melendez, "Building Resilient and Responsible Critical Minerals Supply Chains for the Clean Energy Transition," *ADB Briefs* No. 298 (Manila: ADB, May 2024), https://www.adb.org/publications/critical-minerals-supply-chains-clean-energy-transition.

184) "About AIIB," Asian Infrastructure Investment Bank (AIIB), https://www.aiib.org/en/about-aiib/index.html.

185) Seth O'Farrell, "The AIIB's 10 Biggest Beneficiaries," *FDI Intelligence*, 18 July 2023, https://www.fdiintelligence.com/content/data-trends/the-aiibs-10-biggest-beneficiaries-82718.

development.[184] India, Indonesia, and Türkiye are among the main recipients of AIIB financing.[185] Despite the infrastructure focus, interviewed stakeholders from the AIIB clarified that it could potentially invest in other infrastructure-related sectors in critical minerals value chains—such as steel, solar panel, and battery manufacturing—but that it is currently not in the Bank's strategic priorities to do so. They also mentioned that the AIIB makes indirect equity investments through funds focused on climate and energy transition themes, thereby exposing the Bank to critical minerals value chains and technologies including those of lithium and batteries. Noting that the information on specific projects is confidential, stakeholders referred to AIIB's Venture Capital (VC) Investment Programme for Green and Technology-Enabled Infrastructure, which dedicates USD 130 million through small-scale VC funds to early-stage companies to support sustainable green technological innovation and innovative business models.[186]

India's Australia–India Strategic Research Fund (AISRF), launched in 2024, is an example of India's focus on collaborative R&D. The fund offers grants between AUD 0.5 to 1.0 million (approx. USD 0.3 to 0.7 million). Within the mining sector, the Indo-Australian Science & Technology Fund (part of the AISRF and administered by DST in India) focuses on downstream processing, recycling, and tailings reclamation of critical minerals.[187]

Enabling the financial feasibility of critical minerals mid- and downstream activities is India's exemption of 25 critical minerals from custom duties, which ranged from 2.5–10% prior.[188] This policy arose from the Finance Minister's Union Budget for 2024–25, which was met with some scepticism due to a lack of continuation of the Electric Mobility Promotion Scheme (EMPS) 2024.[189] The EMPS expired on 31 July 2024, ending financial incentives that boosted the domestic EV market; however, the new exemption provides an indirect continuation of the effort to promote domestic EV manufacturing and downstream critical minerals activities.

As mentioned in Section 3.1, India joined the MSP, with its MSP Finance Network launching in September 2024. The network partners development finance institutions and export credit agencies with member governments in order to promote the financing of projects that will create more sustainable supply chains.[190] At the time of writing, the MSP Finance Network is less than a month old, so no tangible financing plans have been made, but it could become an important financing pathway for India.

Digital India (2015)[191] and **Startup India** (2026)[192] are government initiatives launched to improve internet infrastructure and supporting entrepreneurs that have consistently provided seed funding for research and innovation in multiple sectors, including critical minerals.

Finally, the Indian Ministry of Mines has sent letters to the CSIR-National Institute for Interdisciplinary Science and Technology (NIIST) and other research institutions requesting their support in advancing critical minerals extraction and beneficiation techniques. Reuters reports that the Ministry allocated nearly USD 50 million in funding, and that approved projects could receive up to 75% of the total funding.[193] The country's reliance on critical minerals imports means that even upstream-focused incentives have major implications for the mid- and downstream segments.

186) Asian Infrastructure Investment Bank, interview by the authors, 5 September 2024; "Multicountry: AIIB Venture Capital ("VC") Investment Program for Green and Technology-Enabled Infrastructure (the "VC Program")," AIIB, https://www.aiib.org/en/projects/details/2022/approved/Multicountry-AIIB-Venture-Capital-Investment-Program-for-Green-and-Technology-Enabled-Infrastructure.html; "AIIB Launches VC Program for Green, Technology-Enabled Infrastructure," *AIIB*, 9 February 2023, https://www.aiib.org/en/news-events/news/2023/AIIB-Launches-VC-Program-for-Green-Technology-Enabled-Infrastructure.html.

187) "Australia-India Strategic Research Fund – Collaborative Research Projects – Round 14," Australian Department of Industry, Science, and Resources, https://business.gov.au/grants-and-programs/australia-india-strategic-research-fund-aisrf.

188) "Budget 2024: Finance MInister Nirmala Sitharaman Announces Exemption of Custom Duties on Critical Minerals," *The Hindu*, 23 July 2024, https://www.thehindu.com/business/budget/budget-2024-finance-minister-nirmala-sitharaman-announces-exemption-of-custom-duties-on-critical-minerals/article68435971.

189) "Union Budget," India Ministry of Finance, https://www.indiabudget.gov.in; "Ministry of Heavy Industries Electric Mobility Promotion Scheme 2024," India Ministry of Heavy Industries, https://heavyindustries.gov.in/ministry-heavy-industries-electric-mobility-promotion-scheme-2024.

190) "Joint Statement on Establishment of the Minerals Security Partnership Finance Network."

191) "Digital India," India Brand Equity Foundation (IBEF), https://www.ibef.org/government-schemes/digital-india.

192) "About Startup India," India Department for Promotion of Industry and Internal Trade, https://www.startupindia.gov.in/content/sih/en/about-startup-india-initiative.html.

193) "India to Offer Incentives for Critical Minerals Extraction, Govt Source Says," *Reuters*, 13 August 2024, https://www.reuters.com/world/india/india-offer-incentives-critical-minerals-extraction-govt-source-says-2024-08-13.

Since **Indonesia's** ban on raw nickel exports was announced in 2019, investment has skyrocketed, especially in the form of FDI.[194] Much of this investment came from China—not only from individual companies, but as part of government-led projects. For example, in 2023, China's Belt and Road Initiative, a global infrastructure project, targeted Indonesia as its single largest recipient of investment with USD 7.3 billion.[195] China's Contemporary Amperex Technology (CATL), a supplier of Tesla, signed onto a nearly USD 6 billion project in 2022 with Indonesia Battery Corporation (IBC) and ANTAM which involves nickel mining and processing, EV battery manufacturing, and battery recycling.[196] FDI is not restricted to China; IBC also partnered with South Korea–based LG to secure a USD 9.8 billion investment for constructing an EV battery cell manufacturing plant.[197]

There is also the potential for venture capital to play a role in downstream segments in Indonesia. AC Ventures is a domestic early-stage technology venture fund that has a Climate and Sustainability focus, funding startups such as an EV Manufacturing firm (Maka Motors) and a solar energy company (Xuriya).[198] AC Ventures partnered with the Electric Mobility Ecosystem Association (AEML) to publish Indonesia's Electric Vehicle Outlook,[199] which looks to boost the country's appeal for investors in the downstream (citing FDI projects mentioned above).

With financing support from the World Bank, a USD 1 billion Accelerating the Market Transition for Distributed Energy programme offers grants and loans to expand **Türkiye**'s solar energy and battery storage sector, including by supporting SMEs to adopt new technologies.[200]

The Turkish Growth and Innovation Fund (TGIF) of EUR 200 million (approx. USD 218 million), backed by an EUR 60 million (approx. USD 65 million) commitment from the European Investment Fund (EIF), supported equity investment in innovative and technology-oriented businesses with high growth potential.[201] This has had an expansionary effect where funds backed by TGIF have

194) Gracelin Baskaran, *Diversifying Investment in Indonesia's Mining Sector* (Washington, DC: Center for Strategic and International Studies (CSIS), 11 July 2024, https://www.csis.org/analysis/diversifying-investment-indonesias-mining-sector.

195) Cristoph Nedopil, *China Belt and Road Initiative (BRI) Investment Report 2023* (Brisbane: Griffith Asia Institute, February 2024, 4, https://www.griffith.edu.au/__data/assets/pdf_file/0033/1910697/Nedopil-2024-China-Belt-Road-Initiative-Investment-report.

196) China's Contemporary Amperex Technology (CATL), "CATL Partners Up With Indonesia to Boost E-mobility With an Investment of Nearly 6 Billion USD," news release, 15 April 2022, https://www.catl.com/en/news/922.

197) Faisal Maliki Baskoro, "Indonesia Working With LG Consortium to Construct EV Battery Plant With $9.8B Investment," *Jakarta Globe*, 4 August 2023, https://jakartaglobe.id/business/indonesia-working-with-lg-consortium-to-construct-ev-battery-plant-with-98b-investment.

198) "Portfolio," AC Ventures, https://acv.vc/portfolio.

199) AC Ventures and AEML, *Indonesia's Electric Vehicle Outlook: Supercharging Tomorrow's Mobility* (Jakarta: AC Ventures, July 2023), https://acv.vc/wp-content/uploads/2023/07/Report-Indonesias-Electric-Vehicle-Outlook-Supercharging-Tomorrows-Mobility_NEW.

200) World Bank, "World Bank and Türkiye Sign Agreement for USD 1 Billion Program to Support Renewable Energy Expansion Efforts," press release, 16 May 2024, https://www.worldbank.org/en/news/press-release/2024/05/27/world-bank-and-t-rkiye-sign-agreement-for-1-billion-program-to-support-renewable-energy-expansion-efforts; World Bank Group, interview by the authors, 16 September 2024.

201) "Turkish Growth and Innovation Fund," European Investment Fund, https://www.eif.org/what_we_do/resources/tgif/index.

invested in 131 portfolio companies for a commitment of over EUR 1 billion (approx. USD 1.01 billion).[202] The EU is also investing EUR 12 million (approx. USD 13.4 million) into REEs, specifically. In April 2023, it launched a two-year project which bolstered research and development at institutions like Munzur University, and established a recycling facility at the General Directorate of Mineral Research Exploration.[203]

Beyond partnering with international organizations and foreign countries, Turkish policies provide incentives with the goal of becoming a global hub for EV research and production. For instance, the High Technology Investment Programme (HIT-30) includes USD 30 billion in incentives for battery production, semiconductor manufacturing, and other EV-specific technology. The Advance Loans Against Investment Commitment, which at the end of 2023 projected an allocation limit of TRY 300 billion (approx. USD 8.8 billion) over the next three years, has been very successful, with 238 technological and strategic project applications valuing TRY 1 trillion 258 billion (approx. USD 36.7 billion) being submitted as of July 2024.[204] Table 14 summarises the strengths and areas for improvement in India, Indonesia, and Türkiye regarding their enabling environment (policy, initiatives, and financial delivery mechanisms) for technological innovation in critical minerals.

TABLE 14. Enabling environment in the deep-dive countries in ASP

	Strengths	Areas for improvement
ASP	• Circular economy, recycling, and waste management policies • Tax incentives for technology development • Special Economic Zones (SEZs) for industrialisation and downstream activities • Cooperation with developed countries: Minerals Security Partnership • National financial mechanisms (e.g. Make in India; Indonesia Battery Corporation; Turkish Growth and Innovation Fund [USD 218 million]) • Policies advancing SDGs 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Regional cooperation and initiatives • Reliance on imported fossil fuel–based energy • Policies advancing SDGs 7 AFFORDABLE AND CLEAN ENERGY; 13 CLIMATE ACTION

Source: Prepared by the authors.

202) EIF, *Turkish Investment Initiative: Advised by the EIF*, (Luxembourg: EIF), https://engage.eif.org/eif-tii-turkiye/tgif.

203) Ragip Soylu, "Türkiye Joins Western Critical Minerals Club Amid EU-China Rivalry," *Middle East Eye*, 20 September 2024, https://www.middleeasteye.net/news/turkey-joins-western-critical-minerals-club-amid-eu-china-rivalry; "Enhancing the Rare Earth Elements (REEs) Research and Innovation Capacity of Türkiye," Republic of Türkiye Ministry of Foreign Affairs Directorate for EU Affairs, https://ab.gov.tr/enhancing-the-rare-earth-elements-rees-research-and-innovation-capacity-of-turkey_53434_en.

204) President of the Republic of Türkiye Investment Office, "President Erdoğan Unveils High Technology Investment Program," news release, 25 July 2024, https://www.invest.gov.tr/en/news/news-from-turkey/pages/president-erdogan-unveils-high-technology-investment-program.aspx; Central Bank of the Republic of Türkiye, "Press Release on Advance Loans Against Investment Commitment," press release, 23 November 2023, https://www.tcmb.gov.tr/wps/wcm/connect/77ff7c87-e889-4d20-b428-9f2738b2c4ee/ANO2023-48.

Innovators, Technologies, and Projects

This section presents findings on technological innovations in the mid- and downstream segments of critical minerals value chains throughout the ASP region, the innovators involved, and their projects, with a focus on the three Phase 2 countries: India, Indonesia, and Türkiye. Data were collected through desktop-based research and stakeholder interviews. The information collected through stakeholder interviews provide the baseline for the analysis that follows, with additional references cited. Appendix C lists the names, affiliations, and stakeholder groups of those interviewed.

Due to its proximity to China, with its massive battery recycling market, and Australia, with its strong mining and mineral processing technology hub, ASP developing countries appear to be more involved with the mid- and downstream processes of this segment. For instance, stakeholders noted that, with regard to technology transfer and innovation within Indonesia, there is a specific focus on the downstream sector, and some multinational companies are bringing in their technology. Companies from Australia with expertise in the full segment of critical elements processing are supporting this transfer of technology to be used in the recycling sector. Upstream technologies such as automation and sorting technologies are suggested to improve e-waste management and utilisation in mid- and downstream processes. This approach can help address the environmental issues from mining and extractive metallurgy, such as hazardous tailing dams and red mud waste from aluminium production.

Some stakeholders also noted that improving mid- and downstream processing of PGMs in the region could bring more attention to the available—but very low-grade—PGM resources in India. Availability of this segment can very well incentivise the attention to even upstream processes in this segment.

Global stakeholders also referred to notable technological developments in Indonesia. For example, IEA stakeholders highlighted the **high-pressure acid leaching process for midstream processing of nickel** in Indonesia. This process uses sulfuric acid to process nickel from low-grade nickel laterite ores. Implementing this technology in Indonesia was improbable and difficult to scale up 10 years ago. However, this process has been implemented by different companies in Indonesia. Even though this technology poses additional challenges in terms of water use and waste management, overall, the result of implementing this technology in Indonesia has been positive and resulted in emissions reductions due to the fact that it is a less energy intensive process compared to conventional processing technologies. Indonesia has also been implementing **efficient waste management practices** within critical minerals value chains. Although these processes do not involve the development of indigenous technological innovations, the country has successfully adopted and applied these practices domestically in recent years.[205] World Bank stakeholders, when discussing their ongoing engagement with the Indonesian government on scaling up nickel processing and battery manufacturing, emphasised that the country is taking initial steps to move from mineral extraction to the mid- and downstream segments, and that it is difficult to consider indigenous technological innovation at this very early stage.[206]

ACE Green Recycling

ACE Green Recycling is a forward-thinking battery recycling technology platform that offers sustainable solutions for managing end-of-life batteries.[207] The company's mission is to develop localised circular systems that enable the recovery and reuse of critical battery materials within the regions where battery waste is produced (see Figure 19). By focusing on retaining valuable resources within these areas, ACE Green Recycling aims to promote a more efficient and environmentally responsible approach to battery recycling, helping to reduce dependency on virgin materials and minimise the environmental footprint of battery disposal.

ACE focuses on recycling battery materials, particularly Lithium Nickel-Manganese-Cobalt Oxide (NMC), and Lithium iron phosphate (LFP) batteries, using room-temperature processes and non-sulfuric acid-based technology. ACE is currently based in India and has existing facilities there, as well as in Taiwan, Province of China, and is notably aiming to expand to South Africa, as well as Israel, South Korea, the United Kingdom, and the United States (Texas).[208]

205) IEA, interview by the authors, 6 September 2024.

206) World Bank Group, interview by the authors, 16 September 2024.

207) "Advancing Sustainable Global Electrification," ACE Green Recycling, https://www.acegreenrecycling.com.

208) Ace Green Recycling, interview by the authors, 19 September 2024.

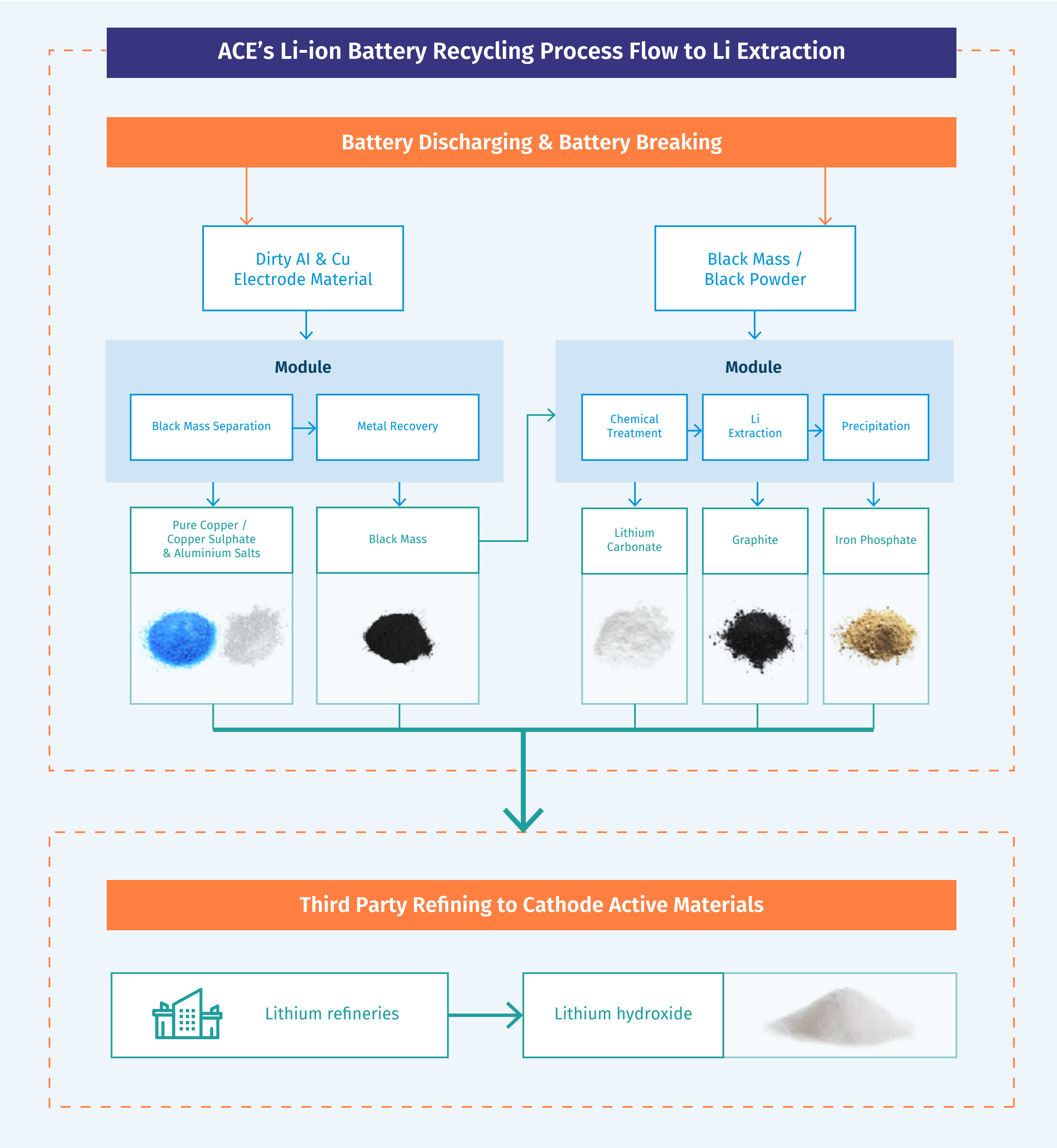


Figure 19. ACE's LithiumFirst™ process flowsheet for LFP batteries processing

Source: ACE Green Recycling.[209]

209) "Advancing Sustainable Global Electrification," ACE Green Recycling, https://www.acegreenrecycling.com;

Most chemicals required for ACE's operations are available in countries like Argentina, Brazil, Indonesia, South Africa, and Türkiye. However, some proprietary reagents are strictly controlled and managed by the company. Despite these limitations, the logistics were identified as not being a significant issue for the operation of ACE in developing countries. The majority of the company's R&D occurs in India, and it also has an anchor investor, Circulate Capital, which is an impact fund.[210]

Some of the challenges impacting the battery recycling industry include the transportation of hazardous materials (including end-of-life batteries) from one country to another, and the need for localised recycling closer to urban centres.[211] Recent studies demonstrate that in-country recycling significantly outperforms overseas recycling, primarily due to the substantial reduction in transportation costs. It has also been suggested that the development of a local recycling system is extremely beneficial, which can reduce transportation distances and costs, minimise safety risks associated with transporting end-of-life lithium-ion batteries, lower greenhouse gas emissions from transportation, and enhance the security of the local supply chain for critical minerals.[212] The contribution of this approach to SDGs is undeniable, especially in terms of its contribution to the local economy, employment, and poverty reduction. ACE rejected the solid extraction process due to its high water and emission disposal issues.

All batteries are recyclable, contrary to popular belief and the actual Lithium-ion battery recycling rate of 5%.[213] Stakeholders believe that the actual rates are higher than the reported numbers as the misconception arises from the fact that much of the recycling process is unreported as it occurs through unorganised channels. In India, informal recycling practices are common, where people extract materials from batteries using dangerous methods. While these practices may not be compliant, they do indicate that recycling is happening. One must also consider the economic viability of recycling batteries, as they contain valuable materials like gold and lead.

Touching upon the landscape of recycling technology, particularly in the context of lithium batteries, there is a need for innovation to adapt to changing battery chemistries, such as the shift from NMC to LFP. As such, ACE is focusing on LFP recycling for the next 10–15 years, developing local ecosystems in specific markets and developing countries.

Hindalco

Hindalco Industries Limited is an Indian multinational company and a flagship subsidiary of the Aditya Birla Group, primarily engaged in the production of copper, as well as aluminium. The company operates across the entire value chain, from mining and refining to manufacturing finished products, serving industries such as automotive, construction, and packaging. Hindalco has identified EVs as a high-priority growth area, given the significance of copper and aluminium as essential components in battery production. For Hindalco, environmental mitigation and energy efficiency remain key focus areas.

Hindalco plans to significantly expand its manufacturing capacity of fine-quality metals used in Lithium-ion and Sodium-ion cells in rechargeable batteries to serve the rapidly growing EV market and energy storage systems. The company is investing to build a new plant that will initially produce 25,000 metric tons of aluminium battery foil.[214] Hindalco is enhancing its digital capabilities and focusing on ESG transformation, with goals for net-zero emissions, zero waste to landfill, biodiversity preservation, and water positivity.[215] It has achieved the highest ESG score in the sector since 2020.

---

210) Ace Green Recycling, interview by the authors, 19 September 2024.

211) Xiaolu Yu, Weikang Li, Varun Gupta, Hongpeng Gao, Duc Tran, Shatila Sarwar, and Zheng Chen, "Current Challenges in Efficient Lithium-Ion Batteries' Recycling: A Perspective," *Global Challenges* 6, no. 12 (2022): 2200099, https://onlinelibrary.wiley.com/doi/10.1002/gch2.202200099.

212) Laura Lander, Tom Cleaver, Mohammad Ali Rajaeifar, Viet Nguyen-Tien, Robert JR Elliott, Oliver Heidrich, Emma Kendrick, Jacqueline Sophie Edge, and Gregory Offer, "Financial Viability of Electric Vehicle Lithium-ion Battery Recycling," *iScience* 24, no. 7 (2021), https://www.sciencedirect.com/science/article/pii/S2589004221007550.

213) Roy M. Harrison and Ronald E. Hester, eds. "Environmental Impacts of Road Vehicles: Past, Present and Future," *Royal Society of Chemistry* 44, 2017, https://books.rsc.org/books/edited-volume/675/Environmental-Impacts-of-Road-Vehicles-Past; Luqman Azhari, Sungyool Bong, Xiaotu Ma, and Yan Wang, "Recycling for All Solid-State Lithium-Ion Batteries," *Matter* 3, no. 6 (2020): 1845–1861, https://www.sciencedirect.com/science/article/pii/S2590238520305816.

214) HINDALCO, "Hindalco to set up battery foil manufacturing facility in Odisha to tap EV-market," press release, 12 December 2023, https://www.hindalco.com/media/press-releases/hindalco-set-up-battery-foil-manufacturing-facility-odisha-tap-ev-market.

215) "Becoming Water Positive," Aditya Birla Group, https://www.adityabirla.com/en/media/stories/world-water-day.html.

Tata Chemicals

With limited domestic resources for primary extraction of several critical minerals, India is focusing its efforts on developing a robust downstream processing infrastructure, targeting sectors like battery recycling, e-waste processing, and battery manufacturing and assembly. Tata Chemicals is at the forefront of this approach, with initiatives spanning lithium-ion battery recycling, recovery of critical minerals like lithium and cobalt, production of nickel hydroxide cake, and battery energy storage solutions. The company has also established partnerships with leading Indian R&D institutions, such as the Indian Space Research Organisation (ISRO), the Central Electrochemical Research Institute (CSIR-CECRI), and the Centre for Materials for Electronics Technology (CMET) to foster indigenous capabilities in battery material development, cell manufacturing, and advanced recycling technologies. At the Innovation Centre in Pune, Tata Chemicals is advancing research on multiple battery chemistries, cell design, and active material manufacturing. The company has also launched a new lithium-ion battery recycling line, the Battery Pack Engineering Centre, and is developing innovative cell and active manufacturing technologies to reduce dependency on virgin lithium mining and promote sustainable battery production.[216]

In line with its commitment to building a domestic battery supply chain, Tata Chemicals signed a memorandum of understanding (MOU) in June 2023 with the government of the Indian state of Gujarat to establish a lithium-ion cell manufacturing facility in Sanand. This factory, with an initial capacity of 20 GWh and potential for expansion, supports the state's vision to achieve 100% electric vehicle adoption and a 50% reduction in carbon emissions by 2030.[217]

Other companies in India are also expanding downstream operations to support clean energy goals. Amara Raja is producing batteries for energy storage and EVs,[218] while Attero is advancing e-waste recycling and lithium-ion battery management.[219]

216) "Lithium-ion, Dry Cell and Other Batteries," Tata Chemicals, https://www.tatachemicals.com/applications/lithium-ion-dry-cell-and-other-batteries.

217) Sumit Khanna, "India's Tata Group Signs $1.6 Billion EV Battery Plant Deal," Reuters, 2 June 2023, https://www.reuters.com/business/autos-transportation/indias-tata-group-signs-16-bln-ev-battery-plant-deal-2023-06-02.

218) "Amara Raja," Amara Raja, https://www.amararaja.com.

219) "Attero e-Waste Management," Attero, https://attero.in/e-waste-management.

PT QMB, PT QMB New Energy Materials, and GEM

PT QMB and PT QMB New Energy Materials, located in the China-Indonesia Comprehensive Industrial Park in Morowali, Central Sulawesi, represent a significant international collaboration in nickel, cobalt, and manganese processing for battery-grade products. With 63% Chinese ownership (primarily GEM, Green Eco Manufacture) and additional investment from Indonesian, Japanese, and South Korean entities, PT QMB is one example of Indonesia's intent to develop a domestic battery supply chain. The facility employs advanced High-Pressure Acid Leaching (HPAL) technology to process laterite ores, producing high-purity nickel-cobalt-manganese products such as mixed hydroxide precipitate (MHP) and nickel, cobalt, and manganese sulphate crystals (see Figure 20). With a TRL of 9, this large-scale operation, designed to produce 96,000 tons of nickel metal equivalent annually, serves as a foundation for midstream and downstream battery manufacturing. The nickel, cobalt, and manganese products will eventually be used domestically once Indonesia's first battery cell plant—currently under construction near Jakarta on Java Island—becomes operational.[220]

Both PT QMB and nearby Huayue Nickel & Cobalt (HNC) have leveraged Indonesia's established infrastructure, ore supply routes, and experienced labour force, especially in nickel pig iron (NPI) production. Smaller ventures like Lygend have similarly benefited from constructing facilities on brownfield sites with pre-existing NPI production setups. Together, these projects showcase the role of upstream processing capabilities in enabling downstream development of battery materials and clean energy technology supporting the country's strategy to position itself as a leading battery hub.[221]

PT QMB, GEM INDONESIA, HIGH PRESSURE ACID LEACHING TECHNOLOGY (HPAL) FOR NICKEL LATERITES PROCESSING

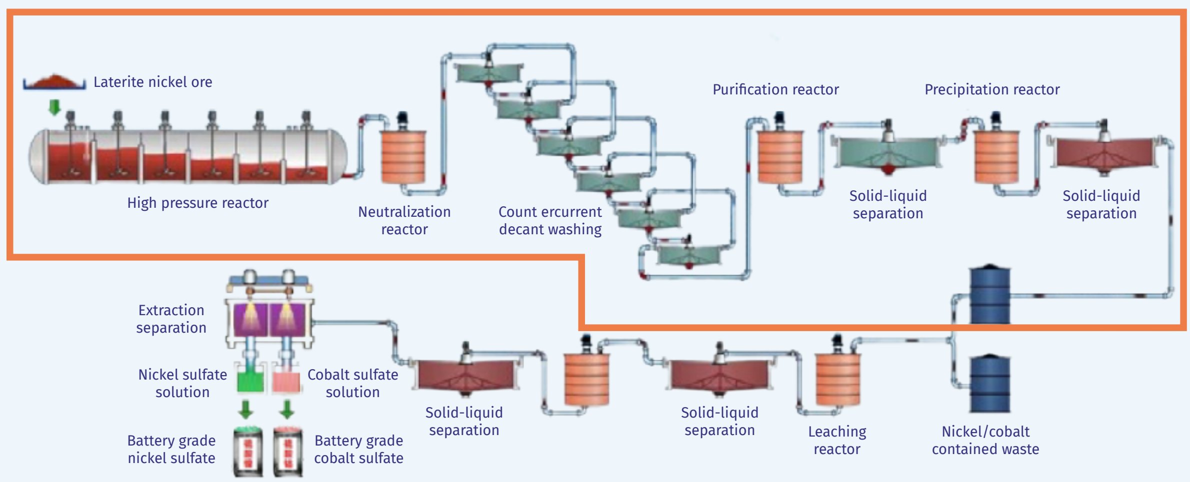


Figure 20. PT QMB, GEM Indonesia, High Pressure Acid Leaching Technology (HPAL) for nickel laterites processing

Source: PT QMB, GEM Indonesia.[222]

220) "QMB (PT QMB New Energy Materials)," QMB, http://en.gemindonesia.com/gsjs/index.aspx.

221) Isabelle Huber, "Indonesia's Nickel Industrial Strategy," *Center for Strategic and International Studies (CSIS), 8 December 2021*, https://www.csis.org/analysis/indonesias-nickel-industrial-strategy.

222) "HPAL Technology", http://en.gemindonesia.com/HAPLTechnology/index.aspx.

PT Vale Indonesia

PT Vale Indonesia (INCO.JK) plans to build a third high-pressure acid leaching plant named "SOA HPAL" with an annual output capacity of 60,000 metric tons of nickel metal in the mixed hydroxide precipitate (MHP) in Sulawesi at an estimated cost of approximately USD 2 billion. MHP, a key component for EV batteries, is increasingly valuable as Indonesia seeks to become a central hub for battery-grade nickel production. In addition to the planned SOA HPAL plant, Vale Indonesia is already constructing two HPAL facilities in Pomalaa and Sorowako, also located on Sulawesi Island. These ongoing projects are in partnership with Zhejiang Huayou Cobalt and will contribute significantly to Indonesia's nickel processing capacity to supply battery materials to the growing number of battery companies and aligns with the government's initiative to develop a robust domestic battery value chain, reducing reliance on raw material exports and maximising value-added processing within Indonesia.[223]

PT Freeport Indonesia

PT Freeport Indonesia commissioned the new Gresik Smelter & Refinery (majority owned by Indonesia) in 2024. This smelter uses Mitsubishi continuous smelter technology to process the copper concentrate produced at the PTFI mine site in Papua. This technology produces high-purity anode copper and is recognized to be environmentally friendly and economically efficient. The anode copper is then processed in the refinery using the ISA technology to produce LME Grade A (99.99% Cu) copper cathodes. Both technologies are at TRL 9. The smelter design capacity is processing 1.7 million metric tons of copper concentrate. The refinery can produce 650,000 tons of copper cathode and 50 to 60 tons of gold. The by-products, slag, anode slimes, copper slag, gypsum, copper telluride, and sulphuric acid will be used or further processed in Indonesia. This facility will have a significant impact on several SDGs. The Mitsubishi smelter meets the environmental regulatory limit of 280 ppm of SO_2 stack emission with a sulphur capture level of approximately 97%. Another new smelter may likely be built in Papua, close to the mine site. This new smelter is a major milestone for Indonesia to build mid- and downstream processing capabilities and is the result of the country's ban of exports of all raw minerals from June 2023.[224]

223) "About PT Vale Indonesia," PT Vale Indonesia, https://www.vale.com/indonesia/about-pt-vale-indonesia; "Indonesia Says Nickel Miner Vale to Build Another $2 bln HPAL Plant," Reuters, 18 March 2024, https://www.reuters.com/markets/commodities/indonesia-says-nickel-miner-vale-build-another-2-bln-hpal-plant-2024-03-18.

224) "Freeport Indonesia Launches $3.7 bln Gresik Copper Smelter to Meet Renewables Demand," *Reuters*, 27 June 2024, https://www.reuters.com/markets/commodities/freeport-indonesia-launches-37-bln-gresik-copper-smelter-2024-06-27; "Smelter," PT Freeport Indonesia, https://ptfi.co.id/id/smelter; "PT Freeport Indonesia, How We Operate: - PT Freeport Indonesia (PTFI) Currently Employs Two Mining Methods," PT Freeport Indonesia, https://ptfi.co.id/en/how-we-operate.

Kalyon PV Group

Kalyon Photovoltaic Solar Technologies Factory (Kalyon PV) of Kalyon Holding is a large vertically integrated facility, the first outside of China, consisting of production of high-purity silicon ingots, wafers, and solar cells followed by solar panel manufacture using established and innovative technologies (see Figure 21). This facility at TRL 8–9 began operation in 2020, has an onsite R&D centre, and has obtained quality, performance, and efficiency certificates from internationally recognized institutions for technology and solar PV modules. Kalyon Holding also has numerous Photovoltaic Panel Factory and Solar Power Plant investments in Türkiye and the world. Expected to generate clean, green power for two million households in Türkiye, where 20% of total power comes from solar energy. The country expects to eliminate at least 1.5 million tons of annual fossil fuel waste and harmful carbon emissions. Kalyon PV and other solar power investments underscore Türkiye's emergence as a leader in renewable energy.[225]

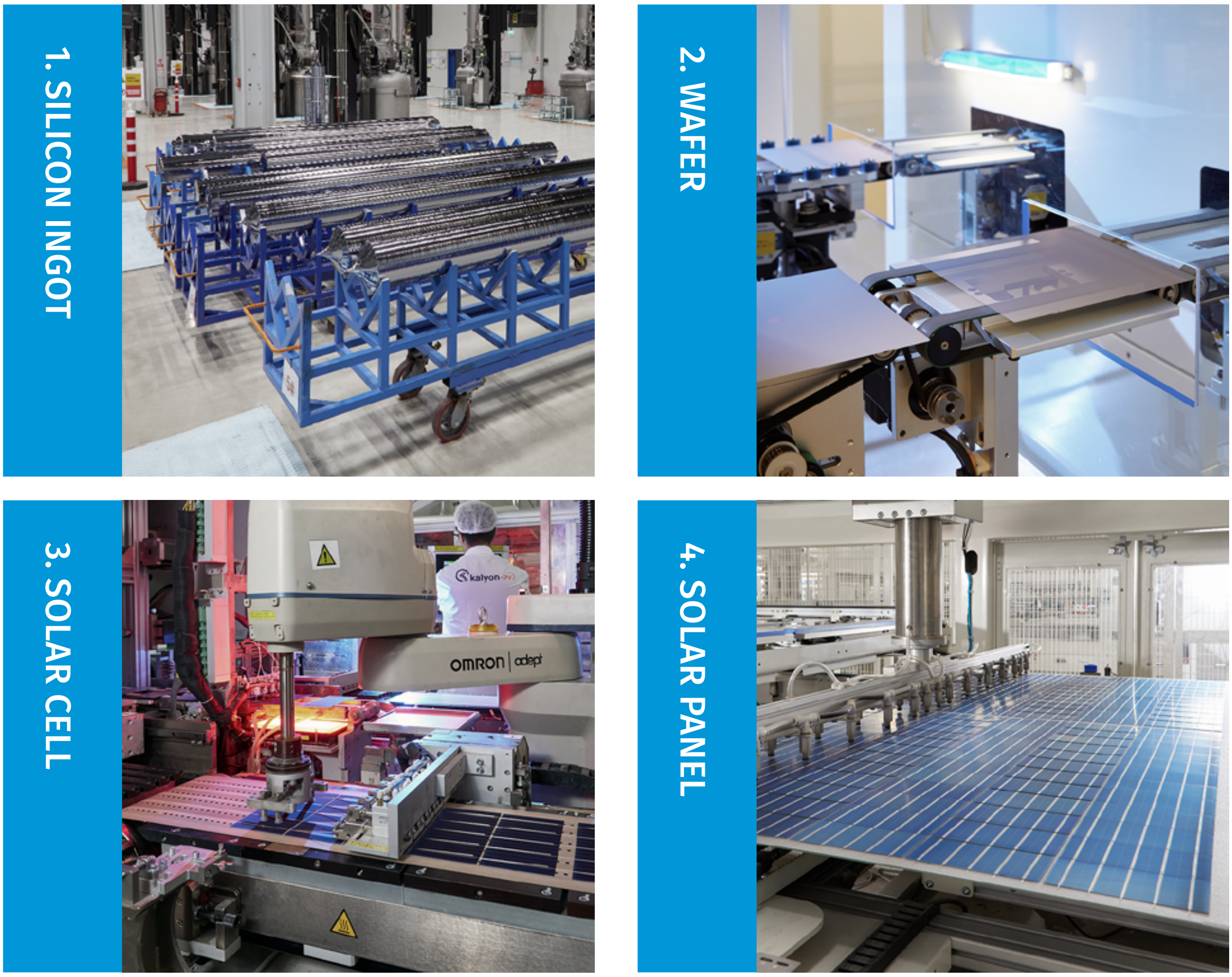


Figure 21. Kalyon PV facility consisting of production of silicon ingots, wafers, solar cells, and solar panels

Source: Kalyon PV of Kalyon Holding.[226]

225) "Energy of the Future: A Brighter World with Kalyon PV," Kalyon PV, https://kalyonpv.com/en.

226) "Our Integrated Factory," Kalyon PV, https://kalyonpv.com/en/our-integrated-factory.

3.4 LAC: ARGENTINA, BRAZIL, AND MEXICO

Stakeholders

Using the categorisation of stakeholders developed during Phase 1 (Section 2.1), the analysis in Phase 2 focused on mapping regional and national stakeholders with actual or potential roles in fostering technological innovation in the mid- and downstream segments of critical minerals value chains in Argentina, Brazil, and Mexico (Table 15). Further analysis of their roles and relationships is presented in the following sections.

TABLE 15. Selected regional and national stakeholders relevant to Argentina, Brazil, and Mexico (Phase 2)

Stakeholder	Argentina	Brazil	Mexico
Regional organizations	• Latin American Energy Organization (OLADE)		
Government bodies and regulatory agencies	• Ministry of Productive Development • Ministry of Mining • Ministry of Economy and Public Finance (Trust Fund for the Development of Renewable Energy) • Federal Mining Council (COFEMIN) • Argentinian Geological Survey (SEGEMAR) • National Lithium Roundtable • Ministry of Industry • Ministry of Strategic Affairs of the Nation • Ministry of the Environment and Sustainable Development	• Ministry of Economy • Ministry of Mines and Energy • Ministry of Science, Technology, and Innovation • Ministry of Development, Industry, Trade and Services • Council for Industrial Development (CNDI)	• Ministry of Economy • Ministry of Energy • Ministry of Finance and Public Credit • Ministry of Environment and Natural Resources • Mexican Geological Service • Federal Electricity Commission • National Commission for the Efficient Use of Energy
Mining and metals companies	• Y-TEC	• Vale • Rio Tinto • Baterias Moura • Sigma Lithium	• Lithium for Mexico (LitioMx)

TABLE 15. Selected regional and national stakeholders relevant to Argentina, Brazil, and Mexico (Phase 2) (continued)

Stakeholder	Argentina	Brazil	Mexico
Mining and metals companies		• Companhia Brasileira de Metalurgia e Mineração (CBMM) • Companhia Brasileira de Lítio (CBL) • AMG Lithium Brazil	
Industry associations	• Association of Metallurgical Industrialists of the Argentine Republic (ADMIRA)	• Brazilian Mining Institute (IBRAM)	• Mexican Mining Chamber (CAMIMEX)
Financial institutions	• Inter-American Development Bank (IDB) • Latin American Development Bank (CAF)		
		• Brazilian Development Bank (BNDES) • Funding Authority for Studies and Projects (FINEP)	• Nacional Financiera (NAFIN) • Banco Nacional de Obras y Servicios Públicos (BANOBRAS)
Academic and research institutions	• National Institute of Industrial Technology (INTI) • National Scientific and Technical Research Council (CONICET) • National Centre for Lithium Battery Development (CENBLIT)	• National Service for Industrial Training (SENAI) • Centre for Mining Technology (CETEM) • Brazilian Industrial Research and Innovation Company (Embrapii) • Instituto Tecnologico Vale (ITV)	• Institute of Electricity and Clean Energy • National Council on Science and Technology

Source: Prepared by the authors.

Policy, Legal, and Regulatory Frameworks

Phase 2 resulted in a deep-dive analysis of the policy, legal, and regulatory frameworks in Argentina, Brazil, and Mexico. Figure 22 presents policy highlights for the region, and the country-specific narratives that follow present key details about each country's policies, laws, and regulations governing critical minerals extraction, processing, and refining; renewable energy; environmental protection and sustainability; technological innovation & R&D; industrial assembly and manufacturing; and circular economy and waste management; among others.

Appendix B provides a list of legal instruments and other references consulted for the preparation of the narratives. A policy tracker spreadsheet compiling over 370 policies, laws, and regulations by region and country, which served as the baseline for this analysis, is available upon request.

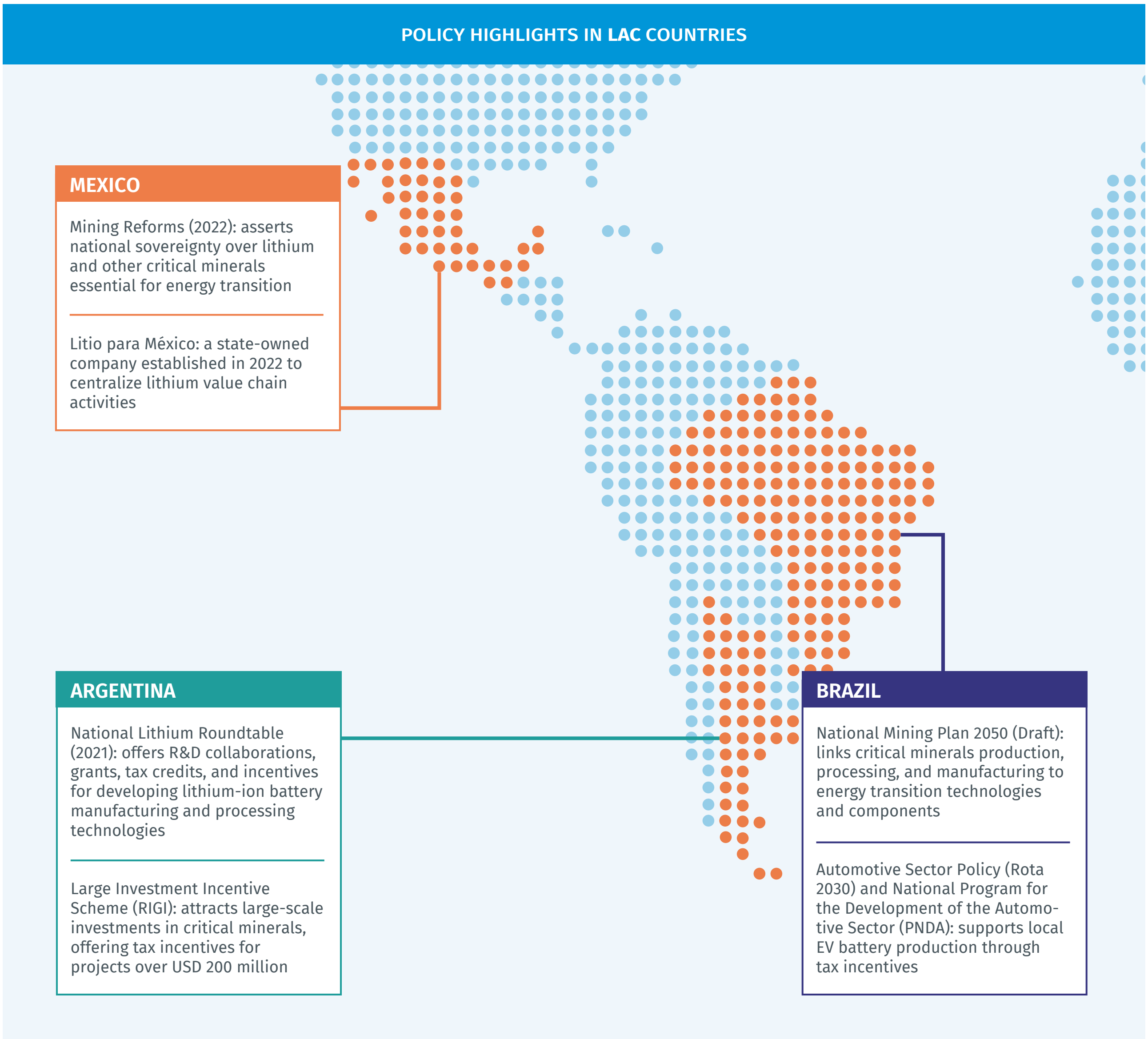


Figure 22. Policy highlights in LAC countries: Argentina, Brazil, and Mexico (Phase 2)

Source: Prepared by the authors.

ARGENTINA

The Mining Code (Law No. 1919/1886), significantly amended through Law No. 24,196 in 1993, provides the foundational legal structure for mining activities across the value chain in Argentina, including processing activities. It incentivises the development of mining projects and processing plants through various measures such as tax benefits.

Resolution No. 47/2020 approved the Mining Strategic Plan. This plan aims for the rational use of mining resources to benefit the socioeconomic development of the country. The plan sets forth seven main goals: promoting sustainable development and investment in mining; supervising the fiscal cost of mining promotion policies versus actual investment development;

transforming mining activities into opportunities for the integral development of communities by strengthening the whole mineral value chain; effectively communicating the potential of mining within the national productive development model; promoting access to information and transparent management of the sector; contributing to environmental preservation as mandated by Law No. 24.585, which focuses on environmental protection in mining activities across the value chain; and fostering governance and strengthening international, regional, provincial, and local commitments within the mining sector.

Law No. 24.585, which amended the Mining Code in 1995, incorporates environmental provisions. This law mandates that all entities involved in mining activities (including the beneficiation of critical minerals) present an Environmental Impact Assessment (EIA) before initiating any activity. This assessment must comply with specific requirements at different stages of mining. The law also prescribes that any environmental damages caused by mining activities must be mitigated or restored by the responsible party.

Law No. 27.191, primarily focused on renewable energy, indirectly impacts the processing of critical minerals by promoting the use of renewable energy sources in industrial processes. This law provides various tax incentives, including accelerated depreciation and VAT reimbursement, which could benefit processing facilities powered by renewable energy.

The National Strategic Plan for Mining Development (2021) outlines the government's strategy to integrate sustainability into the mining sector, particularly in downstream activities. This plan includes measures to support the manufacturing of products derived from critical minerals, such as EV lithium batteries, through subsidies, tax credits, and support for public–private partnerships.

The National Lithium Roundtable, a national policy established in 2021, promotes the integration of lithium into various manufacturing processes. The programme emphasises the industrialisation of lithium, incorporating advanced research and development in collaboration with universities, research centres, and institutions such as INTI (National Institute of Industrial Technology) and CONICET (National Scientific and Technical Research Council). It offers grants and subsidies for the development of lithium-ion battery manufacturing plants, R&D tax credits, and support for technological innovation in battery manufacturing. A draft law on the industrial development of lithium aims to regulate lithium value chains, including the processing segment. This draft law includes provisions such as tax exemptions, low-interest loans, and grants for research and development in processing technologies.

The recently passed Large Investment Incentive Scheme (RIGI) aims to generally attract large-scale investments into several sectors, including critical minerals value chains. This new law applies to the entire value chain for projects entailing investments higher than USD 200 million. This law is intended to attract large investments in lithium and copper processing, as well as battery production facilities. As part of the incentives offered by this law, companies will have a 10% reduction in income tax and will provide fiscal stability for 30 years. Under this law, a technological innovation proposal and a commitment that at least 20% of the project's supplier payments be allocated to local suppliers must be included within the investment project in order for it to get approval.

The National Strategy for the Circular Economy (April 2024) holds manufacturers responsible for the end-of-life management of their products, thereby incentivizing the development of recycling and other circular economy initiatives. This policy aims to integrate circular economy principles across various sectors, including critical minerals. Provisions include subsidies for recycling facilities, grants for circular economy projects, and incentives for companies that incorporate recycled materials into their products.

BRAZIL

Brazil's Mining Code (Decree-Law No. 227/1967) provides the foundational legal structure for all mining activities across the value chain. The National Mining Agency (ANM) was established under Law No. 13.575/2017 to regulate and oversee mining activities, and ensure compliance with stringent environmental and safety standards. ANM Resolution No. 20/2019 further delineates the requirements for mineral processing plants, emphasising adherence to advanced technological standards and robust environmental safeguards.

Law No. 6938/1981 establishes the National Environmental Policy, which requires that public and private actors carry out an EIA and obtain a permit prior to undertaking any potentially polluting activity. An amendment made by Law No. 10.165/2000 listed the exploration and processing of critical minerals as activities subject to environmental permitting.

The 2030 National Mining Plan (PNM-2030) is a framework for strengthening the sustainable development of the mining industry over a 20-year period. Complementing these efforts, Decree No. 10.657/2021 establishes a policy to support the environmental licensing of investment projects for strategic minerals production. Notably, the National Strategic Pro-Minerals Policy emphasises the federal government's commitment to prioritising Critical Strategic Minerals (CSM) production projects. This policy is intricately linked with the Investment Partnership Programme (PPI) law (Law No. 3,334/2016), which includes the Policy to Support Environmental Licensing for Investment Projects, mandating the state to ensure the timely completion of prioritised investment projects, even suggesting that certain regulatory processes and environmental licences may be bypassed in the national interest.

The National Mining Plan 2050 is a draft initiative currently being discussed as part of the next Mining Plan cycle, focusing on the critical mineral production chain, essential for the energy transition. Anchored on three pillars—exploitation of mineral resources, competitiveness, and sustainability—the plan includes linking Brazil's mineral production to technologies needed for the energy transition, such as wind turbines and EV batteries, and addressing urban e-waste recycling challenges.

Through Ordinance GM/MDIC nº 162/2023, the Ministry of Development, Industry, Trade and Services designated IBRAM, the Brazilian mining industry association, to create the National Council for Industrial Development (CNDI), with the purpose of productive and technological development, increase the competitiveness of Brazilian industry.

The government provides tax incentives for companies investing in R&D under Law No. 11.196/2005. These incentives include tax deductions and credits for investments in innovative mineral processing technologies. Additionally, the Growth Acceleration Programme (PAC) facilitates infrastructure investments aimed at improving logistics and reducing costs associated with mineral processing.

Decree No. 11.120/2022 governs the foreign trade of lithium and its derivatives. By allowing unrestricted trade of lithium products, it enhances Brazil's competitiveness in the global lithium midstream segment, facilitating the export of processed lithium essential for developing lithium-ion batteries and other technologies.

The National Solid Waste Policy (PNRS) (Law No. 12.305/2010) establishes comprehensive guidelines for waste management, including the recycling of critical minerals and requirements to establish reverse logistics systems for collecting and recycling e-waste. This policy promotes a circular economy by encouraging the reuse and recycling of industrial waste, including e-waste containing critical minerals. Incentives are provided for companies investing in recycling technologies and processes, reinforcing the principles of shared responsibility among manufacturers, importers, distributors, consumers, and waste management service providers.

The Automotive Sector Policy (Rota 2030) (Law No. 13.755/2018) offers incentives for manufacturing EV and related components, such as batteries. This policy encourages local production of EV batteries through tax incentives and subsidies for companies investing in battery technology. The National Programme for the Development of the Automotive Sector (PNDA) supports the development and production of automotive components, including those derived from critical minerals, by providing differentiated rates of the industrial production tax (IPI) for sustainable vehicles, generation of financial credit based on investment in innovation, and tax incentives.

Law No. 12.546/2011 offers incentives for technological innovation through the Special Regime for the Incentive of Technological Innovation (REINTEGRA), which provides tax rebates for exported manufactured goods incorporating technological innovation. This regime encourages manufacturers to adopt advanced technologies in producing goods derived from critical minerals.

Bill No. 2780/2024, presented in July by six federal deputies, proposes the creation of national-wide guidelines for the critical and strategic minerals sector in Brazil and extends subsidies for mining companies for the exploration of inputs used in the energy transition.

MEXICO

The General Mining Law governs all mining value chain activities in Mexico. It outlines the requirements for exploration, extraction, beneficiation, and processing of minerals, including critical minerals, while emphasising environmental protection and sustainable development. The law offers tax incentives and deductions for investments in processing infrastructure.

Further modernisation of the mining sector is addressed by the Decree by Which Various Provisions of the Mexican Mining Law (and Others) are Amended, Added, and Repealed (Mining Reforms 2023). These reforms incorporate new technologies, improve environmental and social governance, and promote the sustainable use of resources. Updated guidelines for the exploration, extraction, and processing of minerals encourage the adoption of innovative technologies and practices, offering potential financial and regulatory benefits for companies leading in sustainability and technological advancements.

The Energy Transition Law promotes the use of renewable energy and the transition to cleaner technologies. It includes provisions to support the development of a domestic supply chain for renewable energy components, including those derived from critical minerals. Tax credits and subsidies are available for companies that manufacture renewable energy components, such as EV batteries, in Mexico. Moreover, this law created the Energy Sustainability Fund (FOTEASE) to support research, development, and deployment in energy efficiency, renewable energy, clean technology innovation, and diversification of primary sources of energy.

Mining Reforms in 2022 aim to ensure national self-determination and energy sovereignty over lithium and other critical minerals essential for energy transition, technological innovation, and national development. It mandates a decentralised public organization to handle the exploration, exploitation, beneficiation, and use of these minerals. The reform emphasises preserving Mexico's significant lithium reserves for the public interest, prohibiting exclusive private capital in lithium-related mining activities across the whole mineral value chain. Decree DOF 23/08/22 established the Decentralised Public Entity Lithium for Mexico (Litio para México), a state-owned entity responsible for the exploration, exploitation, beneficiation, and utilisation of lithium resources in Mexico. This entity aims to ensure the strategic control of lithium's economic value chains, a key mineral for battery production. The primary objective of these two policies is to develop a national lithium processing and EV battery industry, with substantial resources dedicated to this effort. The government aims to encourage public–private partnerships to establish lithium processing facilities and EV battery manufacturing plants.

The General Law for the Prevention and Integral Management of Waste regulates waste management practices in general, including recycling critical minerals from industrial waste and end-of-life products. Companies engaged in recycling and circular economy practices can benefit from reduced waste management fees and grants for technology innovation in recycling processes. However, the country still lacks a specific law on recovered critical minerals. NOM-157-SEMARNAT-2009 is a standard that focuses on environmental protection measures and procedures for managing mining tailings. It requires a comprehensive environmental impact assessment, detailed design and construction guidelines for tailings facilities, regular monitoring and reporting, and the implementation of closure and post-closure plans. This standard encourages the adoption of advanced tailings management technologies, improving environmental performance.

Initiatives

In addition to the global initiatives identified during Phase 1 (Section 2.1) and Phase 2 (Section 3.1), regional- and national-level initiatives were identified and evaluated with relevance for technological innovation in the mid- and downstream segments of critical minerals value chains in Argentina, Brazil, and Mexico (see Figure 23). Mechanisms of a primarily financial nature are covered separately.

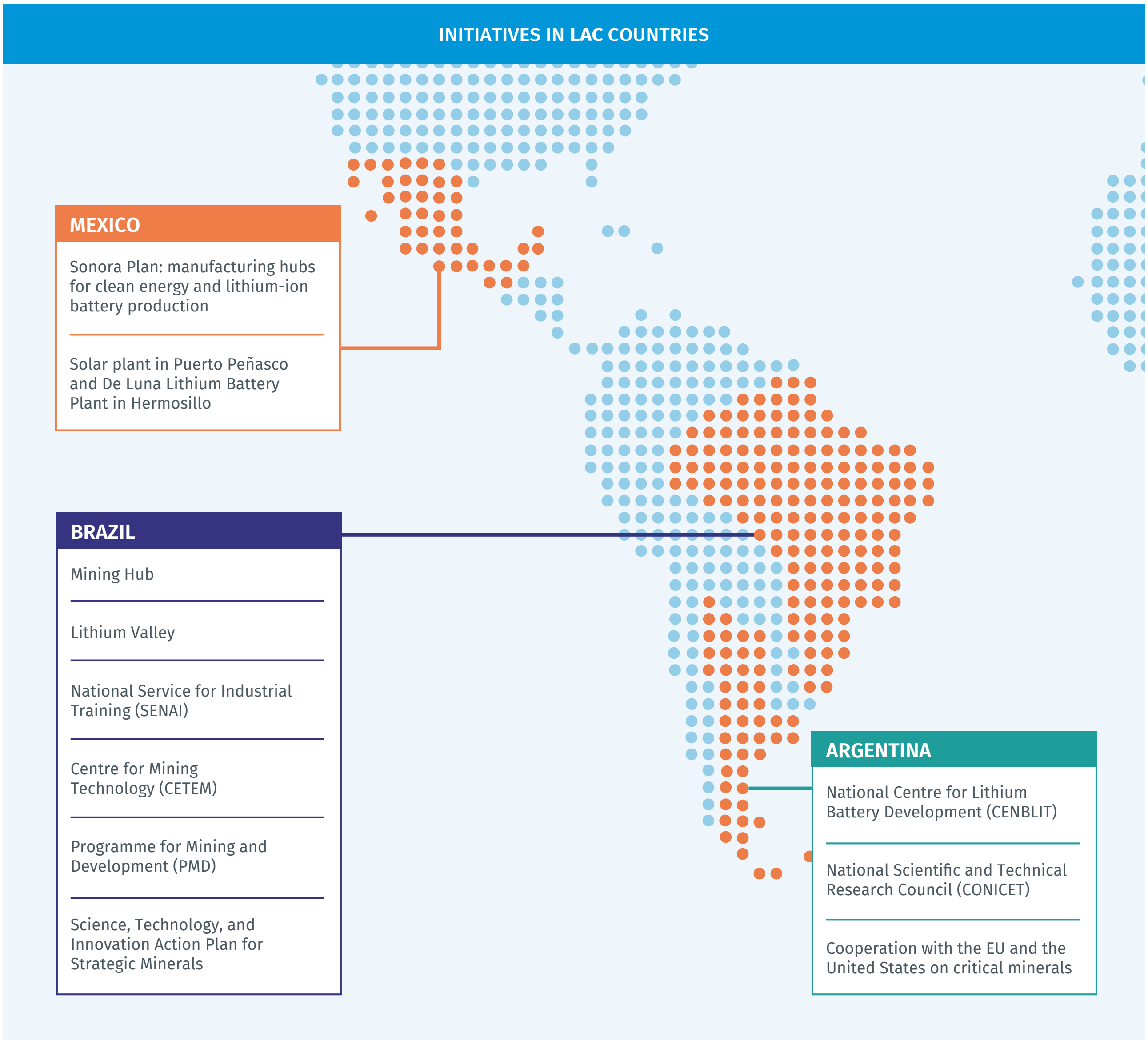


Figure 23. Selected initiatives in LAC countries: Argentina, Brazil, and Mexico (Phase 2)

Source: Prepared by the authors.

In **Argentina**, the National Centre for Lithium Battery Development (CENBLIT) aims to support the development and testing of lithium batteries, providing technological services to companies involved in the lithium battery industry. It represents a significant investment in public-private partnerships to drive innovation in energy storage and mobility solutions.[227]

The National Scientific and Technical Research Council (CONICET) is Argentina's main research institution, spanning the four key areas of engineering sciences, biological and health sciences, natural sciences, and social sciences.[228] One of their main objectives is technology transfer, which involves monitoring technological and scientific supply and demand, and accordingly advising and disseminating programmes to stakeholder companies.[229]

CONICET has spearheaded multiple initiatives that have resulted in significant technological innovation within the lithium value chain, particularly in the mid- and downstream segments. For example, in partnership with YPF, the country's largest energy company, it created Y-TEC. Today, **Y-TEC** is Argentina's leading company in R&D of technological innovation for the energy industry and the critical minerals sector. It is 51% owned by YPF and 49% by CONICET.[230] Y-TEC has developed several technological innovations in the mid- and downstream segment of the lithium value chain such as brine lithium processing into lithium carbonate and proprietary models of lithium cathodes and batteries, which are at very incipient stages.[231] Additionally, CONICET established the **Scientific and Technological Centre (CCT) CONICET Salta-Jujuy** in 2010, in the lithium-rich region of Jujuy, as part of a strategy to decentralise and promote scientific research in rural Argentina. The CCT Salta-Jujuy incentivises technological innovation in critical minerals through scholarships and grants.[232]

In July 2023, **Argentina and the EU** signed an MOU establishing a partnership on sustainable raw materials value chains that aims to foster the development of secure and sustainable supply chains for the minerals necessary for the energy transition. It also seeks to support the development of a critical minerals industry in Argentina and promote the creation of local added value, quality jobs, and sustainable, inclusive economic growth, benefiting both parties.[233]

In August 2024, **Argentina and the United States** signed an MOU to collaborate on not only the exploration and extraction of critical minerals, but also processing, refining, recycling, and recovery. The participants' stated goal is to increase awareness of opportunities for investment, as well as work together to identify co-financing opportunities.[234]

The **Mining Hub** in **Brazil** positions itself as a counterpoint to traditional practices within the sector by seeking to transform its culture and enhance its reputation. As an open innovation initiative, it engages all members of the mining value chain, driving connection, collaboration, and the empowerment of innovation across the industry. The Hub brings together diverse voices to actively shape the sector's future, fostering a community where scientists, thinkers, workers, and startups unite to pursue sustainable, inclusive, and responsible mining. Through its integrated approach, the Hub not only influences the evolution of mining practices but also seeks new alternatives to advance the entire value chain, amplifying the impact of individual efforts through collective action. This collaborative spirit defines the Hub's vision for the future, where the impact of individual efforts is amplified through collective action.[235]

The **National Service for Industrial Training (SENAI)** is one of **Brazil**'s leading institutions dedicated to professional education and industrial development.

227) "Primer Centro Nacional Para el Desarrollo de Baterías de Litio," Government of Argentina, https://www.argentina.gob.ar/ciencia/dnpe/proyectos/primer-centro-nacional-para-el-desarrollo-de-baterias-de-litio.

228) "Description," CONICET, https://www.conicet.gov.ar/about-the-conicet.

229) "Technology Transfer," CONICET, https://www.conicet.gov.ar/technology-transfer-office.

230) "Sobre Y-TEC," CONICET, https://www.conicet.gov.ar/ytec/sobre-y-tec.

231) Argentina Ministry of Economy, Mining Secretariat, interview by the authors, 16 September 2024.

232) "CONICET Salta-Jujuy," CONICET, https://salta-jujuy.conicet.gov.ar.

233) European Commission, "Global Gateway: EU and Argentina Step Up Cooperation on Raw Materials," press release, 12 June 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3217.

234) Argentina Ministry of Foreign Affairs, International Trade, and Worship, "Argentina and the United States Signed a Memorandum on Cooperation on Critical Minerals," news release, 22 August 2024, https://www.cancilleria.gob.ar/en/announcements/news/argentina-and-united-states-signed-memorandum-cooperation-critical-minerals.

235) "About Mining Hub," Mining Hub, https://mininghub.com.br/en/quem-somos.

SENAI's primary mission is to promote industrial competitiveness and support the country's economic development through technical and vocational training, technological innovation, and applied research. The organization plays a crucial role in bridging the skills gap in Brazil's workforce, providing education and training across various industrial sectors, and fostering a culture of innovation.[236] In the critical minerals sector, SENAI's initiatives include specialised training programmes that equip workers with the skills needed for modern mineral extraction and processing, as well as research projects aimed at developing new technologies to optimise resource use and minimise environmental impact. SENAI also collaborates with companies and startups to drive innovation through its network of technology and innovation institutes, which focus on areas such as mineral processing, automation, and sustainable technologies. These collaborations have resulted in several technology developments in the downstream segment of critical minerals value chains implemented by companies such as Baterias Moura, BYD, Marcopolo, PowerCo, Eletra and Tesla, particularly in the development of lithium-ion batteries.[237]

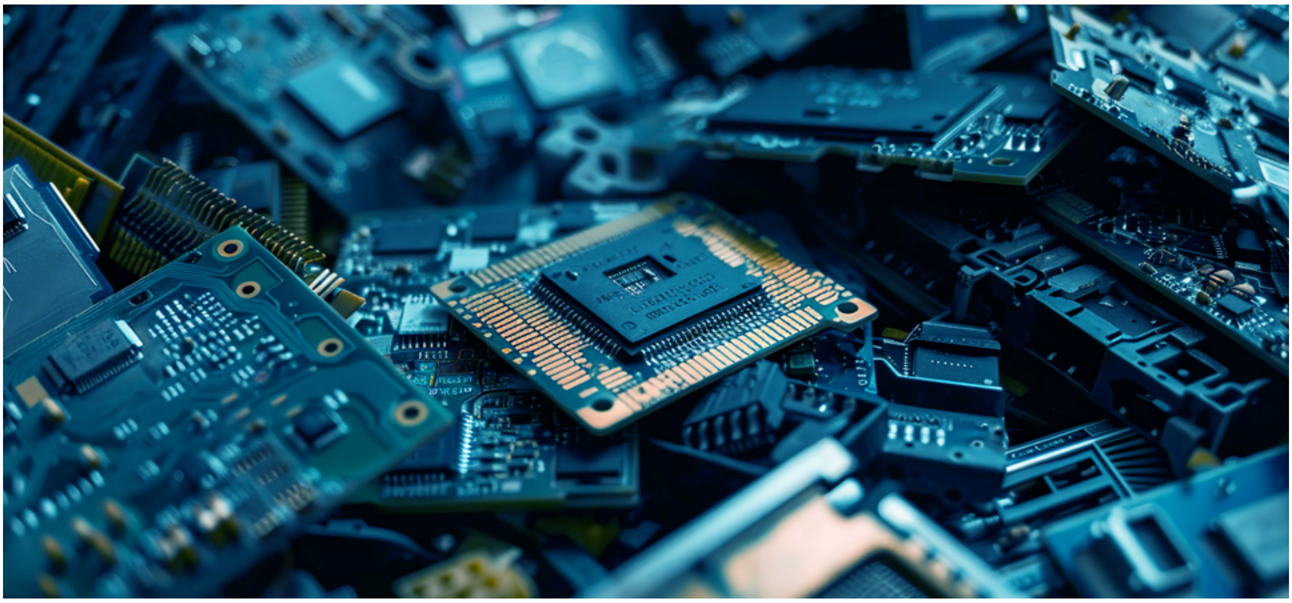
The **Centre for Mining Technology (CETEM)** in **Brazil** is a leading research institution focused on advancing sustainable practices and technological innovation in the mineral sector. Operating under the Ministry of Science, Technology, and Innovation, CETEM's mission is to promote the efficient and environmentally responsible use of Brazil's mineral resources. CETEM conducts cutting-edge research on critical minerals, including graphite, lithium, and REEs, with efforts aimed at improving extraction and refining processes, developing high-value materials, and implementing circular economy practices.[238] CETEM also contributes, directly and in partnerships, to research on cleaner production technologies and waste management solutions, collaborating with industry and academia to scale up sustainable innovations and support Brazil's competitiveness in the global mineral economy. It has contributed to research and innovation projects in the midstream segment of the critical minerals value chains in partnership with companies such as Rio Tinto, AMG Brazil, Companhia Brasileira de Lítio (CBL), and Sigma Lithium, particularly in technologies for the processing and refining of critical minerals.[239]

236) "Serviço Nacional de Aprendizagem Industrial," Portal Industria, https://www.portaldaindustria.com.br/senai.

237) IBRAM, interview by the authors, 4 September 2024; IBRAM, *Fundamentos para Políticas Públicas em Minerais Críticos e Estratégicos para o Brasil* (Brasília: IBRAM, June 2024), https://www.ibram.org.br/wp-content/uploads/2024/07/IBRAM_MINERAIS_CRITICOS-E-ESTRATEGICOS_web.pdf.

238) "Centro de Tecnologia Mineral – CETEM," Ministério da Ciência, Tecnologia e Inovações, https://www.gov.br/cetem/pt-br.

239) IBRAM, *Fundamentos para Políticas Públicas em Minerais Críticos e Estratégicos para o Brasil*.



Lithium Valley in **Brazil** is a government initiative that aims to transform Brazil's lithium-rich region in the state of Minas Gerais into a global hub for lithium production and processing. The initiative seeks to leverage Brazil's abundant lithium resources, particularly from hard-rock pegmatites, to support the growing global demand for lithium used in EV batteries and renewable energy storage. It focuses on attracting investment, fostering technological innovation, and enhancing the entire lithium value chain—from extraction and refining to the development of advanced materials and battery manufacturing. By integrating research institutions, industry, and government efforts, Lithium Valley aims to not only boost Brazil's position in the global lithium market but also create local economic opportunities and support the transition towards a low-carbon economy. The project intends to establish Brazil as a key player in the global supply chain for critical minerals.[240]

The **Brazilian Programme for Mining and Development (PMD)** by the Department of Mines and Energy spanned from 2020–2023 and aimed to align the mining sector with the country's goals for sustainable development. Multiple focus areas applied to innovations in the mid- and downstream segments of critical minerals value chains. For example, the programme pushed sustainable technologies in mineral processing, management of tailings and waste, and promoted more broadly the use of low-impact practices in the mining sector.[241]

The Brazil Ministry of Science, Technology, and Innovation's **Science, Technology, and Innovation Action Plan for Strategic Minerals** lasted from 2018–2022 and targeted REEs, lithium, and silicon. One of the three strategic programmes listed under CETEM's Master Plan of the Unit (PDU), the strategic minerals programme aimed to develop technologies and studies that increased competitiveness and reduced Brazil's dependency on imports regarding critical minerals, especially rare earths. The second strategic programme (water and energy, waste and sustainability programme) is also relevant—it looked to boost efficiency in the mineral industry by developing technologies for the reprocessing of waste and tailings, and propose solutions for the circular economy of the mining sector in Brazil.[242]

240) "From Ore to Battery," Lithium Valley Brazil, https://www.lithiumvalleybrazil.com.br.

241) Brazil-Canada Chamber of Commerce (BCCC), *Report on Brazil's New Program for Mining and Development 2020–2023* (Rio de Janeiro: BCCC, September 2020), https://brazcanchamber.org/wp-content/uploads/2020/12/Flash-Report_Brazil%E2%80%99s-new-Program-for-Mining-and-Development-2020-2023_TCSBrazil_ConsulateRIO.

242) Mineral Technology Center – CETEM, *Master Plan of the Unit 2017–2022 (English)* (Rio de Janeiro: CETEM, May 2020), 3–6, https://www.gov.br/cetem/pt-br/acesso-a-informacao/documentos-de-gestao/plano-diretor-da-unidade-pdu. See also updated version, available in Portuguese only: CETEM, *Plano Diretor 2017–2024* (Rio de Janeiro: CETEM, April 2024), https://www.gov.br/cetem/pt-br/acesso-a-informacao/dados-abertos/disponibilizacao-das-bases-de-dados-programadas-para-abertura-no-pda-do-orgao/plano-diretor-da-unidade-pdu.

The **Mexican** government has partnered with private companies to establish manufacturing hubs specialising in lithium-ion battery production. This initiative is part of the Sonora Plan, launched in April 2022, following the nationalisation of lithium exploration and exploitation. The plan aims to transform the Mexican state of Sonora into a clean energy hub, backed by an investment of over USD 48 billion, and additional investments from the United States, South Korea, and China,[243] This investment is set to strengthen the Sonora–United States supply chain, promote the manufacturing of batteries and EV, and construct clean energy power plants, including Latin America's largest solar plant in Puerto Peñasco. A key component of this initiative is the De Luna Lithium Battery Plant in Hermosillo, Sonora. With an investment exceeding USD 80 million, the plant is a collaborative effort involving De Luna Lithium Battery, the Mexican government, and Sonora state authorities. Expected to commence production in late 2023, the plant will initially produce 20,000 units in its first year, with plans for scaling up based on demand. This plant plays a strategic role in developing a robust supply chain for EV batteries and other renewable energy technologies in Mexico, reinforcing the country's commitment to sustainable energy solutions.[244]

Financial Delivery Mechanisms

During Phase 2, in addition to global-level mechanisms (Section 3.1), the analysis looked into regional and national mechanisms identified as potentially or practically effective in facilitating technological innovations in the mid- and downstream segments of critical minerals value chains in Argentina, Brazil, and Mexico. This section focuses on qualitative data to provide a contextual understanding and detailed perspectives on the challenges and opportunities within the funding ecosystem, as well as on quantitative data, where available (see Table 16).

243) Mexico Energy, "The Potential for Lithium Mining in Mexico", https://mexicoenergyllc.com.mx/blogs/mexico-energy-insights/the-potential-for-lithium-mining-in-mexico.

244) Karen Bilge, "Sonora Plan Advances With US$16 Billion Investment," *Mexico Business News*, 29 February 2024, https://mexicobusiness.news/energy/news/sonora-plan-advances-us16-billion-investment.

TABLE 16. Selected financial delivery mechanisms for technological innovations in the mid- and downstream segments of critical minerals value chains in Argentina, Brazil, and Mexico

Country / Region	Financial Delivery Mechanism	Description	Amount	Date
LAC	Inter-American Development Bank (IDB)	Financing for projects that enhance the value chain for critical minerals, facilitate public-private partnerships, and improve resource efficiency	Not specified	Not Applicable
Argentina	International Finance Corporation (IFC)	Loan for developing the Sal de Vida lithium operation in Catamarca	USD 180 million	July 2023
	International Finance Corporation (IFC) RenovAr programme	Financing renewable energy projects	USD 11 billion as of May 2024	Launched 2016, fully implemented by 2025
Brazil	Brazil Critical Minerals Fund, a partnership between the National Bank for Economic and Social Development (BNDES), the mining company Vale, and the Ministry of Mines and Energy	Stimulating investments in critical minerals, targeting SME projects to enhance supply chain capabilities for clean energy technologies and decarbonisation beyond extraction	USD 200 million	Mobilises investments in March 2025
	Funding Authority for Studies and Projects (FINEP)	Grants, loans, and equity investments for companies, universities, and research institutions	USD 7 billion in the period 2024–2028	2024–2028
	New Industry Brazil (NIB) programme, a partnership between Brazil's Funding Authority for Studies and Projects (FINEP) and BNDES	Financing technological innovation at an interest rate of 1.7% per annum	USD 3.5 billion	2024–2033
Mexico	Nacional Financiera (NAFIN)	Development funding allocated for sustainable debt into projects that help to achieve the SDGs	USD 395 million	Launched in 2021 USD 326 million due 2031 USD 65 million due 2026
	Banco Nacional de Obras y Servicio Públicos (BANOBRAS)	Funding for social and environmental development projects, notably in infrastructure and energy	Not specified	Not applicable
	Banco Nacional de Comercio Exterior (BANCOMEXT)	Loans for direct and indirect exporters in critical minerals value chains	USD 3 million	Not specified

Source: Prepared by the authors.

The **Inter-American Development Bank (IDB)** is a leading source of development finance in LAC, established to support economic, social, and institutional development in the region. Its mandate is to reduce poverty and inequality, promote sustainable economic growth, and strengthen institutions through financial and technical assistance. In the critical minerals sector, the IDB focuses on fostering sustainable mining practices, supporting infrastructure development, and advancing policies that balance economic benefits with environmental protection. The Bank's activities include financing projects that enhance the value chain for critical minerals, facilitating public-private partnerships, and promoting innovative approaches to improve resource efficiency. Through these efforts, the IDB aims to help the region leverage its rich mineral resources and support technological innovation through the critical minerals value chains.[245] However, IDB financing initiatives in critical mineral value chains are perceived to be primarily focused on the upstream segment, even if the organization recognises the potential economic benefits of expansion into the mid- and downstream segments.[246]

According to interviewed IDB stakeholders, one of the primary obstacles hindering LAC's progress in the critical minerals sector is the inadequacy of financial mechanisms to support R&D and foster innovation. The region has long struggled with underinvestment in R&D, which in turn hinders the development of new technologies and processes essential for adding value along the mineral value chain. Moreover, LACs relatively weak track record in intellectual property development further complicates efforts to cultivate an innovation-driven economy. Without a robust framework for financing technological advancements and incentivizing intellectual property creation, the region risks lagging behind in the global race for sustainable and competitive industrial growth. Addressing these financial barriers is therefore vital for enabling LAC to harness its natural resource wealth more effectively and to build an enabling environment for technological innovation in the mid- and downstream segments of critical minerals value chains.[247]

Argentina has attracted investment from foreign countries and international organizations alike. The IFC (see Section 3.1) loaned a total of USD 180 million to develop the Sal de Vida lithium operation in Catamarca, Argentina.[248] In 2024, a collection of French, Korean, and U.S. financial institutions financed the Sal de Oro lithium plant for USD 668 million.[249] Although upstream processes are not the focus in this assessment, the sheer scope of investment into extraction during what has been called Argentina's lithium "rush" is notable.[250] Indeed, out of the countries in the "Lithium Triangle," only Argentina allows private ownership, exploration, and production of lithium, providing no restrictions on foreign investment and the most favourable tax code for said investors.[251]

Beyond the upstream segment, the Government of Argentina partnered with the IFC for their RenovAr programme, which funded 210 renewable energy projects for approximately USD 11 billion as of May 2024.[252] The IDB also plays a major role in sustainable finance for the country, as it extended its Sustainable Financing Protocol for another five years in 2024.[253] The Bank issued a USD 350 million loan in June 2023 for sustainable growth, aiming to promote the circular economy and the approval of Argentina's first medium- and long-term energy transition plan.[254]

245) "We Are the IDB," IDB, https://www.iadb.org/en/who-we-are/about-idb.

246) Paulo de Sá, interview by the authors, 3 October 2024.

247) IDB, interview by the authors, 16 September 2024.

248) International Finance Corporation (IFC), "IFC Makes First Investment in Lithium, Supports the Development of Sal de Vida in Argentina," press release, 24 July 2023, https://www.ifc.org/en/pressroom/2023/ifc-makes-first-investment-in-lithium-supports-the-development-of-sal-de-vida-in-argentina.

249) Milbank LLP, "Milbank Advises Financing Parties on Flagship Lithium Brine Mining Project in Argentina," news release, 20 May 2024, https://www.milbank.com/en/news/milbank-advises-financing-parties-on-flagship-lithium-brine-mining-project-in-argentina.

250) Julia Gerlo and Marius Troost, *The Foreign Financiers of Argentina's Lithium Rush: Export Credit Agencies' Support for Lithium Mining* (Utrecht: Both ENDS and Fundación Ambiente y Recursos Naturales, October 2023), https://www.bothends.org/uploaded_files/document/The_foreign_financiers_of_Argentina_s_lithium_rush.pdf.

251) Gracelin Baskaran, *Leveraging Argentina's Mineral Resources for Economic Growth* (Washington, DC: CSIS, 14 May 2024), https://www.csis.org/analysis/leveraging-argentinas-mineral-resources-economic-growth.

252) "RenovAr," RELP, https://www.energygreenmap.org/renovar.

253) IDB Invest, "IDB Invest Renews Argentina's Sustainable Financing Protocol for Five More Years," news release, 6 September 2024, https://www.idbinvest.org/en/news-media/idb-invest-renews-argentinas-sustainable-financing-protocol-five-more-years.

254) IDB, "Argentina Promotes Sustainable, Resilient Growth with IDB Assistance," news release, 26 June 2023, https://www.iadb.org/en/news/argentina-promotes-sustainable-resilient-growth-idb-assistance.

In **Brazil**, the government announced the creation of the **Brazil Critical Minerals Fund** in February 2024.[255] The Fund is a BRL 1 billion (approx. USD 200 million) initiative established through a partnership between Brazil's development bank, the **National Bank for Economic and Social Development (BNDES)**, the mining company Vale, and the Ministry of Mines and Energy. Its goal is to stimulate investments in strategic critical minerals, including lithium, nickel, cobalt, and REEs. The fund specifically targets small and medium-sized companies, supporting projects that enhance Brazil's supply chain capabilities for clean energy technologies and decarbonisation efforts beyond the mere extractive process. BNDES and Vale have each committed up to BRL 250 million (approx. USD 50 million) as initial investments, with the rest expected to come from private investors. A consortium comprising JGP Asset Management, BB Asset, and Ore Investments was selected to manage the fund, aiming to attract further capital and support around 20 small and mid-sized companies particularly focused on research and innovation that will result in adding value to critical minerals, promoting sustainable mining practices, and advancing new technologies. The initiative reflects Brazil's broader efforts to increase its share of the global critical minerals market and enhance local production, prioritising mid- and downstream operations in strategic minerals essential for EV batteries and renewable energy storage.[256]

255) Brazilian Regulatory Standards, "BNDES Critical Minerals Fund to Invest R$1 Billion," news release, 14 October 2024, https://braziliannr.com/2024/10/14/bndes-critical-minerals-fund-to-invest-r1-billion.

256) Bloomberg, "Vale Backs Brazil Critical Minerals Fund in Nod to Government," *Mining Weekly*, 3 October 2024, https://www.miningweekly.com/article/brazilian-miner-vale-development-bank-bndes-to-create-strategic-minerals-fund-2024-10-03.

Brazil's Funding Authority for Studies and Projects (FINEP) is a government agency under the Ministry of Science, Technology, and Innovation. It plays a crucial role in funding and promoting research, development, and innovation across various sectors of the Brazilian economy. Finep provides financial support through grants, loans, and equity investments to companies, universities, and research institutions. Its goal is to stimulate technological advancements and foster the development of innovative products, processes, and services that enhance Brazil's competitiveness and economic growth.[257] FINEP and BNDES work together to advance different initiatives and programmes such as the **New Industry Brazil (NIB) programme**, which has BRL 20 billion (approx. USD 3.5 billion) from BNDES to finance technological innovation at an interest rate of 1.7% per year, along with an additional BRL 40 billion (approx. USD 7 billion) from Finep over the next four years.[258]

Mexico has three main national development banks that provide both broad and narrow financial support to causes such as sustainable mining: *Nacional Financiera* (NAFIN) provides general development funding; *Banco Nacional de Obras y Servicio Públicos* (BANOBRAS) focuses on social and environmental development; and *Banco Nacional de Comercio Exterior* (BANCOMEXT) supports infrastructure in energy and mining-metallurgy:[259]

- In November 2021, NAFIN allocated MXN 7.8 billion (approx. USD 395 million) of sustainable debt into projects that help to achieve the SDGs.[260] Though not specifically earmarked for critical minerals–related projects, it demonstrates the importance that one of the largest development banks in the country places on green projects and represents a potentially important source of financing for technological innovation in mineral value chains.

- BANOBRAS contributes more explicitly to the clean energy transition, managing the Ministry of Foreign Affairs' Project Hub. The Hub provides a platform that details all infrastructure and energy projects being considered in the public sector, promoting greater visibility for potential private investors.[261] One project of note is a solid waste separation and processing plant in Chihuahua, netting an investment of MXN 765 million (approx. USD 45 million) from the Mexican government.[262]

- BANCOMEXT aims to support the development of the mining industry as a whole, granting loans of USD 3 million and above to direct and indirect exporters in the field.[263] They also have close ties with foreign development banks; in 2016, Germany's KfW Development Bank pledged a loan of EUR 80 million (approx. USD 87 million) for BANCOMEXT to supply to companies advancing technological innovation

257) "About Finep," Finep, http://www.finep.gov.br/about-finep.

258) IBRAM, *Fundamentos para Políticas Públicas em Minerais Críticos e Estratégicos para o Brasil* (Brasília: IBRAM, June 2024), https://www.ibram.org.br/wp-content/uploads/2024/07/IBRAM_MINERAIS_CRITICOS-E-ESTRATEGICOS_web.pdf

259) "How to Invest?" Mexico Projects Hub: Investment & Infrastructure, BANOBRAS, https://embamex.sre.gob.mx/republicacheca/index.php/es/avisos/448-mexico-projects-hub-investment-and-infrastructure.

260) Global Green Growth Institute, "Mexican Development Bank Nacional Financiera (NAFIN) Allocates MXN $7.8 Billion of Sustainable Debt in the Local Market," press release, 30 November 2021, https://gggi.org/mexican-development-bank-nacional-financiera-nafin-allocates-mxn-7-8-billion-of-sustainable-debt-in-the-local-market.

261) "Projects Hub," Mexico Projects Hub: Investment & Infrastructure, BANOBRAS, https://www.proyectosmexico.gob.mx/en/projects-hub.

262) "Project: Construction, Operation, and Maintenance of a Solid Waste Separation and Processing Plant in Chihuahua, in the State of Chihuahua," Mexico Projects Hub: Investment and Infrastructure, https://www.proyectosmexico.gob.mx/proyecto_inversion/0946-planta-de-separacion-y-procesamiento-rs-chihuahua.

263) "Mining–Metallurgy," BANCOMEXT, Mexico Secretariat of Finance and Public Credit, https://www.bancomext.com/en/sector/mining-metallurgy.

in solar projects,[264] while in 2020 Japan's Bank for International Cooperation contributed USD 110 million to a new credit line with BANCOMEXT promoting infrastructure to reduce greenhouse gas emissions.[265]

Mexico's Energy Sustainability Fund (FOTEASE) to support research, development, and deployment in energy efficiency, renewable energy, clean technology innovation, and diversification of primary sources of energy. It is also intended as a bridge between the industry and the academic sector to support innovation. It provides financial resources for projects aiming to enhance the sustainability and efficiency of energy production and use. Grants and funding opportunities are available for projects focusing on innovative technologies in the critical minerals sector, such as advanced processing methods and recycling techniques.[266]

Table 17 summarises the strengths and areas for improvement in Argentina, Brazil, and Mexico regarding their enabling environment (policy, initiatives, and financial delivery mechanisms) for technological innovation in critical minerals.

TABLE 17. Enabling environment in the deep-dive countries in LAC

	Strengths	Areas for improvement
LAC	• Financial incentives for companies in mid- and downstream segments (e.g. tax rebates and exemptions) • State-owned company for lithium value chain • R&D frameworks and initiatives • Industry-led initiatives to coordinate stakeholders: Mining Hub • Multilateral development bank (MDB) support (e.g. International Finance Corporation [IFC] loans and Inter-American Development Bank [IDB] programmes) • Policies advancing SDGs: 1 NO POVERTY; 7 AFFORDABLE AND CLEAN ENERGY; 13 CLIMATE ACTION	• Stringent circular economy policies on critical minerals • Policies governing mid- and downstream activities are fragmented across different ministries and minerals, lacking cohesive national frameworks • Regional cooperation and initiatives • Policies advancing SDGs: 12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Source: Prepared by the authors.

264) KfW Banking Group, "Germany Promotes Renewable Energies in Mexico," news release, 12 April 2016, https://www.kfw-entwicklungsbank.de/International-financing/KfW-Development-Bank/News/News-Details_347072.

265) Japan Bank for International Cooperation, "Fourth Credit Line for BANCOMEXT Under GREEN Operations," press release, 12 November 2020, https://www.jbic.go.jp/en/information/press/press-2020/1112-013974.

266) Secretaría de Energía, "Fondo para la Transición Energética y el Aprovechamiento Sustentable de la Energía," *Secretaría de Energía* (blog), 5 October 2023, https://www.gob.mx/sener/articulos/el-fondo-para-la-transicion-energetica-y-el-aprovechamiento-sustentable-de-la-energia-es-un-instrumento-de-politica-publica-de-la-secretaria.

Innovators, Technologies, and Projects

This section presents findings on technological innovations in the mid- and downstream segments of critical minerals value chains throughout the LAC region, the innovators involved, and their projects, with a focus on the three Phase 2 countries: Argentina, Brazil, and Mexico. Data were collected through desktop-based research and stakeholder interviews. The information collected through stakeholder interviews provide the baseline for the analysis that follows, with additional references cited. Appendix C lists the names, affiliations, and stakeholder groups of those interviewed.

One of the significant challenges facing LAC in the context of the critical minerals sector is the need to manage competing demands. On one hand, as a major global supplier of critical minerals, the region must prioritise the development and operationalisation of extraction projects, addressing various issues in the upstream segment, including licensing difficulties, resource management, and regulatory compliance. On the other hand, there is a pressing need to transition from mere extraction to adding value within the region's mineral economy to contribute to local industrialisation and sustainable development.

According to IDB interviewed stakeholders, although discussions about advancing innovation in the mid- and downstream segments of the value chain are ongoing, such advancements are not yet occurring at scale in LAC. They noted that a strategic reassessment of priorities in technological innovation in the critical minerals sector may be warranted. Instead of expending scarce resources striving to catch up with advanced technologies in the mid- and downstream segments of the value chain, already being developed in the Global North, countries in LAC could potentially derive greater benefits by channelling its limited resources towards advancing technological capabilities in the upstream segment. For instance, they noted technological innovation in geological knowledge represents a domain that demands substantial investment of effort and resources and still has great room to be improved.

By prioritising innovation in upstream processes—such as improving extraction methods, developing environmentally sustainable practices, and integrating advanced services—the region could create value locally and build a foundation for future technological leadership in developing a truly "green mine."[267]

As noted by interviewed stakeholders, this approach would not imply abandoning aspirations for mid- and downstream growth; rather, it would reflect a pragmatic recognition that the region's comparative advantage lies in its resource-rich environment. That being said, the potential for local value creation remains significant, particularly midstream, where efforts to establish local processing capabilities and advanced manufacturing can still yield substantial benefits if more resources were dedicated to them.[268]

Brazil is one of the major countries of interest in the LAC region and it is currently involved in and ramping up the production of battery raw materials.[269] In 2023, Serra Verde began commercial production of mixed rare earth concentrate (MREC). Another country that plays a major role in this region is Argentina, which has signed a 2024 MoU with the United States to strengthen cooperation on critical minerals.[270] Multinational mining and mineral processing companies are generally interested in establishing new processes in the LAC region. For instance, Rio Tinto has announced that it is developing a small starter battery-grade lithium carbonate plant with a capacity of 3,000 tonnes per year at its Salar del Rincon project and production is expected to commence by the end of 2024.[271]

Vale Base Metals (Brazil)

Vale—a Brazilian mining company with operations in Brazil and Indonesia, among others (see Figure 24)—is the second-largest producer of nickel with a global flowsheet in attractive jurisdictions. The operations in Indonesia are 100% fuelled by privately owned hydropower. Vale is amongst the pioneers in having the lowest carbon footprint.

267) IDB, interview by the authors, 16 September 2024.

268) IDB, interview by the authors, 16 September 2024.

269) "China's export restrictions create unexpected opportunity for Brazil's critical minerals sector," *Fastmarkets*, 10 October 2024, https://www.fastmarkets.com/insights/brazils-critical-minerals-sector.

270) The United States of America and the Argentine Republic Sign Memorandum of Understanding to Strengthen Cooperation on Critical Minerals, Department of State, Aug 22, 2024, https://www.state.gov/the-united-states-of-america-and-the-argentine-republic-sign-memorandum-of-understanding-to-strengthen-cooperation-on-critical-minerals.

271) "Rincon Lithium Project," Rio Tinto, https://www.riotinto.com/en/operations/projects/rincon.

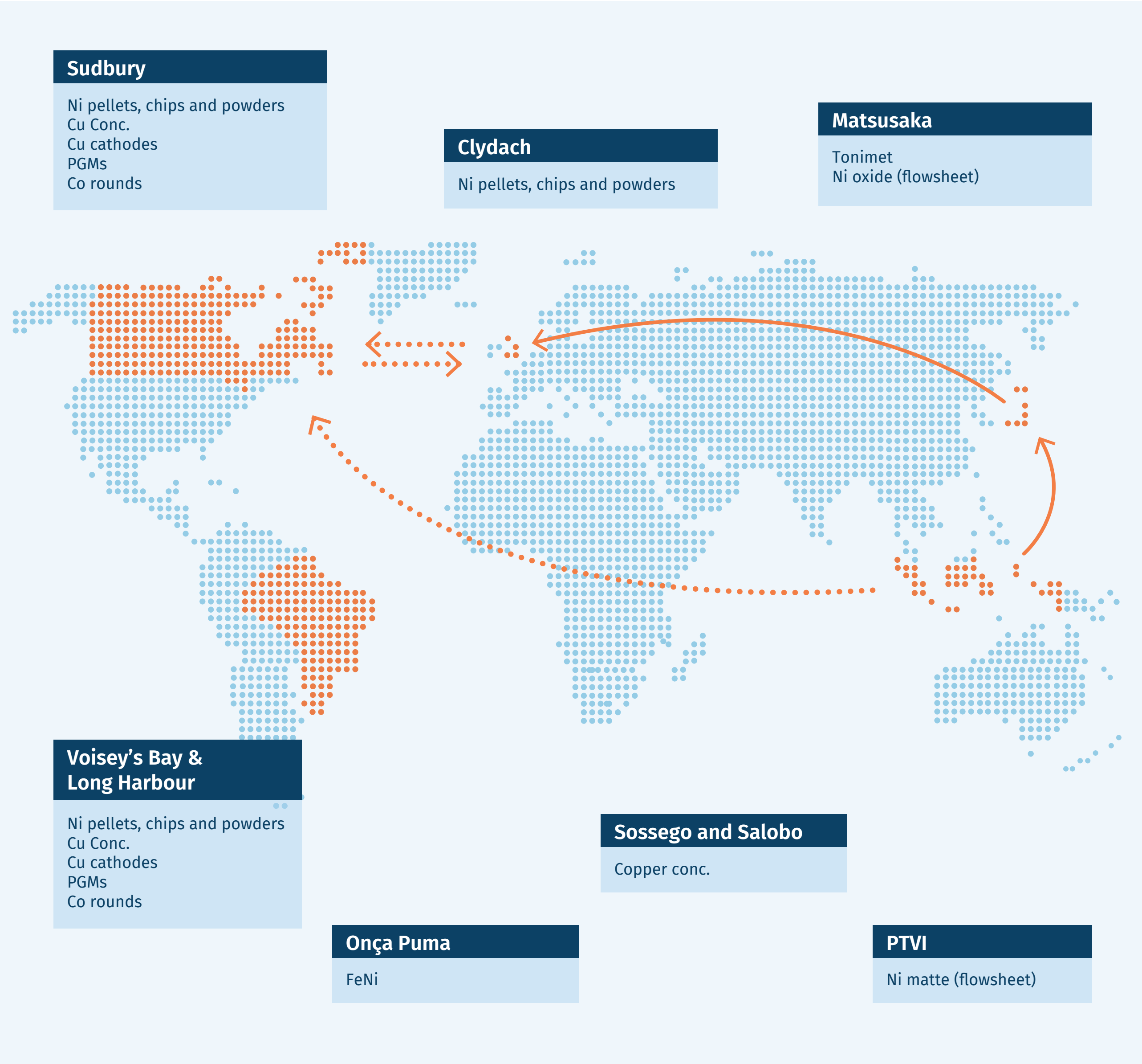


Figure 24. Global distribution of Vale Base Metals projects

Source: Vale Base Metals (2024).[272]

From a nickel industry perspective, processing technologies include High-Pressure Acid Leaching (HPAL), water-based or hydrometallurgical processes for nickel extraction as opposed to pyro-based processes, which are more typically used and relatively belong to upstream processes. However, these technologies are very well suited to serve as a bedrock for the mid- and downstream processes, especially in the recycling efforts. Companies like Vale Base Metals, with their vast knowledge and experience in the processing areas and the technologies they have, play a major role in mid- and downstream processing or recycling.

272) Vale Base Metals, *Asset Review: Webinar* (Vale, June 2024), https://www.publicnow.com/view/2739718BD9DA118AD8432FEF7B7D35F34506404E.

With increased production, tailings management is a challenge that requires more attention. The focus is on decarbonisation efforts and replacing thermal or process reagent inputs. Securing sustainable supply chains is important, and sustainable biomass is a good opportunity in Indonesia.

In terms of global applications, the greatest commonality in the nickel flowsheet is the company's nickel processing operation in Brazil, Onça Puma, where decarbonisation attempts are underway, and best practices across regions are being shared.

From a process technology perspective, all of the above technologies can be classified as TRL 7–9 as part of Vale Base Metals' 2030 roadmap efforts. Every feed that comes into a plant is unique to the region where it is mined and depends on the composition of the minerals on the ground. Even if the technology has been commercialised elsewhere (TRL 9), testing and engineering still need to be undertaken to make sure it will work for their respective feed and processes. Piloting these technologies as they relate to their process, whether at lab scale or full scale.

Midstream processing activities serve the metal industry with nickel going into stainless steel, nickel plating, and alloy production for different functions. In supplying critical minerals for clean energy technologies, increasing emphasis is going into reducing the carbon footprint of mineral value chain activities. This holds true across all of Vale Base Metals' operations, whether the product hails from Brazil, Indonesia, or elsewhere.

Apart from setting internal budgeting, the company also receives government grants in the region it operates (North America, especially Canada). Interviewed stakeholders believe that there are financial and intellectual benefits to partnering with other organizations, academia, and industry associations involved in technology development. They also noted that innovative technologies alone are unable to improve the bottom line. On this matter, they highlighted the importance of enabling policy and market environment, including decarbonisation policies, carbon pricing through carbon taxes or emissions trading systems, and premiums for low-carbon products.

Vale has also announced a strategic partnership with Manara Minerals and Engine No. 1 to accelerate the growth of the energy transition metals business. Vale Base Metals is expected to invest USD 25–30 billion in new projects across Brazil, Canada, and Indonesia over the next decade, and Manara Minerals and Engine No. 1 will invest USD 3.4 billion into Vale Base Metals. The capital programme will drive a significant potential increase in copper production from about 350kt/year to 900kt/year and in nickel production from roughly 175 kt/year to more than 300 kt/year.[273]

273) "Vale announces strategic partnership with Manara Minerals and Engine No. 1 to accelerate growth of energy transition metals business," Vale, https://www.vale.com/w/vale-announces-strategic-partnership-with-manara-minerals-and-engine-no-1-to-accelerate-growth-of-energy-transition-metals-business.

In the view of stakeholders who are familiar with the company's stance, many technologies to help meet net-zero by 2050 either do not exist or might be at an incubation stage with low TRLs. Post 2040, these technologies should target maturity, while for the short term for 2030, the approach would be to have either policy or direct involvement in the projects, according to the company. The solutions will likely be specific in the region of operations and are best supported by local policy or by supplementing the financing of these projects, depending on the timeframe of the projects. They believe startups will play a key role in longer-term results that are more distant in the future. For short-term results, larger companies are better positioned to deploy funds meaningfully, scaling technologies from pilot to a TRL 9 and then serving as a benchmark reference for other companies to follow.

Bacanora Lithium

Bacanora Lithium's Sonora Lithium Project is developing the lithium clay deposits in Sonora, Mexico, and is planning to build a 35,000 TPA battery-grade lithium product along with Ganfeng, the current owner of Bacanora Lithium. Ganfeng is the world's leading lithium enterprise, with operations covering the whole segment from upstream lithium production, midstream lithium refinery and smelting, to downstream lithium battery manufacturing and battery recycling. Ganfeng has secured long-term off-take agreements, including a 10-year agreement with the Japanese trading group Hanwa.[274] In Mexico, Bacanora's proposed process uses gypsum and sodium sulphate roasting of the clay ores to convert lithium-bearing minerals to the soluble lithium sulphate form. The lithium can then be processed further to produce high-purity lithium carbonate, a key component for preparing battery materials and battery production. The project's lithium pilot plant currently produces battery-grade lithium carbonate samples, which are being distributed to potential customers in Asia, establishing Mexico's role in the lithium supply chain and positioning it as a key player in the rapidly expanding lithium market. Bacanora Lithium's

274) "Ganfeng Lithium," Ganfeng Lithium Group, https://www.ganfenglithium.com/index_en.html.

collaboration with Ganfeng Lithium is an example of transferring high TRL technology to a developing country for further refinement and alignment with the local market and needs.[275]

Arcadium Lithium

Arcadium Lithium, a vertically integrated lithium chemicals producer formed in January 2024 from the merger of Livent and Allchem, was later acquired by Rio Tinto. This merger makes Arcadium the largest producer of lithium in Argentina and represents a powerful example of upstream lithium processing infrastructure supporting downstream applications, enabling efficient lithium supply for the growing battery market. Arcadium's Salar Hombre Muerto project in the Catamarca Province and Olaroz project in the Jujuy Province are currently operating, and they use Direct Lithium Extraction (DLE) technology. Arcadium has positioned itself as a critical supplier for Y-TEC, a subsidiary of Argentina's state-owned energy company YPF. Y-TEC plans to open Latin America's first lithium battery cell manufacturing plant, aiming to produce its first pilot models by December 2024. The plant, targeting an annual capacity of 13 MWh, will support Argentina's renewable energy initiatives, with production slated for stationary storage batteries and large batteries designed for electric buses.[276]

In addition to its DLE process, Arcadium Lithium is advancing the LIOVIX® technology, a proprietary lithium processing method at TRL 8, for manufacturing lithium metal sheets tailored to improve battery performance and lifespan. The LIOVIX® technology is gradually being integrated into commercial production and has garnered global validation for its effectiveness in enhancing energy density and battery durability. This midstream technology underscores Arcadium's commitment to innovation in lithium products, supporting downstream applications from energy storage to electric transportation. With its active and expanding lithium extraction and processing projects, Arcadium is strategically supporting Argentina's development as a lithium hub, not only by supplying battery-grade lithium carbonate but also by driving technological advancements that will underpin future developments in sustainable lithium production across other regions.[277]

Eramet Group

French-based company Eramet, in collaboration with IFPEN (French Institute of Petroleum and New Energies) and Seprosys, has developed an advanced Direct Lithium Extraction (DLE) process for extracting lithium from salar brines and producing battery-grade lithium carbonate. Located at the Centenario site in Salta Province, Argentina, this operation integrates both up- and midstream processing stages, achieving significant advancements in sustainable lithium extraction. The newly commissioned plant faced substantial logistical and environmental challenges due to its high-altitude location and extreme weather conditions, as well as the absence of pre-existing infrastructure. The plant began its first production run in November 2024 and operates at TRL 8–9. The DLE process is highly automated and designed to maximise lithium yield while minimising environmental impact. With an extraction yield of approximately 90% and an overall efficiency of around 87%, the process utilises an aluminium-based adsorbent material to capture lithium from the brines, reaching a water recycling rate of 60%. Unlike conventional methods, this DLE technology operates without acid and at ambient temperature, which reduces chemical and energy use. The process also includes nanofiltration and membrane separation steps to enhance purification and efficiency (see Figure 25). Furthermore, Eramet is exploring the reinjection of brine back into the salt flat, reducing water depletion in the region. Adhering to the International Responsible Mining Assurance (IRMA) guidelines, Eramet is implementing sustainability best practices. With a feasibility study underway, the plant has potential expansion plans to produce an additional 30,000 tonnes of battery-grade lithium carbonate annually. This project has high potential to grow the midstream processing and expand into downstream processing.[278]

---

275) "Bacanora Lithium," Bacanora Lithium, https://bacanoralithium.com/about/default.aspx.

276) "Operations and Projects," Arcadium Lithium, https://arcadiumlithium.com/operations-projects.

277) "Innovation," Arcadium Lithium, https://arcadiumlithium.com/innovation.

278) "Eramet Eramine-Sudamerica, Centenario project," Eramet, https://eramine.eramet.com/en/eramine-sudamerica-s-a/our-project; Eramet, "Eramet, Europe's Leading Producer of Battery-Grade Lithium," Eramet, https://www.eramet.com/en/activities/lithium.

ERAMET CENTENARIO DIRECT LITHIUM EXTRACTION PROCESS

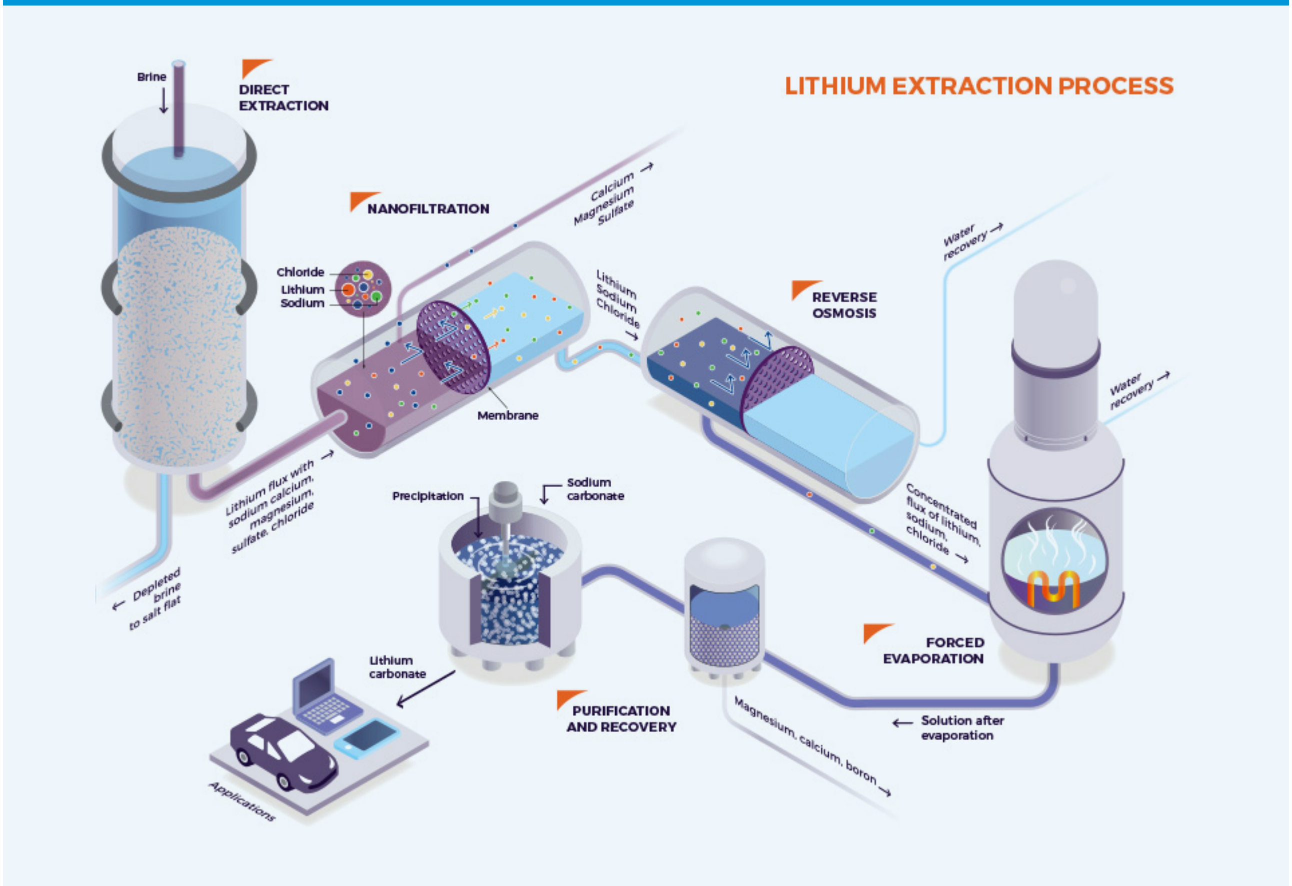


Figure 25. Eramet Centenario direct lithium extraction process

Source: Eramet.[279]

3.5 SDG ASSESSMENT

Theory of Change

The critical minerals sector is pivotal for sustainable development, particularly in resource-rich developing countries, and poses significant opportunities for advancing the SDGs. Minerals like lithium, cobalt, nickel, and REEs are not only essential for modern technologies but also for driving the global shift towards a low-carbon economy. These materials are fundamental components in renewable energy systems, EVs, battery storage, and other clean technologies that are key to meeting sustainability targets and other SDGs. While the upstream segment of critical minerals value chains (primary extraction) lays the groundwork, the midstream

279) "Our Lithium Extraction Process," Eramet, https://www.eramet.com/en/activities/lithium/our-lithium-extraction-process.

(processing and refining) and downstream segments (manufacturing of value-added products, extraction from secondary sources, and end-of-life treatment) offer substantial opportunities for technological innovation and sustainable development to fully converge and contribute to countries advancing SDGs.

Technological advancements in the mid- and downstream segments of critical minerals value chains can create both direct and indirect linkages to various SDGs, generating cross-cutting benefits that extend beyond individual targets. Direct linkages refer to clear, measurable impacts where technological innovations directly address specific SDG targets. For example, technologies that contribute to lithium-ion battery manufacturing capabilities in developing countries directly contribute to SDG 9 (Industry, Innovation, and Infrastructure) by creating innovation, boosting a new industry, and developing novel infrastructure in the country. Similarly, innovations that enhance copper processing contribute directly to SDG 13 (Climate Action) by contributing to the production of components for renewable energy systems. Indirect linkages, on the other hand, represent broader, systemic benefits that emerge from the adoption of these technologies, often supporting multiple SDGs simultaneously. For instance, improvements in recycling and waste reduction processes contribute indirectly to SDG 15 (Life on Land) by preserving ecosystems and biodiversity, and SDG 12 (Responsible Consumption and Production) by minimising waste, even if their primary focus is on enhancing production efficiency.

SDGs were selected where both direct and indirect linkages to technological innovation have been identified to be particularly impactful. These SDGs were selected because they are the areas where direct and indirect linkages with technological innovations can be clearly established, allowing for a targeted assessment of how advancements in the mid- and downstream segments of critical minerals value chains can drive sustainable development (see Table 18).

TABLE 18. SDGs impacted by technological innovation in the mid- and downstream segments of critical minerals value chains

Impact on SDGs with Direct Linkages		Impact on SDGs with Indirect Linkages	
1 NO POVERTY	End poverty in all its forms everywhere	5 GENDER EQUALITY	Achieve gender equality and empower all women and girls
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all
13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns
		15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Source: Prepared by the authors.

This section presents the theory of change underpinning the SDG assessment, which illustrates, through a qualitative-to-quantitative approach, how technological innovations in mid- and downstream segments of critical minerals value chains, particularly in Phase 2 developing countries, contribute to achieving selected SDGs (see Figure 26). This theory of change offers an in-depth analysis of the impact of policy interventions, initiatives, incentives, and specific technologies on the growth and advancement of critical minerals value chains, thereby accelerating progress toward the selected SDGs in developing countries. Through this approach, the assessment aims to demonstrate how these elements, when integrated effectively, can unlock the full potential of mid- and downstream segments, ensuring that technological innovations translate into tangible improvements in sustainable development outcomes.

The SDG assessment and the underlying theory of change are informed by a comprehensive policy and regulatory analysis, findings from existing literature, and consultations with key stakeholders. These sources will be referenced in this section and cross-referenced with other sections of this report, establishing causal links and illustrating the evolution of the mid- and downstream segments of critical minerals value chains across the respective countries and their impacts on selected SDGs. This evidence-based approach ensures that the assessment captures the nature of sustainable development within the mid- and downstream segments of critical minerals value chains.

FIGURE 26. SDG Assessment Theory of Change

Inputs	Activities	Outputs	Impacts	SDG
• **Policy Frameworks:** Mineral beneficiation, industrial development, education and training • **Technology Innovation:** R&D, demonstration projects and startups in mid- and downstream • **Collaboration:** Partnerships, PPPs, hubs • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Develop local processing, manufacturing, and assembly facilities • Develop pilot or demonstration projects for new technologies • Fund R&D and collaboration initiatives • Implement workforce training and formal education programs for skilled jobs	• New technologies at high TRLs • New skilled workforce • Strengthened industrial base that contributes to value addition and economic diversification • Improved local capacity to process critical minerals and manufacture clean energy goods • Reduced dependency on imports	• Jobs created in high value-added sectors through mid- and downstream innovation • Reduced poverty levels through increased incomes • Community livelihoods are improved by new economic opportunities	1 NO POVERTY
• **Policy Frameworks:** Mineral beneficiation, industrial development, infrastructure support • **Technology Innovation:** R&D, demonstration projects and startups in mid- and downstream • **Collaboration:** partnerships, PPPs, hubs • **Investment and Financial Support:** grants, subsidies, tax credits, international cooperation	• Strengthen partnerships for technology transfer • Develop local processing, manufacturing and assembly facilities • Build, expand, upgrade, and share infrastructure • Develop pilot or demonstration projects for new technologies • Fund R&D and collaboration initiatives	• New technologies at high TRLs • New processing and manufacturing facilities • Domestic and international markets for processed critical minerals and goods • Improved industrial base, local capacity to process minerals and manufacture clean energy goods, and export infrastructure	• Industrial infrastructure is developed, enhanced, and shared • Domestic innovation is promoted • Enhanced expertise of local suppliers and value chains • Improved quality of locally produced goods	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
• **Policy Frameworks:** Greenhouse gas emission standards for processing and manufacturing • **Technology Innovation:** In clean energy and transport supply chains • **Collaboration:** Partnerships, PPPs, hubs • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Establish sectoral emissions reduction goals • Integrate efficiencies and clean energy sources into mineral processing and manufacturing to reduce emissions • Develop clean energy and transport supply chains • Fund R&D and collaboration initiatives	• New technologies at high TRLs • New processing and manufacturing facilities • Domestic and international markets for processed critical minerals and goods • Improved industrial base, local capacity to process minerals and manufacture clean energy goods, and export infrastructure	• Industrial infrastructure is developed, enhanced, and shared • Domestic innovation is promoted • Enhanced expertise of local suppliers and value chains • Improved quality of locally produced goods	13 CLIMATE ACTION
• **Policy Frameworks:** Gender equality, inclusive employment, inclusive education and training • **Technology Innovation:** Women-led startups • **Collaboration:** Educational institutions • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Develop professional training programs for women • Set hiring targets in technical, processing, and manufacturing roles • Support women-owned enterprises • Fund R&D and collaboration initiatives	• New economic opportunities for women • Additional female representation in the critical minerals workforce, particularly in technical roles • Additional female leadership	• Increased economic empowerment for women • Reduced gender disparities in the critical minerals sector through a more inclusive industry • Improved socio-economic outcomes for women	5 GENDER EQUALITY
• **Policy Frameworks:** Mineral beneficiation, manufacturing, and RE integration in processes • **Technology Innovation:** In clean energy supply chains • **Collaboration:** Partnerships, PPPs, hubs • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Develop local processing, manufacturing, and assembly facilities for lithium-ion batteries and renewable energy components • Develop pilot or demonstration projects for new technologies • Introduce renewable energy in processes	• Reduced costs of per-unit production of clean energy technologies due to reduced costs in inputs • Increased availability of locally-produced, cost-effective renewable energy components • Expanded domestic renewable energy markets and reduced dependency on imports	• Improved energy efficiency • Increased renewable energy generating capacity • Increased renewable energy consumption • More affordable clean energy that can result in increased local access to energy	7 AFFORDABLE AND CLEAN ENERGY
• **Policy Frameworks:** Waste management, recycling, and circular economy principles • **Technology Innovation:** In recycling • **Collaboration:** Partnerships, PPPs, hubs • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Develop local recycling facilities • Develop pilot or demonstration projects for new recycling technologies • Develop and enforce circular economy principles and standards • Integrate efficiencies into mineral processing and manufacturing	• New recycling technologies at high TRLs • Increased raw material recovery and reduced reliance on imports • Adoption of circular economy practices • Improved resource efficiency • Minimised use of water, energy, and chemicals	• More responsible and sustainable processing and manufacturing methods • Minimised environmental impact of the critical minerals sector • Reduced waste generation • Increased recovery, repurposing, and recycling raw materials	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
• **Policy Frameworks:** Environmental standards • **Technology Innovation:** R&D, demonstration projects and startups in mid- and downstream • **Collaboration:** Partnerships, PPPs, hubs • **Investment and Financial Support:** Grants, subsidies, tax credits, international cooperation	• Develop pilot or demonstration projects for new technologies • Enforce responsible practices along the critical minerals value chain, including sustainable land use • Fund ecosystem restoration projects	• New technologies at high TRLs • Increased sustainability in processing and manufacturing of critical minerals • Reduced land degradation	• Avoided impact on critical habitats • Preserved ecosystem services and biodiversity • Minimised stressed on water and land	15 LIFE ON LAND

● SDG with Direct Linkages ● SDG with Indirect Linkages

Source: Prepared by the authors.

Potential Impact on SDGs with Direct Linkages

SDG 1
Contributing to Poverty Elimination Through Job Creation and Economic Development

The mid- and downstream sectors of critical minerals value chains can significantly contribute to poverty alleviation by creating jobs, fostering economic diversification, and increasing government revenues through higher value-added activities. Processing and refining minerals locally, rather than exporting raw materials, allows countries to capture a larger share of the value chain, thereby generating more economic benefits. For example, local lithium refining in Argentina has the potential to create high-skilled jobs and support local communities by providing economic opportunities beyond traditional agriculture and low-wage services.

Investments in midstream facilities, such as smelters, refineries, and chemical processing plants, are essential for building a robust industrial base. These investments not only generate direct employment but also stimulate the growth of ancillary industries, such as engineering, logistics, and equipment manufacturing. For instance, in Namibia, the government's efforts to promote beneficiation and value addition in the lithium and zinc sectors (see Table 19 [SDG1]) aim to boost economic growth, reduce unemployment, and support sustainable livelihoods by increasing local processing activities.

SDG 9
Driving Industrial Innovation and Building Resilient Infrastructure

The establishment of mid- and downstream facilities in developing countries fosters industrial development, technological innovation, and infrastructure expansion. Developing countries that invest in mineral processing plants and manufacturing facilities can build resilient industrial ecosystems that go beyond raw material extraction and consider sustainability standards from the outset of their industrialisation process. This industrialisation can be, in turn, a catalyst for technological advancement and economic diversification. For example, Brazil's Lithium Valley in Minas Gerais (see Section 2.4.3) is not only set to become a significant lithium processing hub but is also already driving the development of advanced manufacturing techniques, such as battery-grade lithium hydroxide production, which will entail the development of new infrastructure for processing facilities and manufacturing plants. This initiative supports Brazil's efforts to develop a robust critical minerals supply chain and enhance the country's industrial competitiveness on the global stage.

Investment in R&D is also crucial in these segments. Countries that prioritise R&D in mineral processing and manufacturing can stimulate innovation in refining techniques, waste management, and recycling, which can lead to more sustainable and efficient industrial practices and new infrastructure developments. South Africa's robust research infrastructure and specific initiatives on platinum beneficiation and the development of fuel cells (see Table 19 [SDG1]) illustrate the potential of the critical minerals sector to drive technological progress and create more resilient industries.

SDG 13
Supporting Climate Action

Climate action is directly linked to the critical minerals sector, as the mid- and downstream activities are key to producing components for renewable energy systems and technologies that contribute to energy efficiency, as well as components to implement decarbonisation technologies in the transport sector. Moreover, increasing local processing capabilities for minerals used in clean energy technologies helps reduce the emissions associated with transporting raw materials to distant processing facilities. Furthermore, integrating renewable energy into processing operations, such as using solar or wind power in smelting and refining processes, can further contribute to emission reduction goals.

Countries that are leveraging partnerships to develop an integrated EV battery value chain, such as Zambia with the Democratic Republic of the Congo (DRC) (see Section 2.2.3), are actively supporting global climate action initiatives by contributing to the decarbonisation of the road transport sector and also ensuring that the minerals used in clean technologies and renewable energy components are sourced and processed sustainably. This approach not only supports domestic industrial development but also contributes to global efforts to limit greenhouse gas emissions.

Potential Impact on SDGs with Indirect Linkages

SDG 5
Empowering Women and Promoting Gender Equality

The critical minerals sector, particularly in mid- and downstream segments, has traditionally been male-dominated. However, targeted interventions when introducing innovative technologies in the sector can transform it into a more inclusive industry that promotes gender equality. Programmes that encourage women's participation in technical, management, and decision-making positions within mineral processing and manufacturing can help bridge the gender gap and economically empower women. For instance, Zambia's local content policy (see Section 2.2.2) encourages mining companies to integrate gender-sensitive approaches in hiring practices and workforce development programmes, creating pathways for women to enter skilled positions in the refining and manufacturing sectors.

Initiatives that provide technical training and upskilling for women in mineral processing, engineering, and metallurgy can increase female representation in higher-wage and leadership roles. Brazil's partnerships with educational institutions that focus on professional training for women, ensuring that they are equipped to participate in the growing critical minerals sector illustrates this potential (see Table 36 [SDG 5]). Furthermore, policies that support women-owned businesses in the supply chain, such as providing incentives for women entrepreneurs to engage in mineral-related industries, can help achieve greater gender equality in the sector.

More indirectly, technology innovation in the mid- and downstream segments of critical minerals value chains has the potential to alleviate poverty and expand access to affordable and clean energy (as explained in other sections), which entails alleviating time poverty for women and girls in these developing regions promoting, in turn, SDG 5. Greater access to clean energy will ease the burden of labour-intensive caregiving tasks and lower their exposure to indoor air pollution, thereby creating more opportunities for education and paid work.[280] For instance, in rural sub-Saharan Africa, women have to carry an average of 20 kg of wood over 5 km each day to use as cooking fuel, spending nearly 3 hours daily gathering fuel. This prevents them from using that time for other activities, such as pursuing education or seeking formal employment.[281]

7 AFFORDABLE AND CLEAN ENERGY

SDG 7
Expanding Access to Affordable and Clean Energy

The mid- and downstream segments of critical minerals value chains are pivotal in developing and deploying clean energy technologies. Critical minerals like cobalt, lithium, and nickel are essential for manufacturing batteries used in EVs and energy storage systems, which facilitate the integration of renewable energy sources such as solar and wind. Additionally, minerals such as copper, REEs, and silicon are crucial for manufacturing renewable energy components like wind turbines and solar panels, which are key to harnessing clean energy. By advancing local processing capabilities, developing countries can reduce the costs of clean energy technologies, making them more accessible and affordable for local communities.

For instance, Indonesia's policy to ban raw nickel ore exports has led to substantial investments in domestic smelting and battery production, helping the country achieve its goal of becoming a key player in the global EV battery supply chain by 2030 (see Section 3.3 and Table 26 [SDG 1]). These investments not only ensure that the economic and financial benefits of processing high-value minerals are retained within the country but also support Indonesia's clean energy transition.

Expanding the use of renewable energy to power processing facilities can significantly reduce the carbon footprint of the mid- and downstream segments of critical minerals value chains. Several countries' efforts to incorporate solar energy in their mining and processing operations demonstrate a practical approach to achieving sustainable energy goals while expanding industrial capacity.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

SDG 12
Promoting Responsible Consumption and Production

Technological innovation in the mid- and downstream segments of the critical minerals value chain can create strong prospect potential to achieve responsible consumption and production practices. Countries can minimise their environmental impacts and enhance resource use efficiency via

280) Ambuj D. Sagar, "Alleviating Energy Poverty for the World's Poor," *Energy Policy* 33, no. 11 (July 2005): 1367-1372, https://www.sciencedirect.com/science/article/abs/pii/S0301421504000096.

281) IEA, *A Vision for Clean Cooking Access for All* (Paris: IEA, July 2023), https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all.

implementation of sustainable mining, efficient refining, and circular economy principles such as repurposing and recycling. For example, India has set up various recycling initiatives in the critical minerals sector (see Section 3.5), aimed at recovering usable minerals from devices such as used batteries, thereby avoiding primary extraction and, consequently, cutting down on the associated environmental impacts of upstream mining activities.

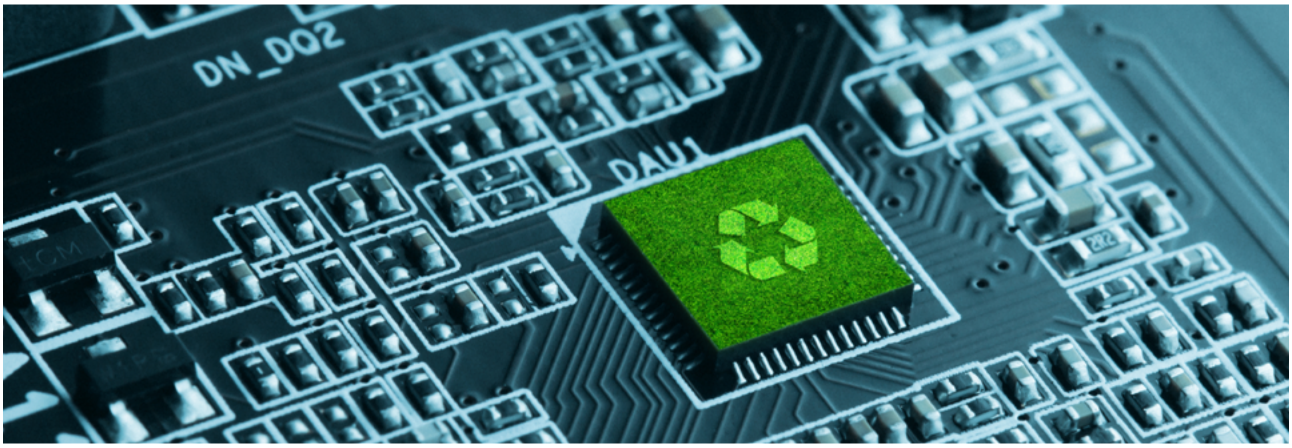
In addition, regulatory frameworks that promote sustainable practices in mineral processing, such as establishing clear thresholds or standards for waste management and greenhouse gas emissions, can contribute to overall sustainability. Indonesia's policies on traceability and transparency in nickel and nickel-based product production, processing, and assembly, supported by strict waste management regulations, seek to ensure that further development of processing capacity will not occur come at the environment's expense (see Section 3.3). These illustrate how technological innovations in the mid- and downstream segments of critical minerals value chains can contribute to SDG 12.

15 LIFE ON LAND

SDG 15
Conserving Terrestrial Ecosystems

Scaling up innovative technologies in the mid- and downstream segments of the critical minerals value chain plays an important role in helping to reduce the emissions, waste, and stress on water, land, and biodiversity of operations of companies of this sector, thereby minimising their impact on terrestrial ecosystems. Moreover, sustainable processing and manufacturing practices and legal frameworks, such as strict environmental impact assessment regulations, land restoration projects, and biodiversity conservation initiatives, can allow countries to oversee mineral processing and product manufacturing while avoiding deforestation, habitat loss, or land degradation.

South Africa's environmental policies requiring rehabilitation of mining sites and the restoration of ecosystems affected by mining activities throughout the value chain (see Section 3.2) are a positive example of how biodiversity considerations can be incorporated into the critical minerals sector. Similarly, in Namibia, policies aimed at lowering the environmental impact of mining and refining activities emphasise protecting ecosystems and sustainable land-use management (see Section 3.2). Innovative technologies, such as direct lithium extraction (DLE) in Argentina and clay lithium extraction in Mexico contribute to reducing habitat disruption and land degradation compared to traditional mining methods, helping to preserve terrestrial ecosystems (see Section 3.5).



Analysis of Country Performance and Potential Impact on SDGs in the Critical Minerals Sector

All Phase 2 developing countries were evaluated regarding the level of alignment of their critical minerals value chains with selected SDGs, as well as the contributions that initiatives, financial mechanisms, and policy frameworks make to advancing sustainable development. This analysis examines the current state of country performance on SDG action in the mid- and downstream segments and identifies the potential for technological innovations to advance sustainable development. The assessment focuses on refining, processing, and recycling technologies and highlights opportunities for enhancing economic, social, and environmental outcomes that support broader SDG objectives. Results of this assessment are presented in this section for the nine deep-dive countries, categorised by region: Namibia, South Africa, and Zambia in Africa; India, Indonesia, and Türkiye in ASP; and Argentina, Brazil, and Mexico in LAC.

The analysis of each country offers an overview of the unique dynamics of its critical minerals value chain and emphasises current efforts to contribute to SDGs, together with areas where policy support, strategic initiatives, and technological innovations can capture further value. Tables 19–39 contain the detailed findings that provide an understanding of the distinct challenges and opportunities present in each country, offering insights into how technological innovations can provide significant improvements toward sustainable development outcomes in critical minerals value chains.

TABLE 19. Impacts on SDGs with direct linkages in African countries (Namibia, South Africa, and Zambia): SDG 1 (No Poverty)

NAMIBIA	SOUTH AFRICA	ZAMBIA
Namibia's critical minerals sector contributes significantly to job creation, directly linked to poverty reduction. In 2023, the sector employed 18,189 individuals, a 12.6% increase from 2022, with approximately 98% of those employed being Namibian nationals.[282] The government's strategy to promote local beneficiation and add value to minerals such as lithium has created additional opportunities for employment in mining, processing, engineering, and related services like logistics and equipment supply.[283] Implementing innovative technologies in this sector can create even more jobs and prompt investment in education and training as more skilled workers are needed. By banning the export of unprocessed lithium, Namibia aims to encourage the establishment of processing plants within the country, further increasing employment and supporting local industries. Given that local value addition will continue to increase and generate more revenue, economic diversification is expected to occur, providing sustainable pathways out of poverty.	The mining sector in South Africa provided direct employment to approximately half a million people in 2023, proving to be a primary source of labour and economic opportunities.[284] Since 2021, the sector has experienced steady employment growth and providing jobs and supporting livelihoods in mining-dependent communities, thereby uplifting them from poverty. The government's beneficiation strategy emphasises local processing of minerals such as platinum and iron. This local value addition focus is expected to offer even more job opportunities in new industries like fuel cell and battery production and battery recycling. Thisdownstream industrialisation promotes economic diversification, supporting long-term poverty reduction by offering new job and capacity-building opportunities.[285]	In 2022, Zambia's mining sector employed 65,409 people, marking a slight decrease from the 66,478 employed in 2021.[286] Despite this decline, the sector remains a critical source of formal employment, directly impacting poverty alleviation. Zambia's policies on critical minerals are focused on job creation and skills development. The government is placing heavy emphasis on developing an integrated EV battery value chain, which will come with new jobs, especially in mid- and downstream activities like battery manufacturing.[287] By going beyond mineral extraction Zambia plans to create higher-value jobs that can provide long-term economic stability, reduce poverty, and improve livelihoods in mining communities. Moreover, partnerships and initiatives by Zambia's universities highlight the country's dedication to enhancing local technical skills, empowering the local population to participate in the new job opportunities generated by emerging industries. For example, local skills development initiatives include the partnership between the African Centre for Batteries, Zambia University, and Copperbelt University (see section 3.2) and the Technical Education, Vocational, and Entrepreneurship Training Authority (TEVETA), which aim to ensure that Zambia has a workforce trained in automation, mechatronics, and materials engineering, among others.[288]

Source: Prepared by the authors.

282) Chamber of Mines of Namibia, *2023 Annual Review* (Windhoek: Chamber of Mines of Namibia, April 2024), https://chamberofmines.org.na/wp-content/uploads/2024/04/2023-Chamber-of-Mines-Annual-Review.-Final-Web.pdf.

283) Ministry of Industrialisation and Trade of Namibia (Namibia MIT), *Mineral Beneficiation Strategy for Namibia Abridged Promotion Version* (Windhoek: Namibia MIT, February 2021), https://mit.gov.na/documents/41692/88507/Mineral%2BBeneficiation%2BStrategy%2Bfor%2BNamibia%2B2021.pdf.

284) Tycho Möncks, Peter Clearkin, Hans Kuipers, Anas Laabi, Emile Detry, and Martin Pocquet, *An Untapped Goldmine: Opportunities for South African Mining* (Boston: Boston Consulting Group, February 2023), https://web-assets.bcg.com/9e/16/3c097032452693ee8174bf3e3211/an-untapped-goldmine-opportunities-for-sa-mining.pdf.

285) Portfolio Committee on Trade and Industry, *Mineral Beneficiation* (Pretoria: South Africa Department of Trade, Industry and Competition, June 2020), http://www.thedtic.gov.za/wp-content/uploads/Beneficiation19-June2020.pdf.

286) Zambia Ministry of Labour and Social Security (Zambia MLSS) and Zambia Statistics Agency, *2021 Labour Force Survey Report* (Lusaka: Zambia MLSS, February 2022), https://www.mlss.gov.zm/wp-content/uploads/2023/08/2021-Labour-Force-Survey-Report.pdf.

287) Eric Werker, *A strategy for resource-led development in Zambia* (London: IGC and Simon Fraser University, September 2023), https://www.theigc.org/sites/default/files/2023-10/Werker%20Policy%20brief%20September%202023.pdf.

288) Clive Siachiyako, "TEVETA Ponders Electric Vehicle Value Chain Skills," *Zambia Daily Mail*, 25 July 2022, https://aiccra.cgiar.org/sites/default/files/2022-07/AICCRA%20Zambia%20in%20Daily%20Mail%20Ag%20Data%20Hub_0.pdf.

TABLE 20. Impacts on SDGs with direct linkages in African countries (Namibia, South Africa, and Zambia): SDG 9 (Industry, Innovation, and Infrastructure)

NAMIBIA	SOUTH AFRICA	ZAMBIA
Namibia's potential to advance SDG 9 through technological innovation in the mid- and downstream segments of critical minerals value chains is evidenced through its 2021 Mineral Beneficiation Strategy, which emphasises industrialisation and technological innovation as key drivers of economic growth. This strategy aims to increase local beneficiation activities by at least 20% by 2025, thereby promoting downstream industries growth and attracting investments.[289] The strategy includes establishing research institutes and funds to promote local participation in R&D and creation of necessary conditions for industrial infrastructure development and technological capacity improvement in Namibia. Specific battery minerals are targeted for beneficiation to create new processing plants, which will in turn create jobs, develop skills, and improve infrastructure. Namibia's international cooperation partnerships, such as the Namibia–EU Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen and the partnership with the Japan Organization for Metals and Energy Security, open up opportunities for fund mobilisation to invest in technological innovations for mineral processing, which can increase the country's industry competitiveness and new infrastructure development.[290]	South Africa's critical minerals beneficiation strategy highlights the importance of technological innovation and enhancing industrial infrastructure. The government aims to grow and strengthen local manufacturing sectors, particularly for platinum-based fuel cells and vanadium redox flow batteries. South Africa is also working to develop a local battery manufacturing industry, focusing on materials such as nickel sulphate and manganese precursors used in lithium-ion batteries.[291] These initiatives are designed to not only create jobs and build new skills in the South African population but also position South Africa as a key player in the global value chains of clean energy technologies and as a hub for technological innovation and workforce training in Southern Africa. Investments from the South African IDC and DBSA in R&D in critical minerals value chains, such as the development of titanium metal production to establish a competitive titanium industry, could significantly enhance South Africa's industrial capacity and export potential. These investments demonstrate the country's commitment to innovation and industrial growth in the critical minerals sector. South Africa is also leveraging its rich PGM resources and long history of primary extraction to expand to mid- and downstream operations of PGM derived products, building up existing expertise and infrastructure.	Zambia's resource-led development strategy prioritises industrialisation and infrastructure development through local content strategies and technological innovation. A bilateral cooperation agreement signed in April 2022 with the DRC to establish a Value Chain in Electric Battery and a supporting MOU signed between Zambia, the DRC, and the United States focus on developing an integrated EV battery value chain in Zambia and the DRC, which includes the local refining of minerals and the establishment of battery manufacturing plants. This initiative will not only foster technological innovation in mineral processing but also contribute to Zambia's industrial infrastructure with new manufacturing facilities both in mid- and downstream activities.[292] Zambia's commitment to industrialisation and infrastructure development is further emphasised in its Critical Minerals Strategy.[293] As part of this strategy, Zambia plans to create a state-owned investment company that will secure a minimum of 30% of production from future critical minerals projects. The strategy mandates that investors in the critical minerals sector source at least 35% of their procurement from local suppliers. This requirement is aimed at building the capacity of Zambian businesses and supporting the development of local industries associated with the mid- and downstream segments, such as mineral refining and battery component manufacturing. The push for local processing aligns with SDG 9 by promoting industrial innovation, infrastructure development, and sustainable economic growth through dedicated resources in higher value-added activities.

Source: Prepared by the authors.

289) Namibia MIT, *Mineral Beneficiation Strategy for Namibia*.

290) European Commission and Republic of Namibia, *Memorandum of Understanding*.

291) Portfolio Committee on Trade and Industry, *Mineral Beneficiation* (Pretoria: South Africa Department of Trade, Industry and Competition, June 2020), http://www.thedtic.gov.za/wp-content/uploads/Beneficiation19-June2020.pdf.

292) United Nations Economic Commission for Africa (UNECA), *Overview of the Zambia–DRC Electric Vehicle Battery Initiative and the Framework for the Sector* (Lusaka: UNECA, October 2023), https://www.uneca.org/eca-events/sites/default/files/resources/documents/sro-sa/sez-for-bevs-zambia/mcti_presentation_on_the_evb_initiative_uneca_workshop_02.10.23_1.pptx.

293) Zambia, "Zambia's Critical Minerals Strategy," https://www.mmmd.gov.zm/?p=3161.

TABLE 21. Impacts on SDGs with direct linkages in African countries (Namibia, South Africa, and Zambia): SDG 13 (Climate Action)

NAMIBIA

Namibia has a target to reduce 91% of its emissions by 2030 as compared to the business-as-usual scenario.

Namibia's critical minerals sector is highly energy- and water-intensive, making the incorporation of renewable energy solutions crucial for reducing emissions and mitigating climate change.[294] Through its Mineral Beneficiation Strategy, the country has committed to integrating green technologies into mineral processing activities to reduce the carbon footprint of its industrial operations, promoting energy efficiency, aligning all mining activities with climate action goals, promoting a greener approach to mineral processing in order to mitigate climate change.[295] Namibia's strategic focus on lithium and other battery minerals also supports the global transition to cleaner energy, directly contributing to climate action by providing essential materials for renewable energy storage and electric mobility technologies. By promoting the use of renewable energy within its own mining and processing activities, Namibia aligns with its national climate goals and broader global efforts to combat climate change and advance SDG 13.

SOUTH AFRICA

South Africa has committed to 31% reduction and a fixed target for greenhouse gas emissions levels of 398–510 MtCO2e by 2025, and 350–420 MtCO2e by 2030.[296]

South Africa's commitment to addressing climate change is reflected in its efforts to reduce the carbon footprint of its mining sector throughout the value chain. The country's mining sector is energy-intensive, with 77% of emissions coming from electricity use (Scope 2 emissions).[297] To mitigate these emissions, the government and mining companies are working to integrate renewable energy sources into mining operations. For instance, companies are exploring using solar and wind energy to power their operations, which could result in significant emissions reductions. Furthermore, South Africa is investing in innovative clean energy technologies in critical minerals value chains, such as platinum-based fuel cells and vanadium batteries, which contribute directly to global efforts to combat climate change by enabling the broader adoption of renewable energy systems and the decarbonisation of hard-to-abate sectors such as road transport.

ZAMBIA

Zambia has set an emissions reduction target from 25% to 47% by 2030 compared to the business-as-usual scenario using 2010 as the baseline year, and has been implementing policies and initiatives to mitigate climate change while still fostering economic growth and industrial development through the critical minerals sector.[298]

Zambia's role in the global energy transition, particularly through its collaboration with the DRC on the EV battery value chain (see Section 3.2) , positions the country as a key player in climate action efforts. Integrating critical minerals such as cobalt and copper into clean energy technologies directly contributes to reducing global greenhouse gas emissions by supporting the production of batteries essential for EVs and renewable energy storage. By increasing the share of renewable energy in its energy mix, Zambia is also on the path to reducing its own emissions.

Source: Prepared by the authors.

294) "Sustainability and key trends in the mining sector in Namibia," Global Infrastructure Magazine, https://www.bus-ex.com/article/sustainability-and-key-trends-mining-sector-namibia.

295) Namibia, Mineral Beneficiation Strategy (2021), https://mit.gov.na/documents/41692/88507/Mineral%2BBeneficiation%2BStrategy%2Bfor%2BNamibia%2B2021.pdf.

296) South Africa, South Africa First Nationally Determined Contribution Under the Paris Agreement (2021), https://unfccc.int/sites/default/files/NDC/2022-06/South%20Africa%20updated%20first%20NDC%20September%202021.pdf.

297) National Business Initiative, Decarbonizing the South African Mining Sector (Sandton: NBI, August 2021), https://www.nbi.org.za/wp-content/uploads/2021/10/NBI-Chapter-4-Decarbonising-the-South-African-Mining-Sector.pdf.

298) "Zambia," NDC Partners https://ndcpartnership.org/country/zmb.

TABLE 22. Impacts on SDGs with indirect linkages in African countries (Namibia, South Africa, and Zambia): SDG 5 (Gender Equality)

NAMIBIA	SOUTH AFRICA	ZAMBIA
Namibia's focus on inclusive growth is reflected in its Vision 2030, aimed at increasing the participation of women, youth, and people with disabilities in the mining value chain by at least 20% by 2025.[299] In addition, gender equality in the critical minerals sector is encouraged through skill development programmes, which are targeted at underrepresented groups. In sum, as mid- and downstream activities expand, the potential for more women to enter the sector, not only in low-skilled roles but also in technical and leadership positions, rises. Targeted actions by both the government and the private sector need to be implemented to avoid missing these opportunities.	Despite being a male-dominated industry, efforts are being made to promote gender equality in South Africa's mining sector. Women comprise 12% of the mining workforce, and efforts are underway to improve this number through the advance of skills development and training programmes aimed exclusively at women.[300] The government and private sector are liaising in their efforts to promote women's access to technical positions and leadership in the midstream and downstream segments of the value chain, thereby contributing to SDG 5. Moreover, policies aimed at increasing female participation in R&D activities related to beneficiation processes could bridge gender gaps in the industry if targeted actions are implemented.	Despite progress in the mining sector, Zambia still faces challenges in promoting gender equality. As of 2022, less than 10% of members of Community Resources Boards (CRBs) were women, with only 3% having ever held leadership positions.[301] However, the government and industry stakeholders are working to increase women's participation in mineral value chains, especially in the mid- and downstream segments. By promoting the inclusion of women in technical and leadership roles within mineral processing and battery manufacturing, Zambia has the potential to advance SDG 5. Training programmes to develop skills in automation, electrical engineering, and manufacturing technology are open to women and supported by targeted action, which could help close the gender gap in the critical minerals industry.

Source: Prepared by the authors.

299) Namibia Office of the President, *Namibia Vision 2030* (Windhoek: Government of the Republic of Namibia, 2004), https://www.npc.gov.na/wp-content/uploads/2021/11/vision_2030.pdf.

300) Commission for Gender Equality (CGE), *Women in the South African Economy 2024* (Pretoria: CGE, December 2023), https://www.parliament.gov.za/storage/app/media/OISD/Reports/Commission_for_Gender_Equality/2024/01-08-2024/CGE_Report_Women_in_the_South_African_Economy.pdf.

301) United States Agency for International Development (USAID), Zambian Department of National Parks and Wildlife (DNPW), and Zambia Community Resources Board Association (ZCRBA), *Zambia Community-Based Natural Resources Management (CBNRM) Governance Manuals: Gender Equality in Natural Resource Management* (Washington, DC: USAID, 2023), https://www.land-links.org/wp-content/uploads/2023/08/Gender-Booklet_508.pdf.

TABLE 23. Impacts on SDGs with indirect linkages in African countries (Namibia, South Africa, and Zambia): SDG 7 (Affordable and Clean Energy)

NAMIBIA

Through its National Renewable Energy Policy, Namibia has set a goal to generate 70% or more of its electricity from renewable sources by 2030, marking an ambitious target to significantly increase its reliance on clean energy sources like solar and wind power.[302] The Environmental Investment Fund of Namibia is working with regional electricity distributors to enhance renewable energy access through projects like a 300 kW solar mini-grid, which will supply energy to 164 households and local businesses in vulnerable communities and peri-urban areas, further demonstrating Namibia's commitment to expanding clean and affordable energy.[303]

Namibia's mineral resources are essential for the development of clean energy technologies. Lithium, in particular, is a key component for batteries used in energy storage systems, EVs, and renewable energy projects such as solar and wind power. By advancing local processing capabilities, Namibia is positioning itself as a key player in the global clean energy supply chain. The country's focus on local value addition is aligned with SDG 7.

SOUTH AFRICA

South Africa aspires to have 33% of its electricity supply from renewable sources by 2030. Most midstream activities in the country—especially those like battery components and fuel cells production—will be valuable in furthering SDG 7. The local manufacturing projects of vanadium redox flow batteries and nickel sulphate for lithium-ion batteries will support the creation of low-cost, clean energy storage solutions. These technologies are crucial in efforts to integrate renewable energy into the grid for reliable energy access. In addition, fuel cell investments in platinum-based fuel cells for various energy-related applications further support the South Africa's clean energy goals and can contribute to advancing South Africa's electrification goals.

ZAMBIA

The government has set a target to increase solar capacity to 500 MW by 2030. With this increase, solar power will account for 25% of total renewable energy generation capacity in Zambia.

Zambia's critical minerals are essential for reaching this goal by advancing clean energy technologies, particularly through the production of components for EVs and renewable energy systems. The country's goals on local refining and battery production directly support the global shift towards affordable and clean energy. By developing its mid- and downstream sectors, Zambia is contributing to the production of affordable EV batteries, which are crucial for expanding access to clean energy both domestically and internationally. Moreover, Zambia's commitment to increasing its solar energy capacity further aligns with SDG 7, as the country seeks to increase its electrification rate from the current 46% and reduce its reliance on fossil fuels.[304]

Source: Prepared by the authors.

---

302) Namibia, Ministry of Mines and Energy, National Renewable Energy Policy, July 2017, https://www.mme.gov.na/files/publications/03f_National%20Renewable%20Energy%20Policy%20-%20July%202017.pdf.

303) Environmental Investment Fund of Namibia (EIF) and Northern Namibia's regional Electricity Distributor (NORED), "Joint Media Release: Environmental Investment Fund of Namibia and NORED Partners for Solar Electrification Drive," press release, 28 August 2024, https://www.eif.org.na/post/joint-media-release-environmental-investment-fund-of-namibia-and-nored-partners-for-solar-electrification-drive.303) Namibia MIT, *Mineral Beneficiation Strategy for Namibia Abridged Promotion Version*, 32.

304) World Bank, "Zambia: Access to Electricity Changes Lives" (Washington, D.C.: World Bank, 16 February 2024), https://www.worldbank.org/en/news/video/2024/02/16/zambia-afe-access-to-electricity-changes-lives.

TABLE 24. Impacts on SDGs with indirect linkages in African countries (Namibia, South Africa, and Zambia): SDG 12 (Responsible Production and Consumption)

NAMIBIA	SOUTH AFRICA	ZAMBIA
Namibia is committed to promoting sustainable practices within its critical minerals sector that contribute to responsible production. The country has adopted measures to reduce waste generation by at least 20% by 2023, through reusing and recycling materials and implementing cleaner production principles.[305] The Mineral Beneficiation Strategy further highlights reducing the environmental impact of mining and processing activities through the incorporation of sustainable technologies and promoting resource efficiency. Namibia's emphasis on local value addition and technological advancement in critical minerals processes, therefore, not only supports economic growth but also aligns with the global push for responsible consumption and production by avoiding the reliance on raw mineral exports and promoting the efficient use of natural resources.	The beneficiation policies in South Africa's align with SDG 12. In this way, South Africa limits its import dependence by localising processing and production of critical minerals and contributes to the efficient use of natural resources. In addition, recycling policies and investment in sustainable production processes within the whole mining sector value chain minimise waste and further reduce the environmental footprint from extractive and processing activities in the critical minerals sector.	Zambia's partnership with the EU on sustainable raw materials value chains enhances the circular economy principles of reuse, recycling, and remanufacturing in critical minerals value chains.[306] These practices contribute to fulfilling SDG 12 through waste reduction and efficient resource use. Through its national policies, local content strategy, and partnerships, Zambia is implementing responsible sourcing standards that ensure the sustainable management of mineral resources throughout the value chain. This is further supported by the development of sustainable mining practices and the emphasis on local beneficiation for efficient use of natural resources.

Source: Prepared by the authors.

305) Namibia MIT, *Mineral Beneficiation Strategy for Namibia Abridged Promotion Version*, 32.

306) Memorandum of Understanding on a Partnership on Sustainable Raw Materials Value Chains Between the European Union Represented by the European Commission and the Republic of Zambia, 16 October 2023, https://single-market-economy.ec.europa.eu/system/files/2023-11/MoU_CRM_EU-Zambia_26_10_2023_signed.pdf.

TABLE 25. Impacts on SDGs with indirect linkages in African countries (Namibia, South Africa, and Zambia): SDG 15 (Life on Land)

NAMIBIA	SOUTH AFRICA	ZAMBIA
Namibia introduced comprehensive environmental legislation to ensure that mining activities along the value chain are undertaken in an environmentally friendly manner, limiting harm to ecosystems or biodiversity. The Environmental Management Act (No. 7 of 2007) enforces sustainable mining practices and land rehabilitation projects as a means of preventing environmental degradation. As the critical minerals sector expands, Namibia focuses on land conservation through policies on the use of sustainable extraction and processing methods. This includes efforts to minimise land disruption and enhance rehabilitation once mining activities are completed. This is in line with the country's commitment to biodiversity protection and land resources use in a sustainable manner.	South Africa has implemented several policies aimed at minimising the environmental impact of mining activities and protecting land ecosystems and critical habitats. The government's focus on sustainable mining practices throughout the value chain, such as mine rehabilitation and land restoration, aligns with SDG 15. For example, policies in South Africa require mining companies to rehabilitate mining sites once operations are completed, ensuring that land is restored to a usable state and biodiversity is preserved in the region (see Section 3.2). Further, the country is investing in technologies that reduce the environmental footprint of its mining operations throughout the value chain, further contributing to protecting natural habitats.	Through responsible mining practices and adherence to strict environmental standards in line with the DRC-Zambia partnership (see Section 3.2), Zambia is committed to reducing the ecological footprint of its mining industry by introducing innovative clean energy technologies into its processes. Rehabilitation of mined land contributes to attaining SDG 15 on sustainable land use practices. Through assurance of sustainability in mining operations, Zambia is contributing to the long-term conservation of biodiversity, including the sustainable use of natural resources. Finally, Zambia's emerging EV industry indirectly contributes to reducing the reliance on fossil fuel consumption, which reduces stress on critical habitats and land ecosystems.

Source: Prepared by the authors.

TABLE 26. Impacts on SDGs with direct linkages in ASP countries (India, Indonesia, and Türkiye): SDG 1 (No Poverty)

INDIA	INDONESIA	TÜRKIYE
The mining sector in India plays a key role in job creation and economic development, directly employing approximately 1.3 million people in 2023.[307] Through the "Make in India" and "Digital India" initiatives, the government is focusing on boosting domestic production in critical minerals and manufacturing, which is expected to generate significant employment opportunities, especially in mid- and downstream activities such as mineral processing and clean technology manufacturing. For instance, the INR 1891 crore (approx. USD 230.9 million) investment by Mitsubishi Electric India in Tamil Nadu will generate over 2,000 jobs.[308] Agreements like the one between the Indian Institute of Technology Indore and the Confederation of Indian MSMEs in ESDM aim to share knowledge and offer technological support, thereby enhancing skills development and education.[309] These initiatives aim to lift communities out of poverty by creating high-quality jobs in the growing critical minerals and clean energy sectors.	Indonesia's critical minerals sector has seen a reduction in employment over the past decade, dropping from approximately 2.9 million in 2011 to around 1.3 million in 2020.[310] However, recent initiatives, such as the ban on nickel ore exports introduced in January 2020, have spurred significant FDI, particularly from Chinese companies. This FDI has fueled the rapid expansion of Indonesia's midstream smelting and refining capabilities for nickel, creating new skilled jobs in processing and manufacturing. The involvement of foreign companies could also promote technology transfer and skills development through collaboration and on-the-job training.[311] These actions can lead to reducing poverty by generating employment opportunities in higher-value segments of the mineral value chain, thus promoting economic diversification and improving living standards.	Türkiye's mining sector has experienced significant growth, with employment in the sector increasing from 132,000 in 2020 to 155,000 in 2023.[312] This growth is mainly attributed to investments in mineral processing facilities and local beneficiation activities, which are generating high-value jobs in various sectors. For example, Türkiye's Beylikova Fluorite Barite and REEs Pilot Plant, which processes around 1,200 tons of REEs annually, is creating skilled jobs in the mining and processing sectors.[313] These job opportunities contribute to poverty reduction by providing stable employment in rural areas where mining activities are concentrated.

Source: Prepared by the authors.

307) "Number of People Employed by the Mining Sector in India From Financial Year 2017 to 2023," Statista, https://www.statista.com/statistics/1284360/india-mining-sector-employment.

308) "Electronics System Design & Manufacturing (ESDM) Industry in India," India Brand Equity Foundation (IBEF), October 2024, https://www.ibef.org/industry/electronics-system-design-manufacturing-esdm.

309) "Electronics System Design & Manufacturing (ESDM) Industry in India," IBEF.

310) "Indonesia Database for Policy and Economic Research," Data Bank, World Bank Group, https://databank.worldbank.org/source/indonesia-database-for-policy-and-economic-research/Series/SL.EMP.MINQ#.

311) Baskaran, *Diversifying Investment in Indonesia's Mining Sector*.

312) "Türkiye İstatistik Kurumu (TÜIK)," Türkiye İstatistik Kurumu, https://www.tuik.gov.tr/Home/Index.

313) Anadolu Agency, "Fueling Economy, Türkiye Aims to Process Tons of Critical Minerals," Daily Sabah, 29 October 2023, https://www.dailysabah.com/business/energy/fueling-economy-turkiye-aims-to-process-tons-of-critical-minerals.

TABLE 27. Impacts on SDGs with direct linkages in ASP countries (India, Indonesia, and Türkiye): SDG 9 (Industry, Innovation, and Infrastructure)

INDIA	INDONESIA	TÜRKIYE
India's focus on domestic manufacturing development aligns with SDG 9 through initiatives such as the Production Linked Incentive (PLI) Scheme, which includes sectors like renewable energy and Advanced Chemistry Cell (ACC) Battery.[314] This scheme incentivises local production of battery components and clean energy technologies, supporting the expansion of mid- and downstream activities. SEZs have also been established to promote industrial growth, with specific incentives for the critical minerals and electronics sectors. By promoting the local processing of critical minerals and manufacturing of clean energy components, India aims to build robust infrastructure and foster technological innovation, which is vital for industrial development and job creation. Most of the minerals included in India's national policies are needed to manufacture clean energy technologies like wind turbines, solar PVs, and EVs—industries that are planned to be developed in India.[315] The Indian startup ecosystem is growing, supported by government initiatives like Digital India and Startup India, which are creating new job opportunities and advancing SDG 9.[316]	Indonesia's industrial strategy emphasises building high-value-added industries integral to its critical minerals value chain. The 2020 ban on nickel ore exports has played a pivotal role in fostering the development of mid- and downstream industries, including nickel smelting and refining operations. This policy has led to substantial investments in industrial infrastructure and technology. The focus is on building a high-value-added industrial base to support the rapid digitalisation and green economy. This includes allocating low-emission energy sources to high-value industries and developing a skilled talent pool by guiding engineering and science graduates toward employment in technology companies. The downstream policy also encourages the development of battery materials, lithium batteries, and EVs, directly contributing to SDG 9 by strengthening industrial capacity, innovation, and infrastructure.	Türkiye is focused on enhancing its industrial capacity through several projects, such as the Beylikova Fluorite Barite and REEs Pilot Plant, which plays a key role in processing critical minerals domestically. This facility is critical for producing rare earth oxides used in high-tech products, renewable energy technologies, and the defence industry. Türkiye's strategic shift from exporting raw materials to producing finished products domestically aligns with SDG 9 by fostering innovation, industrialisation, and infrastructure development. For instance, initially announced in 2017, Türkiye's first domestically produced vehicle, the all-electric Togg or T10X, was launched in 2023, further increasing the country's industrial and infrastructure capacity with the support of government policies that have lowered taxes for the Togg EV.[317] Moreover, Türkiye stands to gain even further industrial development through the potential use of advanced technologies such as next-generation networks, automation and robotics, virtual simulation, IoT, and AI in mineral processing. Türkiye's recent technological innovations in producing lithium from boron waste showcase innovative approaches to resource utilisation that can create additional opportunities for industrial infrastructure.

Source: Prepared by the authors.

314) India, Production Linked Incentive (PLI) Schemes (2020), https://www.investindia.gov.in/production-linked-incentives-schemes-india.

315) Council on Energy, Environment and Water (CEEW), International Energy Agency (IEA), UC-Davis, and World Resources Institute (WRI), India, *Addressing Vulnerabilities in the Supply Chain of Critical Minerals* (New Delhi: CEEW, IEA, UC-Davis, and WRI-India, April 2023), https://www.ceew.in/sites/default/files/addressing-critical-minerals-supply-chain-vulnerabilities-india.pdf.

316) "Electronics System Design & Manufacturing (ESDM) Industry in India," IBEF.

317) Hacer Boyacıoğlu, "Local Electric Car Togg Given Tax Advantage," Hürriyet Daily News, 2 July 2022, https://www.hurriyetdailynews.com/local-electric-car-togg-given-tax-advantage-175009.

TABLE 28. Impacts on SDGs with direct linkages in ASP countries (India, Indonesia, and Türkiye): SDG 13 (Climate Action)

INDIA

India aims to reduce greenhouse gas emissions by one billion metric tons from 2021 to 2030.[318]

Critical minerals such as lithium, cobalt, and REEs are essential to these efforts, as they are crucial for the production of solar panels, wind turbines, and energy storage systems that will contribute to domestic and international decarbonisation of the electricity sector. India's focus on domestic production of these minerals through beneficiation and midstream processing supports its climate goals by ensuring a stable supply chain for clean energy technologies. Additionally, local companies have committed to invest in efforts to mitigate climate change. For instance, Hindustan Zinc has pledged to invest USD 1 billion by 2025 to achieve net-zero carbon emissions.[319]

INDONESIA

Indonesia has made significant strides in integrating its critical minerals sector with broader climate action goals. The country has an unconditional emissions reduction target of 29% and a conditional target of 41% as compared to business-as-usual scenarios.[320] The government's downstream policy for nickel has contributed to this by supporting the production of battery materials and EVs, which are crucial for reducing global greenhouse gas emissions. Additionally, Indonesia is committed to using low-emission energy in its high-value industries and promoting the development of sustainable battery ecosystems. This includes building solar PV power generation systems in critical mineral processing plants to create zero-carbon intelligent factories, aligning with both national and global climate action initiatives.[321]

TÜRKIYE

Türkiye has pledged to reduce its greenhouse gas emissions by 41% through 2030 (695 Mt CO_2 eq in 2030) compared to the business-as-usual scenario.[322]

Türkiye is incorporating sustainable practices into its critical minerals sector to support its climate goals. The country's focus on producing REEs and lithium from boron waste is an example of how Türkiye is aligning its mineral processing activities with SDG 13 by reducing waste and promoting the use of environmentally friendly technologies. These practices contribute to lowering the carbon footprint of mineral processing operations, thus supporting global efforts to combat climate change.

Source: Prepared by the authors.

318) "India," NDC Partnership, https://ndcpartnership.org/country/ind.

319) Vendanta Limited and Hindustan Zinc Limited, *Hindustan Zinc Limited Task Force on Climate-Related Financial Disclosures Report 2022* (Rajasthan: Hindustan Zinc Limited, 2022), https://www.hzlindia.com/wp-content/uploads/HZL-TCFD-Report-21-22.pdf.

320) "Indonesia," NDC Partners, https://ndcpartnership.org/country/idn.

321) Septian Hario Seto, *Critical Minerals Value Added Policies: Indonesia's Story* (Geneva: UN Trade and Development, April 2024), https://unctad.org/system/files/non-official-document/SSE_UNCTAD_Day2_final.pdf.

322) "Türkiye," NDC Partners https://ndcpartnership.org/country/tur.

TABLE 29. Impacts on SDGs with indirect linkages in ASP countries (India, Indonesia, and Türkiye): SDG 5 (Gender Equality)

INDIA	INDONESIA	TÜRKIYE
India's critical minerals sector is contributing to gender equality by actively promoting the inclusion of women in the workforce. The Mitsubishi Electric India project, which aims to create over 2,000 jobs, has committed to reserving 60% of these positions for women.[323] This initiative explicitly addresses the gender imbalance in the manufacturing and clean energy sectors in India. This type of targeted action directly contributes to advancing SDG 5. Moreover, by fostering skills development and offering opportunities in traditionally male-dominated industries, India can further advance gender equality.	Indonesia's critical minerals sector has the potential to promote gender inclusion. As part of its downstream policy, the government has introduced measures that, by having significant job-creation potential (see Table on SDG 1) can include women in the workforce for new industries, such as battery manufacturing and technology-driven sectors. Training programmes and job creation initiatives (see Table on SDG 1) in areas like engineering and science are being implemented to ensure that these opportunities are also available to women. If supported by additional targeted actions from the public and private sectors, these efforts support the broader goal of achieving SDG 5 by fostering an inclusive workforce in the growing midstream and downstream sectors.	As the critical minerals sector grows, new job opportunities are being created (see Table on SDG 1), and targeted efforts should be underway to ensure that women are included in this new workforce. Training programmes and initiatives targeting women for technical roles in processing and manufacturing have the potential to be implemented, aligning with SDG 5 by promoting gender inclusion and equality. Work still needs to be done in Türkiye regarding gender equality since, as of December 2020, only 44% of indicators needed to monitor SDGs from a gender perspective were available.[324]

Source: Prepared by the authors.

323) "Electronics System Design & Manufacturing (ESDM) Industry in India," IBEF.

324) "Türkiye," UN Women | Women Count, https://data.unwomen.org/country/turkey.

TABLE 30. Impacts on SDGs with indirect linkages in ASP countries (India, Indonesia, and Türkiye): SDG 7 (Affordable and Clean Energy)

INDIA	INDONESIA	TÜRKIYE
India has set ambitious targets in advancing renewable energy expansion, such as achieving 500 GW of non-fossil energy capacity and meeting 50% of energy requirements from renewable sources by 2030.[325] India's critical minerals are essential for the production of clean energy technologies, including solar PV products, wind turbines, and energy storage systems. The government's PLI Scheme supports the manufacturing of these technologies, ensuring that India can meet its growing energy demands through sustainable and renewable sources. Developing local manufacturing facilities for clean energy components helps reduce costs and ensures a reliable supply of technologies needed for India's energy transition, directly contributing to SDG 7.	The country aims to increase its renewable energy mix to 23% by 2025, with a focus on solar, geothermal, and bioenergy.[326] Indonesia's focus on developing its nickel and battery materials sectors plays a crucial role in advancing this goal. The country's policy to integrate renewable energy into its high-value industries (see section 3.3), along with the promotion of battery materials for EVs and energy storage systems, supports the global transition to clean energy. These efforts reduce Indonesia's dependence on fossil fuels and promote the use of sustainable energy sources.	Türkiye's National Energy Plan aims to increase the share of renewable energy in electricity generation to 64.7% by 2035.[327] Türkiye's critical minerals, particularly boron and REEs, are essential for producing technologies that support this goal. The country's investment in processing these minerals domestically helps reduce costs and ensures a stable supply of components for renewable energy technologies such as wind turbines and EVs. Several plants and processing facilities are contributing to the production of critical materials necessary for clean energy systems (see Table on SDG 9).

Source: Prepared by the authors.

325) The Council of Energy, Environment and Water (CEEW), International Energy Agency, Institute of Transportation Studies UC Davis, and World Resources Institute India (WRII), *Addressing Vulnerabilities in the Supply Chain of Critical Minerals* (New Delhi: CEEW, April 2023),

https://www.ceew.in/sites/default/files/addressing-critical-minerals-supply-chain-vulnerabilities-india.pdf.

326) BPS-Statistics Indonesia, *Valuation of Renewable Energy Resources in Indonesia* (Geneva: United Nations Economic and Social Council (UNECE), March 2024), https://unece.org/sites/default/files/2024-04/19_Valuation%20of%20Renewable%20Energy%20Resources%20in%20Indonesia.pdf.

327) Türkiye Ministry of Energy and Natural Resources, *Türkiye National Energy Plan* (Ankara: Türkiye Ministry of Energy and Natural Resources, 2022), https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/TUEP/Türkiye_National_Energy_Plan.pdf.

TABLE 31. Impacts on SDGs with indirect linkages in ASP countries (India, Indonesia, and Türkiye): SDG 12 (Responsible Production and Consumption)

INDIA

India is taking significant steps to promote responsible production practices within its critical minerals sector. National policies on e-waste and battery-waste management (see Section 3.3) emphasise the need for reusing and recycling minerals to reduce the demand for new mining. Circular economy initiatives within the electronics sector in India are also projected to unlock USD 7 billion in untapped revenue by 2035 through circular business models, with a projected market size for circular models at USD 13 billion in 2035.[328] These practices are integral to reducing waste and promoting the efficient use of resources, aligning with SDG 12.

INDONESIA

Indonesia's downstream policies are also aligned with efforts to achieve SDG 12. The government has implemented sustainability standards across the mining and processing sectors, geared toward ensuring that industrial waste is managed sustainably. The traceability and transparency systems for nickel production are designed to monitor and evaluate the environmental impact of smelting and refining processes, ensuring compliance with international frameworks. Additionally, the promotion of circular economy practices in the battery industry (see Section 3.3), including recycling and the safe disposal of industrial waste, underscores Indonesia's commitment to responsible production and consumption.

TÜRKIYE

Türkiye's is taking significant steps to ensure that its mineral processing sector aligns with SDG 12 by adopting responsible consumption and production practices. The production of lithium from boron waste at the Beylikova Plant showcases Türkiye's innovative approach to resource utilisation (see Table on SDG 9). This not only reduces waste but also enhances resource efficiency, supporting a circular economy in the critical minerals sector.

Source: Prepared by the authors.

328) "Electronics System Design & Manufacturing (ESDM) Industry in India," IBEF.

TABLE 32. Impacts on SDGs with indirect linkages in ASP countries (India, Indonesia, and Türkiye): SDG 15 (Life on Land)

INDIA	INDONESIA	TÜRKIYE
The Indian government is focused on ensuring that mining activities are conducted in a manner that minimises environmental degradation and protects ecosystems (see Section 3.3). India's commitment to transparent and sustainable mining practices reflects its dedication to aligning the mining sector with the goals of SDG 15. Moreover, technological innovations in the mid- and downstream segments of critical minerals value chains can contribute to minimise environmental impact even further (see Table on SDG 9).	Indonesia's critical minerals sector also addresses SDG 15 by implementing strict environmental regulations in mining and refining processes. The government has banned deep-sea tailings placement and requires all high-pressure acid leach (HPAL) facilities to use tailings dams or dry stacking methods to mitigate the environmental impact of mining.[329] By promoting sustainable land use and ensuring that mining practices minimise harm to terrestrial ecosystems, Indonesia is contributing to the long-term conservation of its natural resources and biodiversity.	Türkiye has implemented several environmental safeguards to protect terrestrial ecosystems from the impact of mining activities throughout the value chain (see Section 3.3). The government is promoting sustainable land use practices in the mining sector and ensuring that extraction and processing activities have minimal impact on biodiversity and natural habitats by introducing innovative technologies in processing and recycling critical minerals (see Table on SDG 9), further advancing SDG 15.

Source: Prepared by the authors.

329) Seto, *Critical Minerals Value Added Policies: Indonesia's Story*.

TABLE 33. Impacts on SDGs with direct linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 1 (No Poverty)

ARGENTINA

Argentina's mining sector, particularly in lithium and copper, has seen job growth, with the mining workforce reaching 40,243 workers in 2023, a 7.6% increase compared to the previous year.[330] Projects like the Chinese Hanaq Group's pilot plant for lithium carbonate, which has a production capacity of 3,000 tons per year, and Arcadium Lithium's expansion that aims to double sales volumes by 2028 are driving this employment growth and indicate progress in downstream capabilities.[331] These initiatives are generating high-value jobs in regions where mining operations are concentrated, contributing to poverty alleviation by offering stable employment opportunities. The continued expansion of Argentina's lithium sector, projected to make the country the second-largest lithium producer globally by 2027, will likely create jobs and require skilled labour. Moreover, the recently passed Large Investment Incentive Scheme (RIGI), which aims to attract large-scale capital investments into strategic sectors, including mining, could lead to job creation and the need for skilled labour in the mining sector.[332]

BRAZIL

As of January 2023, Brazil's mining sector employed 201,357 people, a slight increase from 198,145 the previous year.[333] The expansion of Brazil's lithium sector, especially in the Lithium Valley in Minas Gerais, is expected to create more jobs, particularly in mineral processing. This development directly contributes to poverty reduction by creating high-value employment opportunities in rural regions that rely heavily on mining resources. Companies like Sigma Lithium, which is expanding its production capacity and exploring new ore bodies, are generating job opportunities that support both local economies and national employment growth.[334] The government's drive for critical mineral value chain industrialisation will need a skilled workforce, resulting in job creation and the demand for skill development.The National Service for Industrial Training (SENAI) has included specialised training programmes for mineral processing skills development, as well as research projects aimed at developing new technologies to optimise resource use and minimise environmental impact (see section 2.4.3).

MEXICO

Mexico's mining industry is a significant contributor to the national economy and a major source of employment, particularly in rural and underdeveloped regions. The sector supported more than 400,000 direct jobs and over 2 million indirect jobs, providing livelihoods for communities that otherwise face limited economic opportunities.[335] The recent discovery of large lithium deposits in Sonora (see Section 3.4), estimated to contain 8.8 million tons of lithium, has sparked renewed interest in the country's potential as a global supplier of critical minerals. More importantly, the Mexican government has nationalised lithium production, creating a new state-owned company, LitioMx, to ensure that the economic benefits from the entire lithium value chain are shared with local communities (see Section 3.4). This initiative is expected to create thousands of new jobs, particularly in mid- and downstream processing, contributing to poverty reduction by diversifying employment opportunities and promoting regional development.

Source: Prepared by the authors.

---

330) Dirección Nacional de Promoción y Economía Minera, *Empleo Minero en Argentina* (Buenos Aires: DNPEM, January 2024), https://www.argentina.gob.ar/sites/default/files/14_empleo_minero_en_argentina_-_enero_2024.pdf.

331) "Empresa china Hanaq Group pondrá en marcha una planta piloto de 3.000 toneladas de litio," Ámbito, 28 September 2024 https://www.ambito.com/energia/empresa-china-hanaq-group-pondra-marcha-una-planta-piloto-3000-toneladas-litio-n6064867.

332) Argentina Ministry of Economy, Mining Secretariat, interview by the authors, 16 September 2024.

333) IBRAM, *Mining in Figures* (Belo Horizonte: IBRAM, 2022), https://ibram.org.br/wp-content/uploads/2023/03/Infografico_Mineracao_em_Numeros-2022-ingles.pdf.

334) Renato Rostás, "Brazil's Sigma mulls midstream lithium chemical production," *Fastmarkets*, 5 February 2024, https://www.fastmarkets.com/insights/brazils-sigma-mulls-midstream-lithium-chemical-production.

335) "Minería", Gobierno de México, https://www.gob.mx/se/acciones-y-programas/mineria.

TABLE 34. Impacts on SDGs with direct linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 9 (Industry, innovation and infrastructure)

ARGENTINA	BRAZIL	MEXICO
Argentina's efforts to develop mid- and downstream processing capabilities are directly aligned with SDG 9. The government's Large Investment Incentive Scheme (RIGI) (see Section 2.4.2) is set to promote local value addition and industrialisation, particularly bolstering the lithium-ion battery manufacturing industry, as well as copper processing facilities. The construction of new lithium and copper processing plants is creating industrial infrastructure that supports the growth of clean energy technologies, such as EV batteries. Moreover, the RIGI requirement to include a technological innovation proposal and a commitment that at least 20% of the project's supplier payments be allocated to local suppliers in order for the project to get approval further incentivises industrial and innovation development. Argentina primarily extracts lithium from brine, but instead of exporting the raw brine, the country exports lithium carbonate, showcasing the development of indigenous midstream technology that demands innovation and infrastructure growth. Additionally, given Argentina's vast lithium potential, Y-TEC, in collaboration with La Plata National University, has developed a proprietary battery model, further advancing the country's technological capabilities in the sector.[336] Argentina's ambitions to become a global leader in lithium processing and battery manufacturing represent the country's drive to integrate high-tech innovations into its industrial landscape and advance SDG 9.	Brazil is making significant strides in advancing SDG 9 by emphasising the development of mid- and downstream processing capacities in critical minerals like lithium and REEs. The government's push to industrialise and develop value chains within Brazil is exemplified by programmes such as the Programme for Mining and Development and the Science Technology and Innovation Action Plan for Strategic Minerals, both of which include specific measures to advance new industry and markets, research, development, and innovation.[337] Sigma Lithium's plans to increase production and explore chemical production for lithium highlight Brazil's growing role in the global battery supply chain, further solidifying its infrastructure and industrial capabilities. The involvement of research and innovation institutions such as SENAI and CETEM in developing innovative technologies in the critical minerals mid- and downstream segments of the critical minerals value chains has resulted in significant industrial and infrastructure advancements, with the potential to continue growing in the coming decades (see Section 2.4.3). Mobilisation of resources through different initiatives and financial mechanisms further advance SDG 9 (see Section 2.4.4). For instance, the Brazil Critical Minerals Fund will stimulate investments in strategic critical minerals, including lithium, nickel, cobalt, and REEs, targeting SMEs, supporting projects that enhance Brazil's supply chain capabilities for clean energy technologies and decarbonisation efforts beyond extraction.	Mexico is actively working to strengthen its industrial infrastructure by investing in mid- and downstream processing capacity for critical minerals. The country is already a significant producer of copper, zinc, and silver, but its lithium reserves offer an opportunity to diversify and industrialise further. The Sonora Lithium Project, a joint venture between LitioMx and private investors, aims to establish a local supply chain for lithium-ion batteries, essential for EVs and renewable energy storage (see Section 3.4). As part of this project, De Luna Lithium Battery is constructing a new lithium-ion battery facility in Mexico State and is expected to start producing 20,000 lithium batteries annually. The start of operations of this new plant is expected to enhance Mexico's infrastructure and generate at least 1,000 jobs.[338] De Luna Lithium Battery is also set to supply batteries for several companies to convert diesel trucks to EVs. According to the company, converting combustion vehicles to electric presents a significant opportunity for the country, as it can be done at a quarter of the cost of a new EV, which has the potential to establish a robust EV conversion industry in the country.[339] These initiatives not only enhance Mexico's industrial capabilities but also fosters technological innovation in the production of battery-grade lithium and other advanced materials. Additionally, Mexico is investing in modernising its transport infrastructure, with the aim of creating a more efficient value chain, which further supports SDG 9 (see section 2.4.3).

Source: Prepared by the authors.

336) Argentina Ministry of Economy, Mining Secretariat, interview by the authors, 16 September 2024.

337) Nicholas Pope and Peter Smith, *Brazil's Critical and Strategic Minerals in a Changing World* (Rio de Janeiro: Igarapé Institute, October 2023), https://igarape.org.br/wp-content/uploads/2023/10/Critical-and-Strategic-Minerals.pdf.

338) Tzuara De Luna, "De Luna Lithium Battery le dice adiós a Sonora y traslada su inversión a Edomex," *Expansión*, 14 August 2023, https://expansion.mx/empresas/2023/08/15/de-luna-lithium-battery-adios-sonora-traslada-a-edomex.

339) Tzuara De Luna, "De Luna Lithium Battery invertirá 80 mdd en una planta de baterías de litio," Expansión, 19 January 2023, https://expansion.mx/empresas/2023/01/19/primera-planta-de-baterias-de-litio-sonora.

REGION: LAC

TABLE 35. Impacts on SDGs with direct linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 13 (Climate Action)

ARGENTINA	BRAZIL	MEXICO
Argentina's nationally determined contribution (NDC) aims to limit net emissions to 349 $MtCO_2e$ in 2030. This is a 27.7% reduction from the target in its first NDC, submitted in 2016.[340] Argentina's rich reserves of lithium and copper are essential in achieving this goal and advancing SDG 13, considering their relevance for producing clean energy technologies, particularly EV batteries. The country's commitment to sustainable mining practices reflects Argentina's alignment with SDG 13, with efforts to ensure that its mining activities contribute to reducing global greenhouse gas emissions. Additionally, Argentina's participation in the Extractive Industries Transparency Initiative (EITI) ensures transparency and responsibility in its mining operations, further promoting sustainable development.[341]	Brazil is committed to reducing emissions by 37% in 2025, and by 50% in 2030 as compared to a 2005 base year.[342] Brazil is actively positioning itself as a leader in green technological innovation and climate action. The country's policies, regulations, initiatives, and financial mechanisms directed to the development of critical minerals value chains, particularly for lithium and graphite, fit into the global l efforts to transition to clean energy. Lithium and graphite are vital components of EV batteries and energy storage systems, and Brazil's expansion in this sector supports the global push to reduce carbon emissions . Additionally, Brazil joined the Industrial Deep Decarbonisation Initiative (IDDI) in 2023, committing to sustainable practices in the mining and industrial sectors.[343] These efforts underscore Brazil's role in mitigating climate change through innovation in mineral processing and renewable energy production.	Mexico is committed to its climate goals under the Paris Agreement. It committed to an unconditional emissions reductions target of 35% and a conditional target of 40% by 2030.[344] The development of the lithium value chain is a critical component of Mexico's broader strategy to transition to a low-carbon economy. Lithium, a key component in batteries for EVs and energy storage systems, is central to this transition. The Sonora Lithium Project aligns with Mexico's commitment to SDG 13 by supporting the global shift towards electric mobility and renewable energy, which are essential for reducing greenhouse gas emissions. Mexico's investments in technology innovation to process lithium and in establishing lithium-ion battery plants are crucial for decarbonizing both the energy and transportation sectors (see Table for SDG 9).

Source: Prepared by the authors.

340) "Argentina," NDC Partnership, https://ndcpartnership.org/country/arg.

341) "Argentina," Extractive Industries Transparency Initiative, https://eiti.org/countries/argentina.

342) "Brazil," NDC Partnership, https://ndcpartnership.org/country/bra.

343) UNIDO, "Brazil Joins the Industrial Deep Decarbonization Initiative."

344) "Mexico," NDC Partnership, https://ndcpartnership.org/country/mex.

TABLE 36. Impacts on SDGs with indirect linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 5 (Gender Equality)

ARGENTINA	BRAZIL	MEXICO
As of September 2023, women held 11.6% of total mining jobs in Argentina, with female employment in the sector increasing by 20.2% year-on-year.[345] This growing inclusion of women in mining highlights Argentina's efforts to promote gender equality by creating opportunities for women in technical and leadership roles in traditionally male-dominated industries. However, Argentina is currently facing uncertainty regarding the advancement of SDG 5 following the rise of the Javier Milei Administration, which has made decisions such as dismantling the Ministry of Women's Affairs and the rolling back of gender inclusion policies.[346]	Brazil is promoting gender equality in its mining sector, as demonstrated by initiatives to develop technical and leadership skills among women in mining communities. These initiatives include partnerships with educational institutions that focus on professional training for women, ensuring that they are equipped to participate in the growing critical minerals sector.[347] Such targeted efforts directly contribute to SDG 5 by fostering an inclusive workforce in the expanding clean energy and mining industries.	Mexico has made progress in promoting gender equality in the mining sector, though challenges remain. Women currently represent about 15.8% of the workforce in the Mexican mining industry.[348] The nationalisation of lithium through LitioMx, the development of innovative technologies across the lithium value chain, and the construction of processing and manufacturing facilities present unique opportunities for both the government and the private sector to set new standards for gender inclusion. Laws such as the General Law for Women Equality set the ground for targeted action to further advance SDG 5.[349]

Source: Prepared by the authors.

345) GIZ, *A Gendered Analysis of Employment and Skills in the Large-Scale Mining Sector in Argentina* (Santiago: GIZ, February 2023), https://minsus.net/en/Media-Publicaciones/a-gendered-analysis-of-employment-and-skills-in-the-large-scale-mining-sector-in-argentina.

346) Noël James, "Women This Week: Milei Administration Dissolves Argentina's Ministry of Women," *Council on Foreign Relations* (blog), June 14, 2024, https://www.cfr.org/blog/women-week-milei-administration-dissolves-argentinas-ministry-women.

347) Women in Mining Brazil and EY, *Progress Report of the Action Plan for the Advancement of Women in the Mining Industry - Year 1* (Belo Horizonte: WIM Brasil, October 2021), https://www.wimbrasil.org/wp-content/uploads/2022/04/Report_WIM_2021-EN-v2.pdf.

348) Karin Dilge, "Share of Women Working in the Mining Sector Increases," *Mexico Business News*, 23 September 2022, https://mexicobusiness.news/mining/news/share-women-working-mining-sector-increases.

349) Mexico, General Law for Equality Between Women and Men, latest amendment 29 December 2023, https://www.diputados.gob.mx/LeyesBiblio/pdf/LGIMH.pdf.

TABLE 37. Impacts on SDGs with indirect linkages in LAC countries (Argentina, Brazil, and Mexico): SDG SDG 7 (Affordable and Clean Energy)

ARGENTINA	BRAZIL	MEXICO
Argentina aims to increase the share of non-hydro renewables in its power mix to 20% by the end of 2025 and to 47% by 2030. In 2023, Argentina reached 18%.[350] Argentina's lithium and copper reserves are essential components for advancing these goals and producing clean energy technologies, particularly those used in EV batteries and renewable energy systems. By expanding its mid- and downstream processing capabilities, Argentina is positioning itself as a key player in the global supply chain for clean energy technologies, directly and globally contributing to SDG 7. Projects like the construction of lithium carbonate plants[351] are critical for developing a sustainable supply chain for renewable energy technologies.	Brazil is a leader in renewable energy, with a focus on hydropower, onshore wind, and emerging technologies like offshore wind and green hydrogen, accounting for more than 80% of its electricity mix being clean.[352] The development of critical minerals such as lithium, niobium, and nickel is essential for supporting clean energy solutions, particularly in the production of EV batteries, energy storage systems and renewable energy components. Brazil's commitment to developing innovation in technology in mid- and downstream segments of the critical minerals value chain through multiple programmes and initiatives (see Section 3.4) aligns with SDG 7 by providing the necessary components for the global transition to renewable energy sources.	The government has set targets to increase the share of renewable energy in its energy mix, with a goal of generating 35% of its electricity from clean sources by 2024.[353] The critical minerals sector, particularly the lithium value chain, is essential to this transition. Sonora, the region where the largest lithium reserves are located, is also a hub for solar energy production.[354] Mexico's aim to leverage its lithium reserves to develop a domestic supply chain for lithium-ion batteries, which are crucial for energy storage systems that support the integration of renewable energy into the grid, aligns with SDG 7 by ensuring that Mexico has the necessary resources to produce affordable batteries that can store renewable energy, thus making clean energy more reliable and accessible. Mexico's increasing investments in wind and solar power,[355] combined with its lithium development strategy, position the country as a regional leader in advancing clean energy production.

Source: Prepared by the authors.

350) "Argentina," International Energy Agency (IEA), https://www.iea.org/countries/argentina.

351) Secretariat of Mining, *Mining Potential in Argentina* (Berlin: Argentina Ministry of the Economy, February 2024), https://www.argentina.gob.ar/sites/default/files/mining_potential_in_argentina_pdac_2024.pdf.

352) "Brazil," International Energy Agency (IEA), https://www.iea.org/countries/brazil.

353) Mexico, Energy Transition Law (2015), https://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf.

354) Karina Suárez, "El parque fotovoltaico más grande de América Latina se encenderá en abril en Sonora," *El País*, 3 February 2023, https://elpais.com/mexico/2023-02-03/el-parque-fotovoltaico-mas-grande-de-america-latina-se-encendera-en-abril-en-sonora.html.

355) Mexico, Energy Secretariat, ""México se encuentra entre los primeros diez países del mundo más atractivos y con mayor inversión en energías renovables," *Secretaría de Energía* (blog), 12 August 2018, https://www.gob.mx/sener/articulos/mexico-se-encuentra-entre-los-primeros-diez-paises-del-mundo-mas-atractivos-y-con-mayor-inversion-en-energias-renovables.

TABLE 38. Impacts on SDGs with indirect linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 12 (Responsible Production and Consumption)

ARGENTINA	BRAZIL	MEXICO
Argentina's commitment to sustainable and transparent mining aligns with SDG 12. The country's focus on local beneficiation and the development of downstream processing capabilities, such as lithium carbonate production, ensures that natural resources are used efficiently and sustainably. Argentina's National Strategy for the Circular Economy (see Section 3.4) requires the application of circular economy principles and initiatives across various sectors, including critical minerals value chains. This strategy promotes responsible production and consumption by including subsidies for recycling facilities, grants for circular economy projects, and incentives for companies that incorporate recycled materials into their products.	Brazil is committed to developing sustainable and efficient value chains for critical minerals, consistent SDG 12. The country's Critical Minerals Fund (see Section 3.4), which promotes research and innovation in the mining sector, emphasises the adoption of new technologies in order to increase the sustainability of mineral production. In this sense, Brazil is increasing resource efficiency and promoting reduced consumption and production by adding value to critical minerals domestically, instead of exporting raw materials.	Mexico'sstrict environmental protection policies (see Section 3.4) require that mining activities throughout the value chain, especially the critical minerals extraction and processing, are compatible with sustainable development. The General Law on Mining was updated to incorporate higher environmental and social standards, in accordance with SDG 12 (see Section 3.4). In this context, the regulations demand responsible mining practices, including minimal environmental impact, reduction of wastes, and the protection of ecosystems, among other measures. The government also promotes circular economy principles in the critical minerals sector, especially through recycling initiatives for lithium-ion batteries and innovative lithium processing techniques (see Section 3.4). Mexico's focus on sustainable production is also supported by its commitment to the Extractive Industries Transparency Initiative (EITI), which promotes transparency and accountability in the mining sector.[356]

Source: Prepared by the authors.

356) "Mexico," EITI, https://eiti.org/countries/mexico.

TABLE 39. Impacts on SDGs with indirect linkages in LAC countries (Argentina, Brazil, and Mexico): SDG 15 (Life on Land)

ARGENTINA	BRAZIL	MEXICO
Through its commitment to responsible mining, Argentina contributes to advancing SDG 15 by helping ensure that mining operations are conducted sustainably and that land use is managed responsibly. The emphasis on transparent, responsible, and sustainable mining practices through Argentina's demonstrated commitment to the EITI evidences the country's plan to preserve its biodiversity and terrestrial resources while advancing industrial development.[357]	Brazil's efforts to protect its natural ecosystems, particularly in regions like the Amazon, are aligned with SDG 15. The country is combating illegal logging and mining while promoting sustainable land use in its critical minerals sector.[358] Stringent legal requirements on environmental protection across the critical minerals value chains (see Section 3.4) contribute to efforts to preserve biodiversity and ensure that mining activities do not lead to long-term environmental degradation.	Mexico's mining value chains are subject to stringent environmental regulations aimed at protecting biodiversity and ensuring sustainable land use. The country's critical minerals sector, particularly in the lithium-rich Sonora region, operates under legal frameworks that emphasise environmental conservation and ecosystem protection (see Section 3.4). In addition, companies involved in both the extraction and processing of critical minerals are required to implement land rehabilitation programmes to restore ecosystems affected by their operations. These measures contribute to SDG 15 by promoting the sustainable management of Mexico's natural resources and protecting its diverse ecosystems from the adverse effects of mining.

Source: Prepared by the authors.

357) "Argentina," EITI.

358) Patricia I. Vásquez, "Brazil's Critical Minerals and the Global Clean Energy Revolution," *Wilson Center*, 2 October 2024, https://www.wilsoncenter.org/article/brazils-critical-minerals-and-global-clean-energy-revolution.

SDG Assessment of Technological Innovations

This section systematically scores and ranks the actual and potential contributions of technological innovation projects within the mid- and downstream segments of critical minerals value chains to selected SDGs indicated in Table ABC. Growing demand for critical minerals for the clean energy transition raises concerns regarding sustainable resource management, social equity, and environmental impact. By focusing on technological innovations in the mid- and downstream segments of critical minerals value chains—such as advanced processing, refining, and recycling technologies—the assessment identified solutions that advance not only technological innovation, but also the achievement of the selected SDGs.

The six technological innovations assessed were selected from the project pipeline based on their strong potential to advance sustainable development in the critical minerals sector and country-specific considerations that could leverage and maximise that potential:

- Indonesia has a long history of upstream nickel extraction, and **GEM QMB**'s nickel processing technology can leverage this existing platform to advance SDGs rapidly.
- **Kalyon**'s vertically integrated solar panel production plant in Türkiye is a state-of-the-art facility that covers both mid- and downstream processes of solar panel manufacturing, creating high potential to make progress in various SDGs.
- South Africa serves as a technological innovation hub in Southern Africa, which provides an enabling environment for **Cwenga Lib**'s modular battery recycling technology to drive sustainable development.
- **Arcadium**'s LIOVIX® technology is leveraging Argentina's international cooperation partnerships and robust upstream expertise in the lithium value chain to implement its innovative technology with high potential to propel SDGs.
- The recently discovered clay lithium deposit in Mexico offers the resource availability to scale up **Bacanora**'s lithium processing technology and drive sustainable development in the Sonora region.
- **Tata Chemicals** has a robust infrastructure to maximise its recycling technologies to advance SDGs in India.

The methodology of this assessment employed a qualitative-to-quantitative approach, where a range of indicators corresponding to each SDG is used to evaluate the actual or potential impact of these technologies. These SDG indicators have been selected based on a review of the UN SDG metadata repository[359] database and the White Paper: Mapping Mining to the Sustainable Development Goals: An Atlas,[360] which specifically adapts SDG indicators for relevance to the mining and minerals sector. As a result, the assessment reflects the SDGs as well as the specific challenges and opportunities in the mid- and downstream segments of critical minerals value chains.

Value Creation Analysis, Scoring, and Ranking System

The scoring and ranking system used in the SDG assessment is built on a robust value creation analysis, which evaluates each technology's contributions to the selected SDGs. Each SDG is analysed through a comprehensive set of indicators that help monitor progress of each SDG. For instance, in the case of SDG 1 (No Poverty), a technology might be scored based on its job creation potential and ability to provide inclusive employment opportunities in local communities. Similarly, for SDG 13 (Climate Action), the technology's ability to reduce greenhouse gas emissions or its efficiency in minimising environmental degradation will be key factors in determining its score. All indicators analysed for each SDG are listed at the top of Tables 42–47.

359) "SDG Indicators Metadata Repository," Sustainable Development Goals, https://unstats.un.org/sdgs/metadata.

360) Columbia Center on Sustainable Investment (CCSI), UN Sustainable Development Solutions Network (SDSN), UN Development Programme (UNDP), and World Investment Forum (WEF), *Mapping Mining to the Sustainable Empowered lives. Resilient nations. Development Goals: An Atlas* (Cologny/Geneva: WEF, July 2016), https://ccsi.columbia.edu/sites/default/files/content/docs/publications/Mapping_Mining_SDGs_An_Atlas.pdf.

The value creation analysis is a step-by-step qualitative analysis on the potential that these technologies can unlock to advance SDGs. First, each technology is evaluated based on its specific value proposition, which describes **what** the technology achieves (e.g., more efficient lithium extraction, reduced reliance on virgin materials, or improved energy efficiency). The value creation process—**how** the technology achieves its goals—is then examined, followed by a discussion of how the captured value can potentially contribute to broader environmental, social, and economic outcomes (see Table 40).

TABLE 40. Value proposal, creation, and capture potential

Value Proposition	What the technology achieves
Value Creation Process	How the technology achieves its goals
Value Capture Potential	How the technology *can* contribute to broader environmental, social, and economic outcomes

Source: Prepared by the authors.

The SDG assessment of technological innovations adopts a mixed qualitative-quantitative approach, where the qualitative insights from the value creation analysis are then translated into quantifiable scores. The qualitative inputs in value creation Tables 42–47 are used to inform a scoring metric used to evaluate the actual or potential contribution of the technology to each one of the SDG indicators. The scoring metric follows a scale where indicators are rated on a scale of 1 to 5 (see Table 41). The final score assigned to each technology for each SDG is determined by aggregating the individual scores from multiple indicators. This approach ensures a nuanced evaluation that captures the complex, multifaceted contributions of each technology to sustainable development.

TABLE 41. Scoring scale for quantitative ranking of technologies against SDGs.

Scale	Score	Qualitative Equivalent
1	No impact	THE TECHNOLOGY DOES NOT CONTRIBUTE TO THE SDG IN ANY MEANINGFUL WAY.
2	Limited impact	THE TECHNOLOGY MAKES A MINIMAL CONTRIBUTION, OFTEN INDIRECT OR WEAKLY LINKED TO THE SDG.
3	Moderate impact	THE TECHNOLOGY HAS A MEASURABLE BUT LIMITED CONTRIBUTION TO THE SDG.
4	Significant impact	THE TECHNOLOGY MAKES A STRONG CONTRIBUTION TO ACHIEVING THE SDG, WITH CLEAR, POSITIVE OUTCOMES.
5	High impact	THE TECHNOLOGY HAS A TRANSFORMATIVE IMPACT, SUBSTANTIALLY ADVANCING THE SDG.

Source: Prepared by the authors.

Once the technologies have been scored, they are ranked according to their total contributions across all the selected SDGs. Technologies that offer greater value creation across multiple goals rank higher, while those with more limited or less impactful contributions rank lower. The ranking system helps to prioritise investment, policy-making, and further development efforts toward technologies that maximise SDG outcomes.

To understand the potential of each technology in advancing SDGs, the results of the scoring and ranking system are presented for each technology in Figures 27–32. Each figure represents the technology's score for each SDG, illustrating its strengths and weaknesses in potential to advance the SDGs. These figures provide an overview of technologies that have the highest potential for advancing sustainable development in the critical minerals sector. By comparing the performance of various technologies, stakeholders can identify those that align most closely with their sustainability goals and guide their policy and investment decisions accordingly.

TABLE 42. SDG value creation analysis for GEM QMB's technology

Company	GEM QMB	
Country of Operation	Indonesia	
Technology Description	**Midstream Technology**	QMB utilises advanced third-generation High Pressure Acid Leach (HPAL) technology to process low-grade lateritic nickel ore, which contains 0.8–1.4% nickel, into battery-grade products like nickel hydroxide cobalt manganese and nickel cobalt manganese sulphate crystals.[361]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential. • Providing inclusive employment. • Offering capacity building programs. • Strengthening local value chains. • Leveraging mineral resources for poverty alleviation.	SDG with Direct Linkage	Creating new opportunities in the sector by introducing an innovative approach to processing low-grade laterite nickel ore, which is abundant in Indonesia but traditionally considered uneconomical to process using conventional methods.	Providing direct employment opportunities by processing nickel ore locally into higher-value battery-grade materials instead of exporting raw nickel ore. The Morowali plant employs over 2,000 people.[362] The diversity of roles indicates benefits for individuals with varying skill sets.	Contributing to economic growth by providing large-scale employment and local value-addition opportunities. Fostering the development of midstream facilities, thereby expanding economic opportunities for local communities. Spurring new skills development.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers. • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments. • Harnessing economies of scale and economies of scope. • Promoting shared infrastructure. • Promoting domestic R&D initiatives.	SDG with Direct Linkage	Improving the quality of battery-grade products and aiming to improve the battery manufacturing industry by introducing an innovative approach to processing low-grade laterite nickel ore.	Driving new industrial infrastructure and improvements in local production practices by locally sourcing high-quality inputs for batteries and other assembly processes. The Morowali industrial park provides access to shared resources, and its research centre promotes innovation in new technology and potential for economies of scale.[363]	Enhancing the expertise and knowledge of local communities. Developing new industrial infrastructure. Fostering local innovation. Leading to technological advancements, process improvements, and new product development. Reducing per-unit production costs and providing shared infrastructure for local production.

361) GEM Indonesia, "GSJS: The 11th Indonesia International Geothermal Convention & Exhibition," http://en.gemindonesia.com/gsjs/index.aspx.

362) Hytera, "Indonesian Mine Enhances Coverage, Capacity, and Services Thanks to Hytera DMR XPT System," https://www.hytera.com/en-industries/case-study/utilities-energy/indonesian-mine-enhances-coverage-capacity-and-services-thanks-to-hytera-dmr-xpt-system/.

363) Hytera, "Indonesian Mine Enhances Coverage, Capacity, and Services Thanks to Hytera DMR XPT System," https://www.hytera.com/en-industries/case-study/utilities-energy/indonesian-mine-enhances-coverage-capacity-and-services-thanks-to-hytera-dmr-xpt-system/.

TABLE 42. SDG value creation analysis for GEM QMB's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect, and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognising climate change in planning and investments	SDG with Direct Linkage	Contributing to global decarbonisation by increasing the availability of a key component to battery production and introducing a more sustainable way to nickel processing.	Requiring less energy and producing significantly lower emissions than traditional pyrometallurgical methods commonly used for nickel processing.[364] Contributing to an essential input for producing batteries used in EVs and renewable energy systems.	Reducing the environmental impact of traditional nickel refining processes by minimising emissions and waste. Contributing to cleaner energy value chains and climate resilience by supporting road transport and electric power decarbonisation through the increased production of batteries.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Contributing to renewable energy systems by producing nickel for batteries in a more environmentally responsible and resource-efficient manner.	Contributing to sustainably producing an essential input for producing batteries to store energy generated from renewable sources, such as solar and wind, thereby enhancing energy storage solutions.	Supporting the broader adoption and deployment of renewable energy. Contributing to expanding renewable energy access and increasing renewable energy share in local and global mixes. Making clean energy technologies more affordable by reducing the cost of per-unit production of battery-grade nickel.

364) GEM Indonesia, "GSJS: The 11th Indonesia International Geothermal Convention & Exhibition," http://en.gemindonesia.com/gsjs/index.aspx.

TABLE 42. SDG value creation analysis for GEM QMB's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Contributing to more sustainable production processes by introducing efficiency improvements in nickel processing.	Processing low-grade lateritic nickel ore that traditional methods would deem unusable. Using less energy and producing significantly lower emissions compared to traditional pyrometallurgical methods commonly used for nickel extraction.	Reducing emissions, as well as the use of energy, water, and chemicals in the processing of battery-grade nickel. Minimising waste by repurposing low-grade lateritic nickel ore that would be considered waste.
15 LIFE ON LAND	• Avoiding impact on critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Contributing to a more sustainable method of producing battery-grade nickel that reduces impacts on habitats and ecosystems.	Improving resource efficiency and utilisation, thereby mitigating potential environmental damage and maintaining a healthy ecosystem for long-term operational sustainability.	Minimising waste and reducing stress on water, land, and critical ecosystems.

Source: Prepared by the authors.

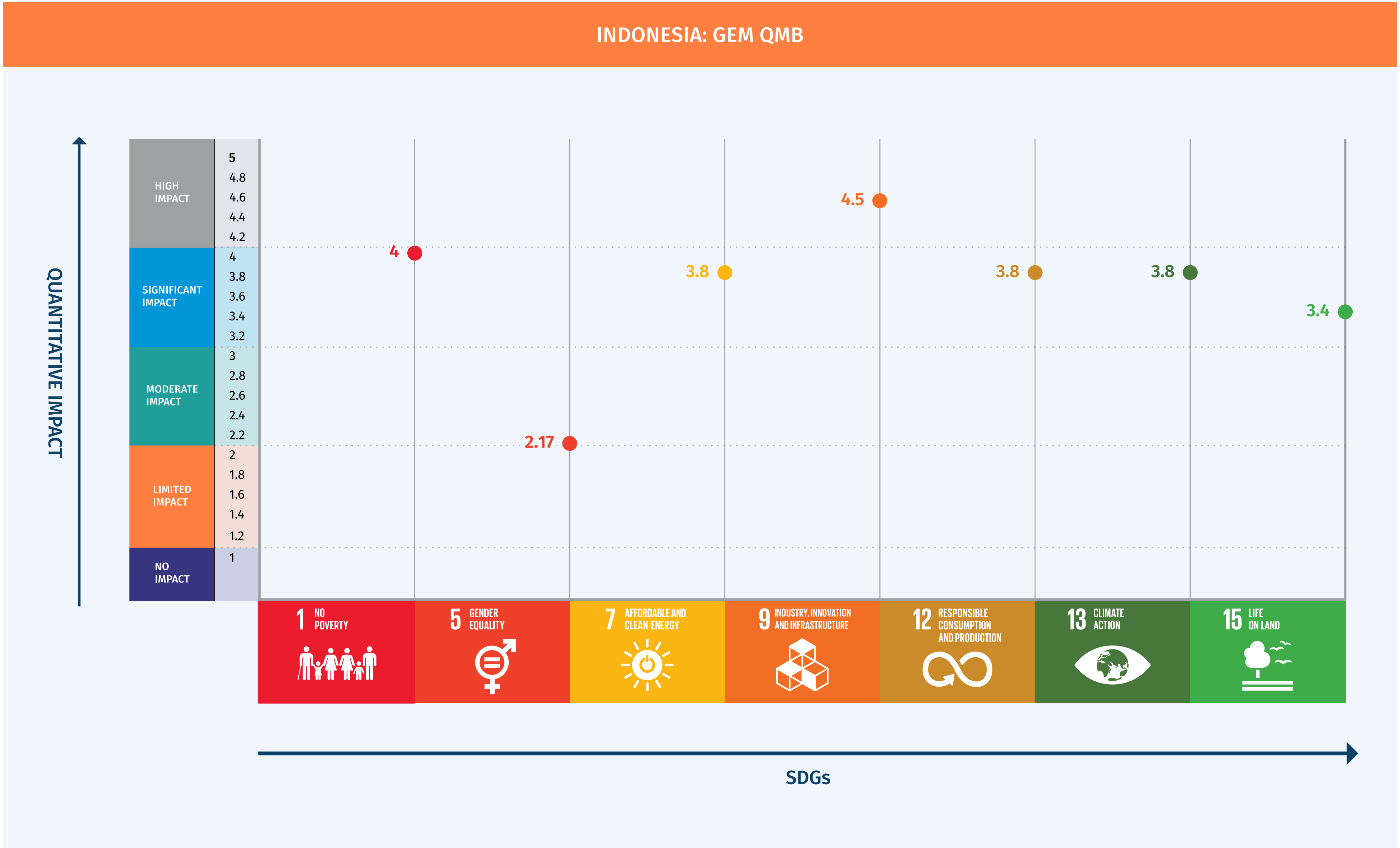


Figure 27. Potential impact of GEM QMB's technology on selected SDGs

Source: Prepared by the authors.

TABLE 43. SDG value creation analysis for Kalyon PV Group's technology

Company	Kalyon PV Group	
Country of Operation	Türkiye	
Technology Description	**Downstream Technology**	First and only fully vertically integrated R&D and technologies, starting from the production of high-purity silicon ingot to wafer and solar cell production, followed by solar panel manufacture using innovative and established technologies.[365]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential • Providing inclusive employment • Offering capacity building programs • Strengthening local value chains • Leveraging mineral resources for poverty alleviation	SDG with Direct Linkage	Creating employment opportunities and capacity building in the sector by establishing a vertically integrated solar panel production facility.	Contributing to job creation in downstream activities by employing more than 2,000 people and increasing the number of jobs yearly.[366] Offering training and skill development for internal and external employees through the Solar Academy program.[367]	Increasing direct employment and the potential for a more diverse and inclusive workforce. Increasing knowledge and skills within the renewable energy sector, potentially leading to improvements in downstream activities.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments • Harnessing economies of scale and economies of scope • Promoting shared infrastructure • Promoting domestic R&D initiatives	SDG with Direct Linkage	Fostering the development of new physical infrastructure, a new industry, technological innovation, and a localised value chain by establishing a vertically integrated solar panel production facility.	Developing a state-of-the-art plant unique to the region, having an ongoing research centre, and achieving a 75% domestic production rate, thereby strengthening local value chains with its fully integrated factory model.[368] Optimising costs through economies of scale and scope.	Developing industrial infrastructure in the country, increasing industrialisation, and promoting domestic R&D initiatives. Improving local access to reliable and durable renewable energy solutions and grid connectivity.

365) Fath, Peter, "Brief Facts about Kalyon PV," page 6 (report, EUREC, August 6, 2021), https://eurec.be/cms/wp-content/uploads/Brief-facts-about-Kalyon-PV-Peter-Fath.pdf.

366) Kalyon Holding, "$1.4 Billion Investment from Kalyon Solar Technologies Factory for Domestic and Renewable Energy" (press release, Kalyon Holding, NA), https://kalyonholding.com/media/1-4-billion-investment-from-kalyon-solar-technologies-factory-for-domestic-and-renewable-energy.

367) Kalyon PV, "Solar Academy," https://kalyonpv.com/en/solar-academy/.

368) Fath, Peter, "Brief Facts about Kalyon PV," page 6 (report, EUREC, August 6, 2021), https://eurec.be/cms/wp-content/uploads/Brief-facts-about-Kalyon-PV-Peter-Fath.pdf.

TABLE 43. SDG value creation analysis for Kalyon PV Group's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognizing climate change in planning and investments	SDG with Direct Linkage	Bolstering local production of key components of renewable energy systems and contributing to the decarbonisation of the energy sector by establishing efficiencies in a vertically integrated solar panel facility.	Integrating solar energy into its operations from a fully-owned solar power plant[369] and providing an efficient, fully integrated solar panel manufacturing facility. Producing solar panels domestically at a large scale, thereby reducing reliance on fossil fuels and promoting the transition to renewable energy sources.	Reducing greenhouse gas emissions in solar panel production. Contributing to the increased and mass production of a key component for solar energy systems, thereby advancing climate resilience and the transition to a low-carbon economy.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Advancing the local production of key components of renewable energy systems and increasing renewable energy deployment by increasing solar panel production.	Reducing energy consumption throughout the value chain. Increasing the renewable energy generation installed capacity and the share of renewable energy in the domestic and global energy mixes by implementing large-scale production of solar panels.	Improving energy efficiency in the solar panel production value chain. Increasing renewable energy generation capacity. Decreasing reliance on fossil fuels as an energy source and increasing energy independence and access to electricity.

369) Kalyon PV, Kalyon PV Corporate Catalog 2024 (catalog, Kalyon PV, July 2024), https://kalyonpv.com/en/wp-content/uploads/2024/07/Kalyon-PV-Kurumsal-Katalog-2024-02-ENG.pdf.

TABLE 43. SDG value creation analysis for Kalyon PV Group's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Enhancing the efficiency of solar panel production by minimising the use of resources and waste production through a vertically integrated model.	Creating efficiencies during the solar panel production process by integrating solar energy into their operations. Reducing reliance on fossil fuels as an energy source.	Reducing the use of water, energy, land, and other resources, as well as waste production due to vertical integration efficiencies. Reducing emissions in solar panel production and the power sector.
15 LIFE ON LAND	• Avoiding impact on critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Reducing the impact on land ecosystems by enhancing efficiency and contributing to renewable energy systems through a vertically integrated production system.	Improving solar panel production efficiency and decarbonisation, as well as reducing resource utilisation, thereby mitigating potential environmental damage and maintaining a healthy ecosystem for long-term operational sustainability.	Minimising waste and reducing stress on water, land, and critical ecosystems.

Source: Prepared by the authors.

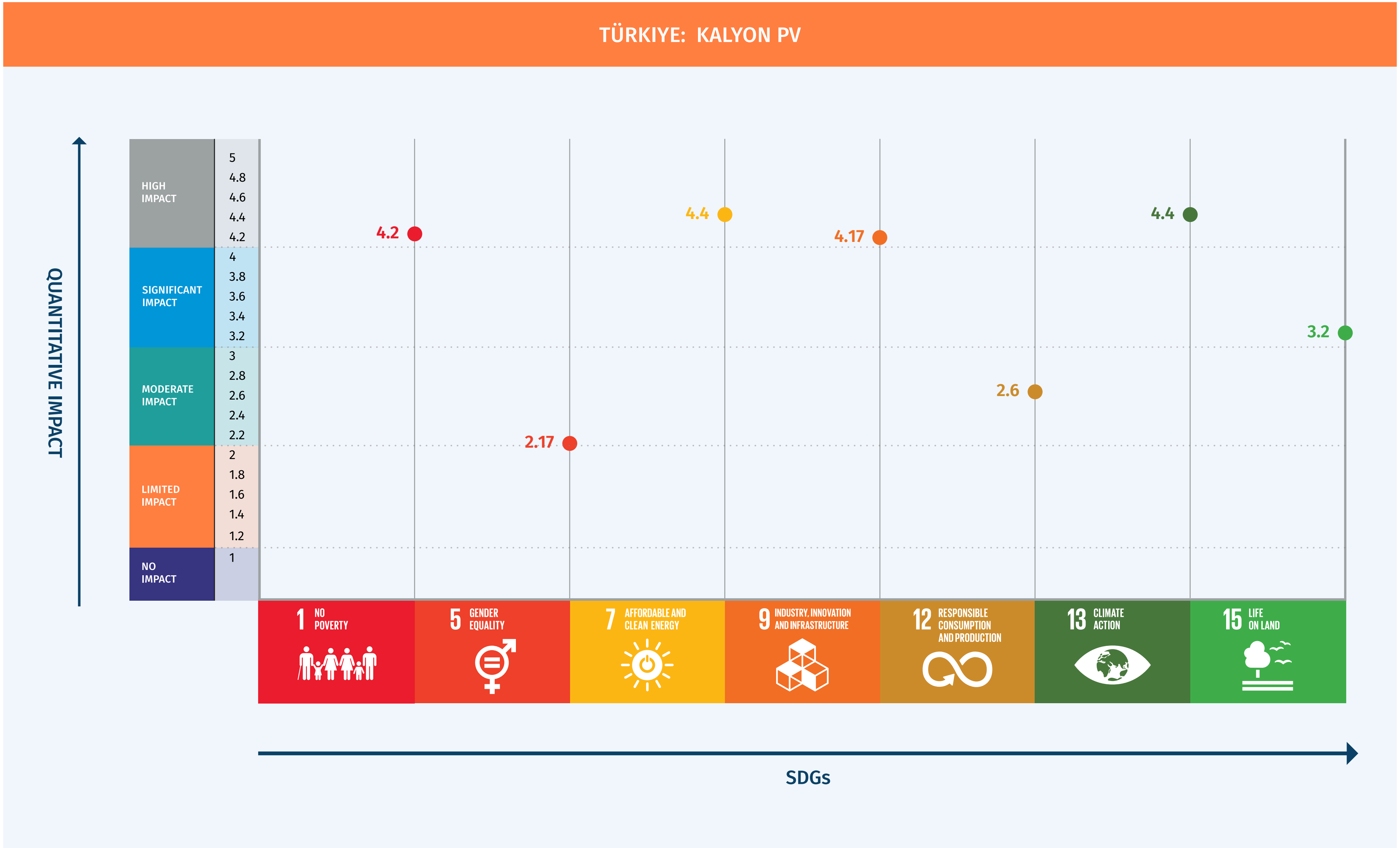


Figure 28. Potential impact of Kalyon PV Group's technology on selected SDGs

Source: Prepared by the authors.

TABLE 44. SDG value creation analysis for Cwenga Lib's technology

Company	Cwenga Lib	
Country of Operation	South Africa	
Technology Description	**Downstream Technology**	An innovative modular lithium-ion battery recycling process that uses environmentally friendly chemicals and modular stations to recover and separate usable critical minerals—such as cobalt, nickel, manganese, and lithium—from used batteries.[370]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential • Providing inclusive employment • Offering capacity building programs • Strengthening local value chains • Leveraging mineral resources for poverty alleviation	SDG with Direct Linkage	Creating a new industrial process that results in new employment opportunities and capacity building in the critical minerals sector by introducing an innovative battery recycling process unique to South Africa.	Providing direct employment in each modular facility. Creating indirect employment along the value chain through partnerships with battery collectors. Contributing to building a skilled workforce through investment in research and mentorship.[371]	Unlocking job creation potential, offering capacity building to local communities, and strengthening local value chains to leverage critical mineral resources for poverty eradication.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments • Harnessing economies of scale and economies of scope • Promoting shared infrastructure • Promoting domestic R&D initiatives	SDG with Direct Linkage	Developing the battery recycling industry in the country, building new infrastructure, and growing R&D capacity by introducing an innovative recycling process unique to South Africa.	Creating new expertise in local value chains such as hydrometallurgy and other battery recycling technologies.[372] Creating new industrial infrastructure with every new modular station. Providing an innovative and reliable local source of high-quality recovered minerals for lithium-ion battery production.	Reducing reliance on imports by providing a local source of critical minerals. Providing new industrial development that creates new infrastructure, enables manufacturers to enhance the quality of their locally- manufactured products (batteries). Providing innovation opportunities through domestic R&D initiatives.

370) Windell, Colin, "First Li-ion Recycling Plant Opens in South Africa," *Medium*, https://medium.com/@colinwindell/first-li-ion-recycling-plant-opens-in-south-africa-9113a2c82d74.

371) Battery Recycling South Africa, "Introducing cutting-edge battery recycling technology to Southern Africa, https://www.batteryrecycling.co.za.

372) Cwenga, "Hydrometallurgy Applications," https://www.cwenga.com/applications/hydrometallurgy.

TABLE 44. SDG value creation analysis for Cwenga Lib's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognizing climate change in planning and investments	SDG with Direct Linkage	Reducing reliance on energy-intensive recycling methods and contributing to global decarbonisation by bolstering battery production through a sustainable recycling process.	Recovering critical minerals from used batteries with efficiencies and environmentally friendlier chemicals compared to traditional battery recycling.[373] Using recovered critical minerals in key components for renewable energy systems and EVs.	Reducing CO_2 and other greenhouse gas emissions, the environmental impact of harmful chemicals, and minimising waste. Building climate resilience and decarbonising the energy and road transport sectors by recovering minerals essential for battery production.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Strengthening and growing renewable energy systems and clean energy by introducing an innovative and less carbon-intensive lithium-ion battery recycling process.	Recovering critical minerals that can be reused in new battery production. Reducing the overall energy required to extract and process minerals from primary extraction. Increasing mineral availability for new battery production.	Enhancing the sustainability and efficiency of battery production while boosting lithium-ion battery output that can support renewable energy storage systems. Increasing the installed renewable energy capacity and strengthening the resilience of renewable energy systems.

373) Cwenga, "Lithium-Ion Battery Recycling: Cwenga LIB," https://www.cwenga.com/news/lithium-ion-battery-recycling-cwenga-lib.

TABLE 44. SDG value creation analysis for Cwenga Lib's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 Responsible Consumption and Production	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Safely recovering and disposing of critical minerals from used batteries, contributing to a circular economy, and minimising environmental impact through battery recycling.	Reducing reliance on primary resource extraction and minimising environmental impact by repurposing waste from used batteries into usable materials for new production. Promoting efficiency and reducing the need for energy-intensive, hazardous methods.	Minimising the use of harmful chemicals and energy, as well as waste and effluent production. Repurposing waste, introducing the recycling of raw materials, and extending responsible sourcing practices to suppliers.
15 Life on Land	• Avoiding impact to critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Minimising environmental impact on land habitats and ecosystems by reducing the environmental impact from the primary extraction of critical minerals.	Reducing reliance on environmentally impactful activities of primary mining on critical habitats and preventing hazardous substances from contaminating land ecosystems.	Reducing stress on water, land, and biodiversity, decreasing pollution, and leveraging potential for circular material flows by minimising and repurposing waste.

Source: Prepared by the authors.

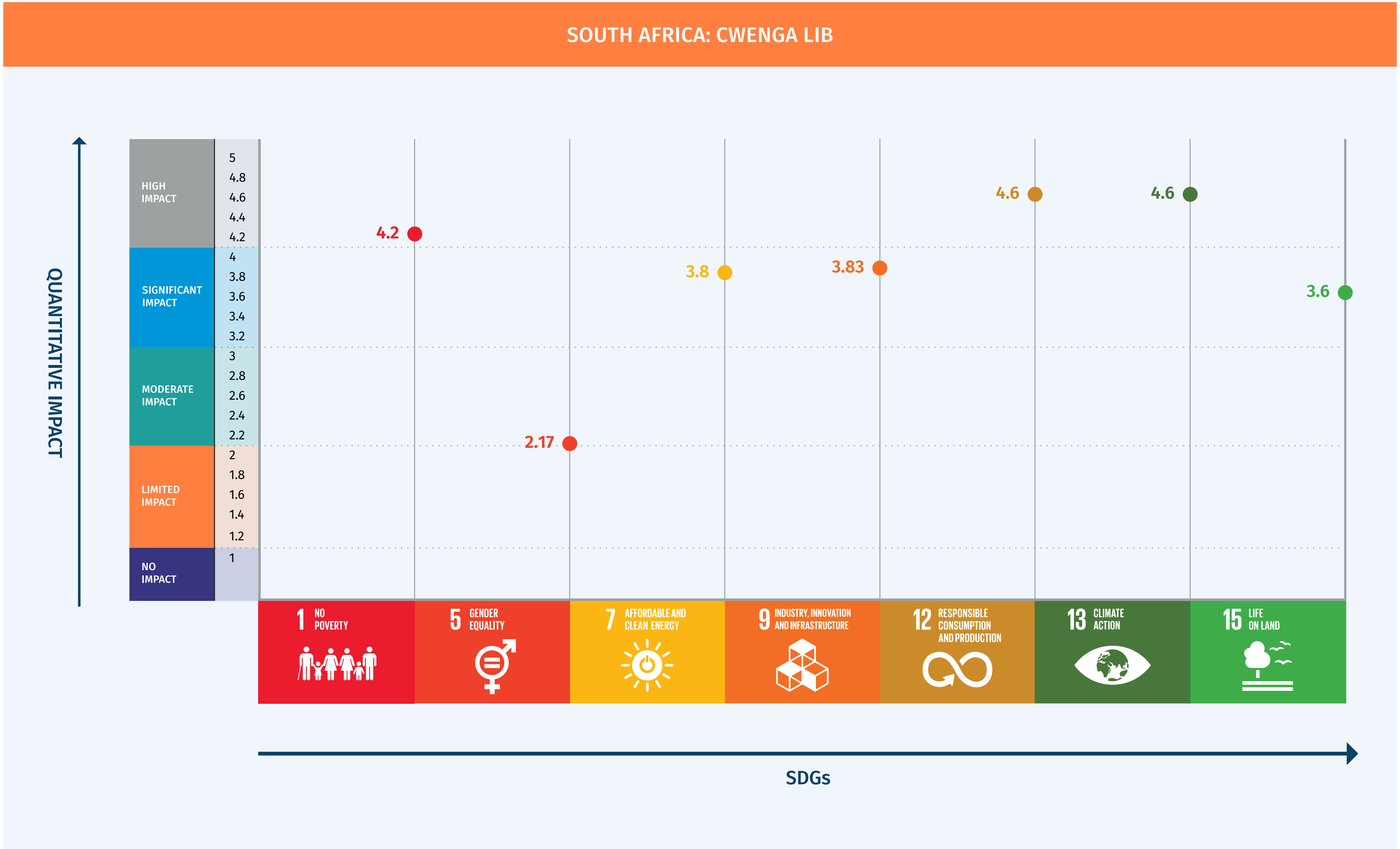


Figure 29. Potential impact of Cwenga Lib's technology on selected SDGs

Source: Prepared by the authors.

TABLE 45. SDG value creation analysis for Arcadium's technology

Company	Arcadium	
Country of Operation	Argentina	
Technology Description	**Midstream Technology**	The production of high-quality lithium metal products from salar brine employing advanced midstream technologies, including Direct Lithium Extraction (DLE) and the proprietary LIOVIX® technology, which is used to manufacture lithium metal sheets tailored for high-performance lithium-ion battery applications.[374]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential • Providing inclusive employment • Offering capacity building programs • Strengthening local value chains • Leveraging mineral resources for poverty alleviation	SDG with Direct Linkage	Creating new job opportunities and capacity building in the lithium value chain by introducing innovative processing methods and products.	Introducing a new processing and manufacturing industry. Enhancing battery performance, thereby reducing manufacturing costs and driving increased demand and production. Creating new job and skill development opportunities.	Transforming lithium into a high-value product and strengthening the local lithium value chain, thereby stimulating economic growth, creating capacity-building opportunities, and contributing to poverty eradication.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments • Harnessing economies of scale and economies of scope • Promoting shared infrastructure • Promoting domestic R&D initiatives	SDG with Direct Linkage	Creating a new processing and manufacturing industry, new infrastructure, and contributing to the innovation and performance of the lithium mid- and downstream segments.	Introducing a new processing and manufacturing industry that improves the execution, capacity, and durability of batteries.[375] Reducing reliance on the primary extraction of minerals and facilitating industry scale-up by leveraging existing expertise and infrastructure.	Reducing manufacturing costs, upgrading the expertise of the lithium value chain stakeholders, improving the quality of domestically produced goods (lithium metal sheets), adding value to critical mineral extraction by harnessing economies of scale and scope, and facilitating domestic R&D.

374) Arcadium Lithium, "Operations & Projects," https://arcadiumlithium.com/operations-projects/#:~:text=The%20Salar%20del%20Hombre%20Muerto,feedstock%20for%20downstream%20lithium%20production.

375) Arcadium Lithium, "A Proprietary Lithium Metal Product That Can Improve the Performance, Safety, and Sustainability of Lithium-Ion Batteries," https://ir.arcadiumlithium.com/investors/news/news-details/2021/Livent-Announces-LIOVIX-a-Proprietary-Lithium-Metal-Product-That-Can-Improve-the-Performance-Safety-and-Sustainability-of-Lithium-Ion-Batteries-11-01-2021/.

TABLE 45. SDG value creation analysis for Arcadium's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect, and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognizing climate change in planning and investments	SDG with Direct Linkage	Contributing to global decarbonisation goals, particularly in the energy and transport sectors, by enhancing energy storage systems while enhancing safety and sustainability.	Increasing battery lifespan,[376] which translates into fewer battery replacements and a reduction in the associated manufacturing and disposal emissions. Increasing the quality and availability of battery-grade materials.	Reducing greenhouse gas emissions due to the implemented efficiencies and sustainable advancements. Reducing battery waste by increasing battery lifespan. Increasing the supply and quality of inputs for lithium-ion batteries, thereby advancing decarbonisation of the power and road transport sectors.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Reducing energy consumption and supporting renewable energy deployment and system resilience by improving the performance of lithium-ion batteries.	Providing higher-capacity, longer-life batteries that require less frequent charging, thereby reducing the energy needed to power devices. Giving battery manufacturers more control in production and increasing the quality and availability of battery-grade materials.[377]	Increasing overall energy efficiency in lithium processing and manufacture. Enhancing energy storage solutions that contribute to increased renewable energy adoption, deployment, and access. Making clean energy more affordable by reducing the cost of lithium.

376) Arcadium Lithium, "A Breakthrough Technology for Advanced Lithium Battery Performance and Innovation" (brochure, Arcadium Lithium, July 2024), https://arcadiumlithium.com/wp-content/uploads/2024/07/AL-8316-Liovix-Marketing-Sheet-ReBrand-English.pdf?v=172943538.

377) Arcadium Lithium, "A Breakthrough Technology for Advanced Lithium Battery Performance and Innovation" (brochure, Arcadium Lithium, July 2024), https://arcadiumlithium.com/wp-content/uploads/2024/07/AL-8316-Liovix-Marketing-Sheet-ReBrand-English.pdf?v=172943538.

TABLE 45. SDG value creation analysis for Arcadium's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Reducing the environmental footprint of battery production by making lithium processing more efficient and improving the performance of lithium-ion batteries.	Adopting second-generation DLE, a less resource-intensive lithium extraction method.[378] Simplifying battery cell manufacturing. Decreasing reliance on resource-intensive processes by providing precise control over the amount of lithium used in battery production.[379]	Reducing environmental impact and energy and water usage by introducing technologies and process efficiencies and minimising material waste during lithium metal sheets and battery production.
15 LIFE ON LAND	• Avoiding impact to critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Reducing the environmental impact on land habitats and ecosystems by making lithium processing more efficient and improving the performance of lithium-ion batteries.	Introducing efficiencies in lithium processing and lithium metal sheet production, reducing the use of water and energy. Producing higher quality inputs for batteries, increasing battery capacity, and reducing the consumption of fossil fuels.	Reducing stress on critical habitats and ecosystems, sustaining water availability for other ecological functions, and reducing the environmental impact from the consumption of fossil fuels.

Source: Prepared by the authors.

378) Arcadium Lithium, "Lithium Investor Day 2024", (presentation, September 2024), https://s203.q4cdn.com/709125885/files/doc_downloads/2024/09/Transcript-for-delivery.pdf.

379) Arcadium Lithium, "A Proprietary Lithium Metal Product That Can Improve the Performance, Safety, and Sustainability of Lithium-Ion Batteries," https://ir.arcadiumlithium.com/investors/news/news-details/2021/Livent-Announces-LIOVIX-a-Proprietary-Lithium-Metal-Product-That-Can-Improve-the-Performance-Safety-and-Sustainability-of-Lithium-Ion-Batteries-11-01-2021/.

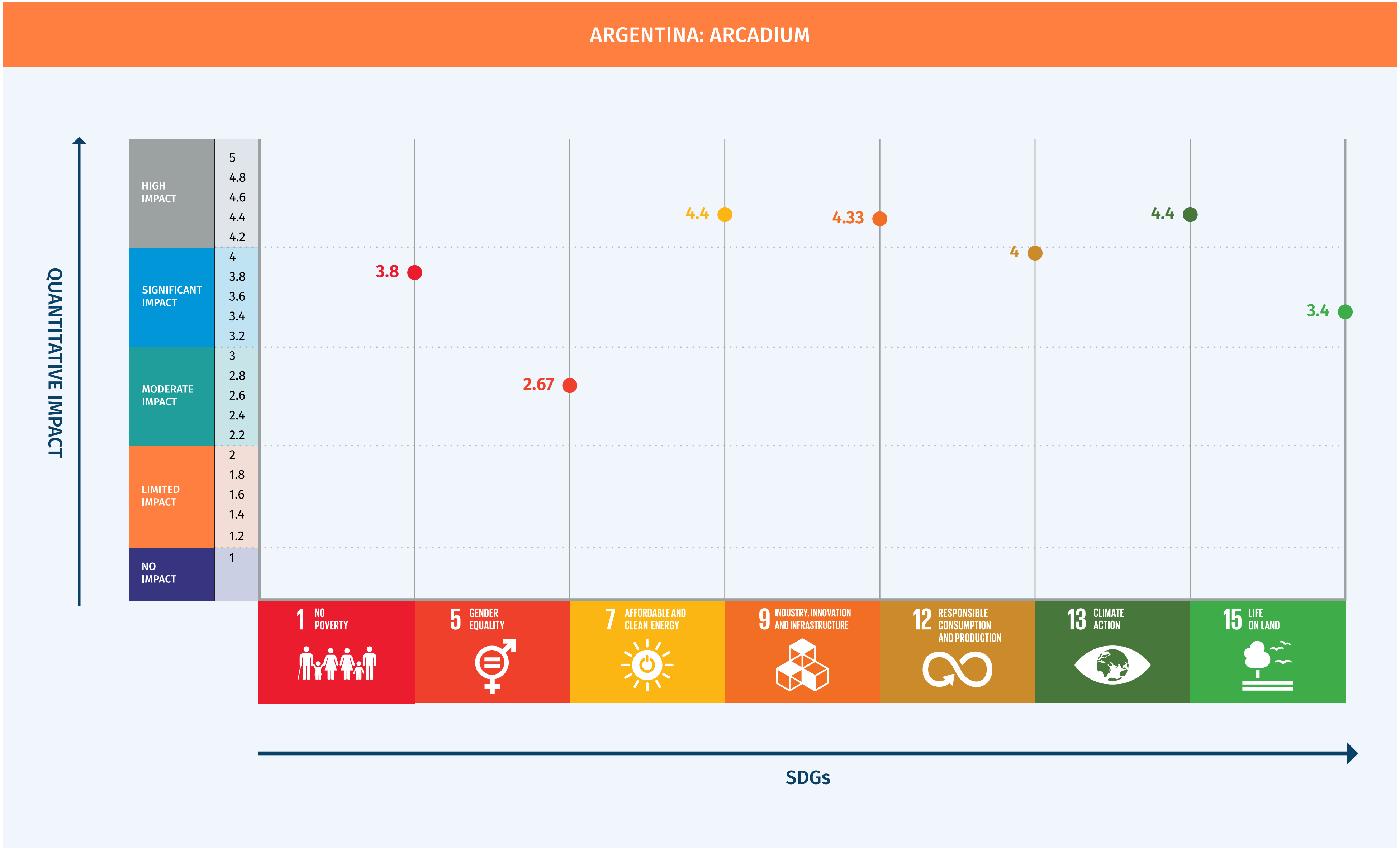


Figure 30. Potential impact of Arcadium's technology on selected SDGs

Source: Prepared by the authors.

TABLE 46. SDG value creation analysis for Bacanora Lithium's technology

Company	Bacanora Lithium	
Country of Operation	Mexico	
Technology Description	**Midstream Technology**	Lithium extraction from clay deposits into an aqueous medium (upstream processing) combined with subsequent midstream processing to produce high-quality, battery-grade lithium carbonate, involving several unit operations: preconcentration, flotation, sulphation roasting, grinding, leaching, purification, evaporation, ion exchange, and precipitation.[380]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential • Providing inclusive employment • Offering capacity building programs • Strengthening local value chains • Leveraging mineral resources for poverty alleviation	SDG with Direct Linkage	Creating a new industry and job opportunities in the lithium processing value chain by introducing new processing methods unique to Mexico.	Introducing a new processing industry and infrastructure. Planning to produce 17,500 tonnes of battery-grade lithium carbonate annually,[381] which is expected to create new job and capacity-building opportunities.	Adding value to raw lithium, thereby strengthening the local lithium value chain. Creating capacity-building opportunities, stimulating economic growth, and contributing to poverty eradication.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments • Harnessing economies of scale and economies of scope • Promoting shared infrastructure • Promoting domestic R&D initiatives	SDG with Direct Linkage	Creating a new industry and growing infrastructure, value chain expertise, and innovation by adding value to raw lithium through innovative processing methods unique to Mexico.	Leveraging economies of scale and scope through a large-scale operation and the generation of other byproducts, such as cesium-rubidium salt cake and high-grade potassium sulphate.[382] Promoting and utilising shared infrastructure, including a nearby power transmission line and well-established road and rail networks.[383]	Contributing to industrial infrastructure and the sector's innovation through state-of-the-art processing facilities. Promoting shared infrastructure. Upgrading the expertise of stakeholders throughout the value chain.

380) Bacanora Lithium, "Technical Report on the Prefeasibility Study for the Sonora Lithium Project, Mexico" (report, Bacanora Lithium, April, 2016), https://bacanoralithium.com/_userfiles/pages/files/documents/technicalreportontheprefeasibilitystudyforthesonoralithiumprojectmexico_compressed.pdf.

381) Veolia Water Technologies, "Bacanora Relies on Veolia to Advance Mexico Lithium Project," https://www.veoliawatertechnologies.com/en/latest-news/bacanora-relies-on-veolia-to-advance-mexico-lithium-project.

382) Bacanora Lithium, "Technical Report on the Prefeasibility Study for the Sonora Lithium Project, Mexico" (report, Bacanora Lithium, April, 2016), https://bacanoralithium.com/_userfiles/pages/files/documents/technicalreportontheprefeasibilitystudyforthesonoralithiumprojectmexico_compressed.pdf.

383) Bacanora Lithium, "Technical Report on the Prefeasibility Study for the Sonora Lithium Project, Mexico" (report, Bacanora Lithium, April, 2016), https://bacanoralithium.com/_userfiles/pages/files/documents/technicalreportontheprefeasibilitystudyforthesonoralithiumprojectmexico_compressed.pdf.

TABLE 46. SDG value creation analysis for Bacanora Lithium's technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect, and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognizing climate change in planning and investments	SDG with Direct Linkage	Contributing to global decarbonisation goals, particularly in the energy and transport sectors, by producing a key component of battery production.	Implementing diversion channels to manage surface water runoff, using a lined tailings storage facility for potentially hazardous waste, employing filtration for the majority of tailings,[384] and increasing the availability of critical minerals for battery production.	Reducing greenhouse gas emissions from lithium processing and mitigating climate-related risks through efficiency implementation and environmental management practices. Ensuring a stable supply of lithium carbonate for battery manufacture, key to decarbonising the power and road transport sectors.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Reducing energy consumption and supporting the deployment and resilience of renewable energy systems by contributing with battery-grade lithium to high-quality renewable energy storage solutions.	Improving the energy efficiency of lithium processing and meeting the growing demand for lithium-ion batteries by increasing the quality and availability of key critical materials for the production of batteries, such as lithium carbonate.	Increasing overall energy efficiency in lithium processing, as well as enhancing energy storage solutions that contribute to increased renewable energy adoption, deployment, and access. Making clean energy more affordable by reducing the cost of lithium.

384) Bacanora Lithium, "Technical Report on the Prefeasibility Study for the Sonora Lithium Project, Mexico" (report, Bacanora Lithium, April, 2016), https://bacanoralithium.com/_userfiles/pages/files/documents/technicalreportontheprefeasibilitystudyforthesonoralithiumprojectmexico_compressed.pdf.

TABLE 46. SDG value creation analysis for Bacanora Lithium's technology (continued)					
SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Reducing the environmental footprint of lithium processing and battery production by introducing a more efficient process.	Implementing diversion channels to manage surface water runoff, using a lined tailings storage facility for potentially hazardous waste, employing a dry-stack tailings method and filtration for the majority of tailings, and repurposing waste and byproducts.[385]	Reducing the environmental impact, developing shared infrastructure, and implementing higher process efficiencies, thereby reducing energy and water usage and minimising material waste during lithium extraction and processing.
15 LIFE ON LAND	• Avoiding impact to critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Reducing environmental impact on land habitats and ecosystems by processing lithium in a more sustainable way.	Involving less extensive excavation and waste generation compared to traditional hard-rock lithium mining[386] and reducing water and energy consumption through implemented efficiencies and clay extraction.	Reducing impact on the surrounding habitats and ecosystems, conserving water, and reducing the use of fossil fuel– generated energy.

Source: Prepared by the authors.

385) Bacanora Lithium, "Technical Report on the Prefeasibility Study for the Sonora Lithium Project, Mexico" (report, Bacanora Lithium, April, 2016), https://bacanoralithium.com/_userfiles/pages/files/documents/technicalreportontheprefeasibilitystudyforthesonoralithiumprojectmexico_compressed.pdf.

386) Veolia Water Technologies, "Bacanora Relies on Veolia to Advance Mexico Lithium Project," https://www.veoliawatertechnologies.com/en/latest-news/bacanora-relies-on-veolia-to-advance-mexico-lithium-project.

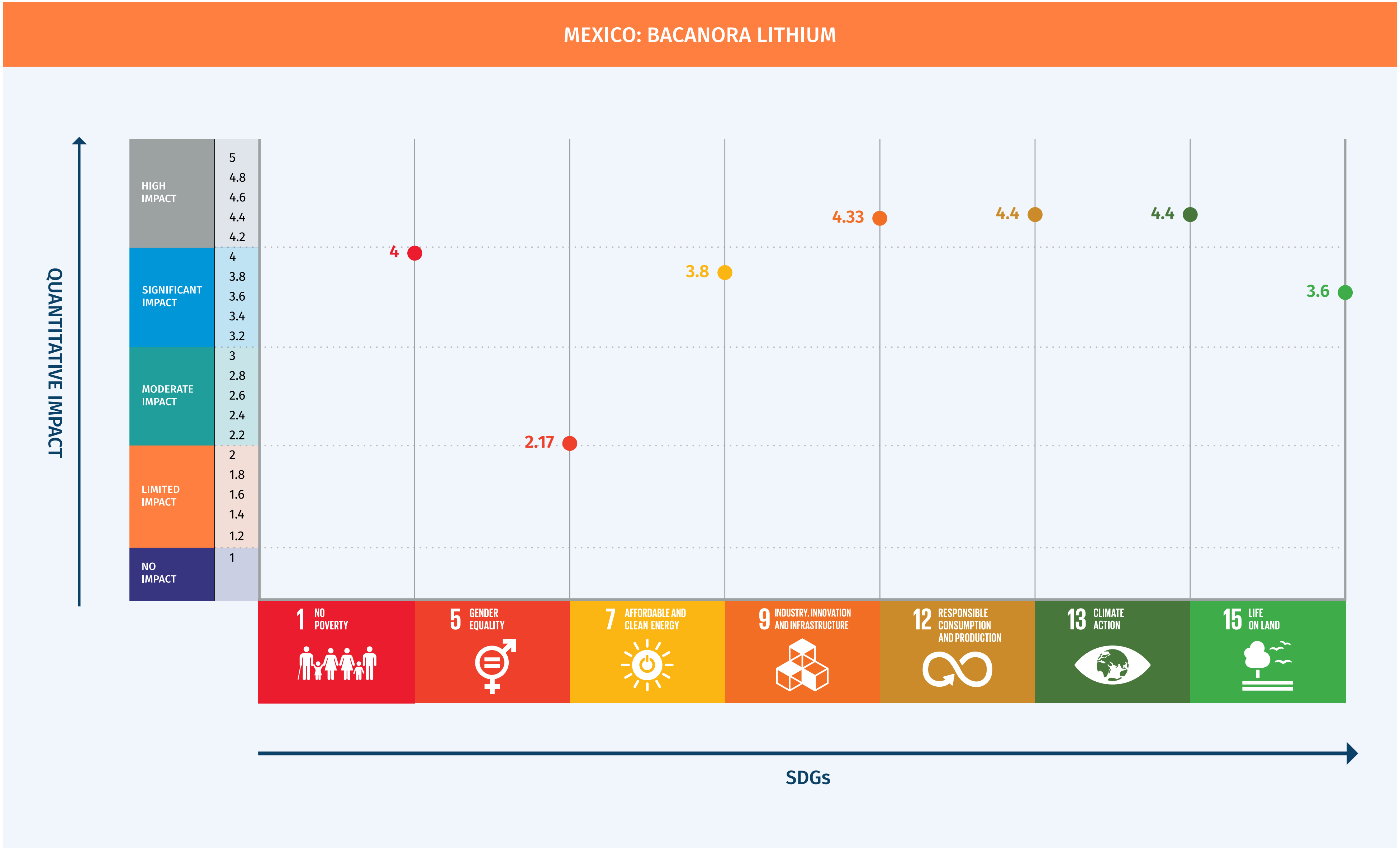


Figure 31. Potential impact of Bacanora Lithium's technology on selected SDGs

Source: Prepared by the authors.

TABLE 47. SDG value creation analysis for Tata Chemicals' technology

Company	Tata Chemicals	
Country of Operation	India	
Technology Description	**Downstream Technology**	Providing battery storage solutions and recycling lithium-ion batteries for the recovery of valuable critical minerals such as lithium carbonate; and the production of byproducts such as nickel hydroxide cake.[387]

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
1 NO POVERTY	• Unlocking job creation potential • Providing inclusive employment • Offering capacity building programs • Strengthening local value chains • Leveraging mineral resources for poverty alleviation	SDG with Direct Linkage	Creating a new industrial process and local job opportunities by providing an innovative process to recover critical minerals from used batteries.	Creating direct and indirect employment opportunities and upskilling the local workforce in the downstream segment by facilitating partnerships with waste management companies, leveraging digital technologies, and contributing to local economic growth.[388]	Creating innovative economic prospects, unlocking job creation potential, offering capacity building to local communities, and strengthening local value chains to leverage critical mineral resources for poverty eradication.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Upgrading expertise of local suppliers • Improving quality of locally produced goods • Implementing co-funding arrangements with local governments • Harnessing economies of scale and economies of scope • Promoting shared infrastructure • Promoting domestic R&D initiatives	SDG with Direct Linkage	Developing new infrastructure and industrial processes and promoting domestic innovation by providing an innovative process to recover critical minerals from used batteries.	Establishing a local supply chain for recycled materials in the country. Contributing to building resilient infrastructure, reducing reliance on resources from primary extraction and imports. Fostering a circular economy.	Fostering inclusive and sustainable industrialisation while developing new infrastructure. Upgrading the expertise of the critical mineral downstream segment. Harnessing economies of scale to produce high-quality, locally produced battery-grade minerals.

387) Tata Chemicals, "Lithium-Ion, Dry Cell, and Other Batteries," https://www.tatachemicals.com/applications/lithium-ion-dry-cell-and-other-batteries.

388) Tata Chemicals, "Tata Chemicals Sustainability," https://sustainability.tatachemicals.com/people-investment/Employees/india/.

TABLE 47. SDG value creation analysis for Tata Chemicals' technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
13 CLIMATE ACTION	• Reducing CO_2 emissions per unit of value added • Measuring and reporting direct, indirect, and product-related emissions • Building climate change resilience • Participating in climate-related R&D and pilots • Recognizing climate change in planning and investments	SDG with Direct Linkage	Reducing reliance on energy-intensive recycling methods and contributing to global decarbonisation by recovering critical minerals from used batteries in a more sustainable way and bolstering battery production.	Reducing reliance on resources from primary extraction and fostering a circular economy. Supporting the broader adoption of renewable energy technologies and decarbonised transportation systems by producing an essential battery input.	Reducing greenhouse gas emissions associated with the primary extraction and processing of critical minerals and building climate resilience by promoting a circular economy. Advancing decarbonisation of the energy and road transport sectors by recovering minerals essential for battery production.
5 GENDER EQUALITY	• Offering equal opportunities for women • Practising gender inclusion across the business and project lifecycle • Making gender-inclusive investments • Offering educational scholarships for women • Establishing gender-sensitive grievance mechanisms • Increasing the proportion of women in managerial positions	SDG with Indirect Linkage	No direct impact on SDG 5 without additional targeted action. Given the potentially significant impact on SDG 1 (ending poverty) through job creation, these technologies could have an indirect impact on SDG 5 by offering new opportunities for women, so long as the companies implementing the technologies adopt targeted action in this regard and policy frameworks in operating countries support these actions.		
7 AFFORDABLE AND CLEAN ENERGY	• Improving energy efficiency • Increasing renewable energy share in the total final energy consumption • Increasing renewable energy-generating installed capacity • Increasing local access to electricity • Supporting local energy initiatives	SDG with Indirect Linkage	Providing the necessary minerals to manufacture batteries to store energy generated from renewable sources, such as solar and wind, through an efficient process to recover critical minerals from used batteries.	Recovering critical minerals that can be reused in new battery production, reducing the overall energy required to extract and process minerals from primary extraction, and increasing mineral availability for battery production.	Improving the sustainability and efficiency of battery production, thereby improving and supporting broad deployment and access to renewable energy, potentially making clean energy technologies more affordable by reducing the cost of critical minerals.

TABLE 47. SDG value creation analysis for Tata Chemicals' technology (continued)

SDG	Indicators	Linkages	Value Proposition	Value Creation Process	Value Capture Potential
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	• Minimising the use of water, energy, land, and chemicals • Minimising the production of waste, effluents, and emissions • Repurposing waste • Introducing the recycling of raw materials • Extending responsible sourcing to suppliers	SDG with Indirect Linkage	Reducing environmental impact and contributing to a circular economy by introducing recycling technologies and repurposing raw materials.	Reducing reliance on resources from primary extraction. Repurposing waste from used batteries, recovering it, and processing it into useful minerals for battery production, thereby promoting efficiency and reducing energy-intensive hazardous methods.	Minimising the use of energy, water, land, and harmful chemicals, as well as the production of waste and effluent production by repurposing waste, introducing the recycling of raw materials, and extending responsible sourcing practices to suppliers.
15 LIFE ON LAND	• Avoiding impact on critical habitats • Preserving ecosystem services • Conducting comprehensive Environmental Impact Assessments • Supporting projects that connect communities and biodiversity • Collaborating on research activities	SDG with Indirect Linkage	Reducing environmental impact and preserving natural habitats and ecosystems by recovering critical minerals from used batteries.	Reducing land degradation and promoting sustainable use of terrestrial ecosystems through reduced environmental impact and reliance on resources from primary extraction.	Reducing stress on water, land, and biodiversity; and minimising waste.

Source: Prepared by the authors.

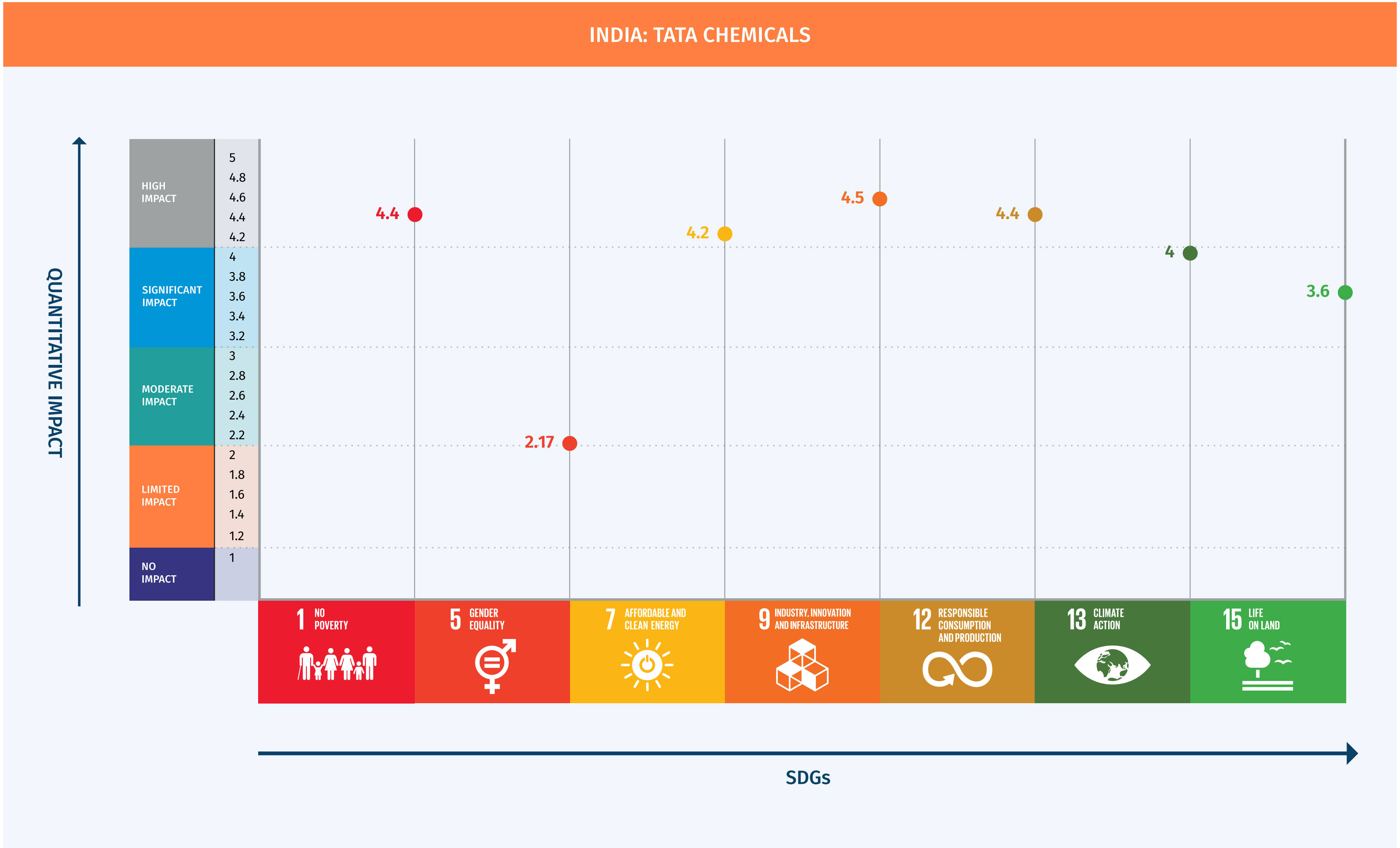


Figure 32. Potential impact of Tata Chemicals' technology on selected SDGs

Source: Prepared by the authors.

4

Conclusion

This section presents a summary of the findings of the market assessment, as well as recommendations for public and private stakeholders to foster technological innovation in the mid- and downstream segments of critical minerals value chains in developing countries.

4.1 SUMMARY OF FINDINGS

A robust **enabling environment** is essential for technological innovation in the mid- and downstream segments of critical minerals value chains, requiring institutional capacity and financial and technical resources within the government to shape conducive policy, legal, and regulatory frameworks; accessible, affordable, and sufficient finance from public and private institutions; and partnerships and other collaborative initiatives among stakeholders at the national, regional, and global levels.

Common in developing countries' successes in fostering such an environment are **policy, legal, and regulatory frameworks that emphasise domestic industrial development** beyond the exploration and extraction phase. For example:

- **Mineral beneficiation strategies** exist in nearly all deep-dive countries, setting the stage to develop domestic and regional value chains.
- **Local content policies** have been enacted in some countries. For example, in Zambia, the policy seeks to leverage technology transfer and local employment from foreign investment in critical minerals value chains, while Indonesia's policy fosters the development of downstream industries, such as EV manufacturers.
- Resource-rich countries like Namibia and Indonesia went a step further, implementing **bans on the export** of select raw critical minerals in an attempt to encourage the development of domestic mid- and downstream operations, though at the risk of distorting markets and discouraging upstream investment.
- **Policy incentives** in other countries include India's exemption of 25 critical minerals from custom duties, Indonesia's pledged tax incentives for SEZs, South Africa's tax incentives for companies that reduce energy consumption and improve energy efficiency in their mineral processing operations, Brazil's tax rebates for exported manufactured goods incorporating technological innovation through the Special Regime for the Incentive of Technological Innovation, and Zambia's increasing tax for exporting raw materials and importing processed products.
- Some countries have established **state-owned companies** responsible for investing in critical minerals value chains, such as *Litio para México*, responsible for the exploration, exploitation, beneficiation, and utilisation of lithium resources in Mexico, and a state-owned investment company geared toward securing a 30% share in Zambia's critical minerals projects.

Policy efforts in developing countries to advance the mid- and downstream segments, and technological innovation within them, are often **structured in a way to reinforce rather than compete with other development priorities,** such as the development of the upstream segment, economic diversification, infrastructure development, education and upskilling, environmental sustainability, access to clean energy, and poverty eradication.

Numerous R&D initiatives and investments exist in developing countries, particularly in deep-dive countries. **National research institutions** like Argentina's CONICET, Brazil's CETEM, and South Africa's Council for Scientific and Industrial Research are increasingly partnering with mining, renewable energy, and battery companies to broaden access to funding for innovative projects. Investment into **critical mineral and clean energy hubs** like Brazil's Mining Hub and Mexico's Sonora Plan also empower innovation through funding and capacity building for workers. Once innovative projects yield results, successful governments continue to invest in and incentivise their adoption; for example, Türkiye pushed tax incentives for its first domestically-produced EV in 2023.

Domestic financial delivery mechanisms through grants and loans provided by national governments and development banks are at the core of enabling innovation in developing countries, often supported by incubators and complemented by private sources, including venture capital and impact funds. Direct funding from national development banks also play a large role, as the Development Bank of South Africa provided over USD 1 billion in lending for renewable energy projects.

International funders and partnerships are also integral to the success of innovative projects in critical minerals. International organizations facilitate initiatives such as UNIDO's A2D Facility, which accelerates the commercialisation of innovative clean energy technologies in developing countries focusing on critical minerals, and the World Bank's RISE Partnership in Southern Africa, offering technical assistance and policy advice to governments as well as finance for governments and the private sector. Bilateral development partners—including Australia, China, the EU, Japan, and the United States—with all Phase 2 developing countries are commonplace. Relationships include strict funding like China's Belt and Road initiative providing Indonesia with USD 7.3 billion, as well as research initiatives like Namibia's joint statement of cooperation with JOGMEC.

Initiatives by international organizations, governments, industry, and other stakeholders support technological innovation in critical minerals in developing countries. A total of **100** global, regional, and national initiatives were analysed, including financing mechanisms **(53%)** and other initiatives **(47%)**; they seek to either finance innovation projects or build up the enabling environment for mid- and downstream activities. **Gaps** in these initiatives include the need for greater scale; finer coordination among them as to policy interventions, minerals, and segments to be prioritised in different markets; and increased sharing of knowledge and data on technologies and their drivers and barriers.

Strikingly, the first takeaway from the assessment of the innovators, technologies, and projects related to critical minerals value chains is that **most technologies arise from developed countries**. Speaking with stakeholders in high-level international organizations confirmed that much of the activity in the mid- and downstream segments of the value chain in developing countries rely not on indigenous technology development, but on technology transfer from developed countries in Europe and North America as well as from China, which dominates the processing, refining, recycling, and manufacturing of end-use goods from critical minerals.

With that said, **homegrown technological innovation in the mid- and downstream segments of the critical minerals sector appears to occur in developing countries, albeit rather slowly**, even though not all global stakeholders are aware of this budding innovation. Existing technologies are nascent, materially aided by policy frameworks, including national and international incentive schemes, implemented largely within the last half-decade. Noteworthy technologies arising from the developing countries within the scope of this assessment include:

- Midstream technology to produce lithium from salar brine (LIOVIX®) (Argentina)
- Midstream technology for salar brine evaporation, impurity removal, and lithium carbonate precipitation (Argentina)
- Midstream technology for lithium extraction from clay deposit (Mexico)
- Downstream technology for recovering nickel hydroxide cake from recycled Lithium-ion batteries (India)
- Downstream technology for mechanical and hydrometallurgical processes to recover battery-grade salts from recycled Li-ion batteries and from e-waste (India)
- Midstream technology for copper smelting using Mitsubishi technology to produce anode copper (Indonesia)
- Midstream high-pressure acid leach (HPAL) technology for the production of Mixed Sulphide Precipitate (MSP) (Indonesia)
- Downstream modular technology to recycle Li-ion batteries using safer chemicals and processes (South Africa)
- Downstream vertically integrated technology to produce high purity silicon ingot for wafer and solar cells, followed by solar panel manufacturing using established and innovative technologies (Türkiye).

Such technologies and their enabling policy frameworks and initiatives contribute to achieving the **SDGs**. Mineral beneficiation strategies develop the domestic workforce and industry, relating to SDGs 1 and 9. The growing workforce and creation of mining hubs promote opportunities for women in mining communities, bolstering SDG 5. SDGs 7 and 13 are guiding principles of the critical minerals industry and the policies that govern it, as they are the backbone of the clean energy transition and climate change mitigation. Finally, embedding circular economy principles into mid- and downstream processes contributes to responsible consumption and production under SDG 12 and supports reducing environmental impacts in line with SDG 15.

The six technologies selected from the project pipeline and assessed—GEM QMB's nickel processing technology in Indonesia, Kalyon's vertically integrated solar panel production plant in Türkiye, Cwenga Lib's modular battery recycling technology in South Africa, Arcadium's lithium processing technology in Argentina, Bacanora's lithium processing technology in Mexico, and Tata Chemicals's recycling technologies in India—were found to promote various SDGs. Among other advantages, these technologies enhance energy storage solutions, reduce environmental impact, create jobs, and strengthen climate resilient local value chains.

This summary of findings understates the reality that the mid- and downstream segments of critical minerals value chains in developing countries, and technological innovation within them, vary **highly across regions and countries, depending on their focus minerals and on the various SDG impacts considered**. The following recommendations are based on broad trends across three completely different contexts, and will have to be carefully implied with the local political and technological environment in mind. Specific recommendations tailored to governments, innovators, and other stakeholders in (or seeking to operate in) the various developing countries covered by this assessment lie outside the scope of this work.

4.2 RECOMMENDATIONS

1. **There is a pressing need for more support in the form of technical assistance, policy analysis and advice, data transparency, capacity building, and access to finance to help developing country governments and stakeholders in the innovation ecosystem enhance countries' institutional, policy, regulatory, data, and R&D capacities in the mid- and downstream segments of critical minerals value chains.** Building comprehensive legal and regulatory frameworks is the groundwork for fostering an environment that attracts R&D and incentivises private sector participation and investment in technological innovation in the mid- and downstream segments of critical minerals value chains.[389] Stakeholders in developed countries should contribute to ensuring that developing countries have the necessary resources to create appropriate governance structures and incentive schemes in this sector. Strengthening institutional capacities through financial mechanisms, policy advice, and technical support will allow developing countries to create enabling environments for technological innovation for critical minerals.

2. **Multilateral Development Banks (MDBs) and other development finance institutions, alongside other relevant international and regional integration organizations, should play a pivotal role in meeting these pressing needs.** Initiatives such as the World Bank's RISE Partnership, providing policy, technical, and financial support for developing countries, should be strengthened, built upon, and tailored to regional and country-specific realities by MDBs such as ADB, AfDB, and IDB; and supported politically at high level by organizations such as the AU, the AfCFTA Secretariat, and regional UN economic commissions. Through tailored programmes, MDBs can support national governments in developing comprehensive and evidence-based policy and technology roadmaps, providing access to finance for investment in R&D, and fostering collaboration between public and private stakeholders. These institutions should prioritise the critical minerals value chain as part of broader economic development strategies, in line with the SDGs.

3. **Creating and bridging global multi stakeholder collaboration platforms is essential for advancing technological innovation in the mid- and downstream segments of critical mineral value chains.** A singular and coordinated global platform for critical minerals that connects international

389) For a broader discussion on policy, legal, and regulatory frameworks for enabling innovation—a National System for Innovation encompassing strategy, public policy, development priorities, intra-governmental coordination, and support to and collaboration among various private stakeholders—see: Columbia Center on Sustainable Investment (CCSI), *Linkages to the Resource Sector: The Role of Companies, Governments, and International Development Cooperation* (Bonn and Eschborn: GIZ, 2016), https://scholarship.law.columbia.edu/sustainable_investment_staffpubs/18.

stakeholders with separate chapters, each dedicated to one of the various critical minerals, could foster communication, knowledge transfer, and collaboration between governments, the private sector, research institutions, and civil society, including collaborative R&D efforts and joint ventures. Additionally, this platform could serve as a global mapping mechanism or tracker, where technologies, best practices, policies, and successful case studies can be shared between stakeholders from developing and developed countries alike. Such a system would enhance transparency, promote knowledge sharing, and accelerate the adoption of new technologies across critical minerals value chains, particularly in developing countries. This level of coordination is necessary to address the complexities of global value chains.

4. **Increased and continuous data gathering and transparency are vital for long-term progress in technological innovation in the critical minerals sector in developing countries.** Relevant stakeholders should prioritise data collection initiatives that focus on production processes, environmental impacts, and technological adoption across mid- and downstream segments. Enhanced transparency can help facilitate better policymaking, identify areas for cross-border collaboration and technological innovation, and support the creation of effective regulatory frameworks. UNIDO's leadership will be crucial in ensuring that data is continually gathered and analysed (well beyond the discrete five-month timeline of this market assessment exercise), for example, through open-ended in-depth surveys of technological innovation; standardised for comparison and made available in publicly accessible databases, and used to drive continuous improvement across the sector.

5. **Public policy should lay the groundwork for supporting innovation, especially in developing countries that lack the technical and financial capacity to advance their technological innovation ecosystems.** Developing country governments must create enabling environments that support innovation through targeted policy interventions. These interventions should focus on improving access to finance, providing clear regulatory guidelines, supporting programmes that foster domestic and international collaborations, and offering incentives for R&D investment. Because of their risks of distorting competition and diversification, any incentives should be transparent, limited in time, subject to monitoring, and conditioned to the achievement of SDGs. In turn, developed country governments should promote international collaboration, facilitate knowledge and technology transfer, and provide affordable access to finance for developing country governments as well as private sector stakeholders in the innovation ecosystems in developing countries. These measures can empower developing countries to actively participate in global critical mineral value chains beyond mere raw material extraction while fostering technological innovation in the mid- and downstream segments, contributing to their sustainable development.

6. **Developing countries should prioritise addressing various energy, communications, and logistics infrastructure constraints that hinder the development of mid- and downstream segments of critical mineral value chains.** Governments should prioritise the development of energy, communications, and logistics infrastructure to ensure a stable and affordable energy supply for industrial operations. Reliable infrastructure is foundational for enabling the successful development, deployment, application, and scale-up of technological innovations, ensuring the long-term viability of critical mineral processing activities, and developing new industries with manufacturing facilities. Governments, with the support of international development partners, must invest in infrastructure projects that align with sustainable development.

7. **Special financing and collaborative programmes should target small and medium enterprises (SMEs) involved in technological innovation in developing countries.** Many SMEs lack access to innovation funding mechanisms, MDB's large-scale funding programmes, or even subsidies and grants from governments or national development banks, and have limited relationships with research institutions for conducting R&D projects due to a lack of knowledge or proper guidance. Policymakers and government agencies must work to bridge this gap by creating more accessible funding programmes and fostering stronger connections between SMEs and research institutions. Without these interventions, the full potential of technological innovation in the critical minerals value chain will remain untapped.

8. **Circular economy approaches and practices are gaining traction among companies in the critical minerals sector, and the new business opportunities they provide should be seized to**

drive both sustainability and profitability. Mining residues formerly considered waste are now seen as valuable resources for recovering critical minerals. To fully leverage this potential, a collaborative effort from policymakers, financial institutions, and private companies is essential. Policymakers should incentivise circular business models through supportive regulations, tax incentives, and funding for R&D, while financial institutions and private companies should focus on demonstrating the business case for circularity by showcasing cost savings, new revenue streams, and improved resource efficiency.

9. **Industry-led initiatives like mining associations and hubs should be encouraged and expanded as important mechanisms for a unified approach to innovation.** Brazil's Mining Hub is a rare yet refreshing model for coordination amongst mining sector stakeholders to agree on common challenges and collectively prioritise next steps. Financial investment into R&D and technology development and deployment will only continue to increase from domestic and international sources as the demand for critical minerals increases, but will only be most efficiently utilised by a critical minerals sector with a unified voice. For added impact, these initiatives should be accessible and widely publicised to attract diverse stakeholders from across the industry.

10. **Besides fostering technological innovation, enabling regulatory and financial conditions need to be put in place to facilitate technology transfer of existing mid- and downstream critical minerals technologies from companies based in developed countries and China.** Further innovation is needed in developing countries for both mid- and downstream segments of critical minerals value chains, but investing resources into reinventing the wheel is inefficient. An increase in volume of critical minerals produced and a decrease in waste of critical minerals and manufactured goods are both required for developing countries to strengthen their local value chains. However, given the lead of countries and regions such as the EU, the United States, and China in high TRL innovations for the mid- and downstream segments, investing in homegrown technological innovation in developing countries to compete with those leading innovations or to play catch-up is likely to be a wasteful use of scarce resources. Instead, resources in developing countries may be more productively invested in improving the efficiency and sustainability of upstream processes, and in transferring and adapting existing technologies for mid- and downstream processes, resorting to homegrown development when economically justified. Governments should reform the WTO TRIPS or conclude additional international agreements to facilitate developing country governments' access to clean energy and other green technologies for critical minerals. Broadening access to intellectual property rights and technology allows for increased innovation not just in developing countries, but in critical minerals value chains worldwide.

APPENDIX A

Methodology for Country Selection

A.1 METHODOLOGY FOR THE SELECTION OF 30 COUNTRIES FOR PHASE 1

For the Phase 1 analysis, 30 countries were selected out of the 131 countries and territories outside of Europe on the List of Official Development Assistance (ODA) Recipients of the Organisation for Economic Co-operation and Development (OECD)'s Development Assistance Committee (DAC). This selection was based on the following criteria:

- **Midstream critical minerals total imports score:** The UN Comtrade Database[390] was used to obtain data on average annual total imports of aggregate and selected critical minerals by country over the past 10 years (2014–2023). Selected critical minerals include Copper ores, concentrates; Nickel ores, concentrates, matte; Aluminium ores, concentrates, etc.; Copper; Nickel; Aluminium; Zinc; Tin. Countries were ranked based on their aggregate net import value over the past 10 years (in million USD), considering that countries that import critical minerals are more likely to have or benefit from technologies used to process these minerals for mid- and downstream use. Countries ranking in the top 40 were assigned a score of 1, while the rest were given the score of 0.

- **Downstream critical minerals total imports score:** The UN Comtrade Database[391] was used again, this time to obtain data on average annual net import of non-ferrous waste materials by country over the past 10 years (2014–2023). Countries were ranked based on aggregate net import value over the past 10 years (in million USD), considering that countries that import critical minerals waste materials are more likely to have or benefit from technologies used to process these materials for downstream use. Countries ranking in the top 36 were assigned a score of 1, while others had a score of 0. The top 36 (rather than the top 40) countries were chosen for this metric because of a 10-country tie starting from the 37th place in the ranking.

- **Policy readiness score:** For this metric, the selection was informed by an analysis of the International Energy Agency (IEA)'s Policies Database.[392] The analysis involved scanning for policies relevant to critical minerals, mining, refining, or processing for all 131 developing countries. Analysing policy and legal frameworks is a relevant criterion to determine the level of an enabling environment, or lack thereof, for technological innovation in the critical minerals value chains. A value of 1 was assigned to the 64 countries with at least one policy instrument relevant to critical minerals, mining, processing, or refining in the IEA policy database, beyond umbrella policies such as Extractive Industries Transparency Initiative (EITI); all other 67 countries scored 0 points.

- **World Governance Indicators score**: The World Bank's World Governance Indicators (WGI)[393] are a proxy for countries' perceived level and quality of governance. The WGIs are six aggregate governance indicators: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. This information is relevant to the country selection process because perceptions of good governance serve as an indicator of how efficiently and effectively investments in technological innovations could bring positive impact to the local economy and advance the Sustainable Development Goals (SDGs), and because political stability is conducive to stable domestic and regulatory frameworks that enable investment. Each country's score in the six aggregate governance indicators in 2022 was averaged and then ranked. Averages were

---

390) "UN Comtrade." United Nations, *United Nations*, 2024, https://comtrade.un.org/labs/data-explorer/#.

391) "UN Comtrade." United Nations, *United Nations*, 2024, https://comtrade.un.org/labs/data-explorer/#.

392) "Policy Database – Data & Statistics." *International Energy Agency* (IEA), IEA, 2024, www.iea.org/policies.

393) "Home: Worldwide Governance Indicators." World Bank, World Bank Group, January 23, 2024, www.worldbank.org/en/publication/worldwide-governance-indicators.

converted into scores ranging between 0 and 1: top-ranking countries (up to the 50th place) scored a 1; mid-range countries (from 51st to 100th place) scored a 0.5; countries beyond 100th place scored a 0.

- **Global Innovation Index score**: The World Intellectual Property Organization (WIPO)'s Global Innovation Index (GII)[394] was used as a proxy for assessing the technological readiness of developing countries. The countries' 2023 GII values were scaled down to scores ranging between 0 and 1 by dividing each index by the largest GII in the dataset (which is China's GII of 55.3). To help differentiate between the rankings of countries that would have otherwise obtained the same overall (integer) scores, the GII score was not made binary. While the binary scoring system used in other criteria controlled the impact of outliers for factors with larger ranges of minimum and maximum values, the GII has a relatively small range, which made it the ideal metric to use as the score differentiator. Moreover, the GII contains the most directly relevant information to the project's goal of evaluating innovative technologies, so a more granular scoring system was appropriate for this metric. Coverage of all countries was maximised where possible; the GII score for Malawi was included from the 2021 report.

Since all Phase 1 country selection factors have similar levels of importance, our final score gives each of them equal weight, according to the formula below:

Final score = midstream net imports score + downstream net imports score + policy readiness score + Worldwide Governance Indicators score + Global Innovation Index score

The application of the formula above, followed by adjustments in agreement with UNIDO to ensure geographical balance—11 countries in Africa, 11 countries in Asia–Pacific (ASP), and 8 countries in Latin America and the Caribbean (LAC)—produced a list of 30 countries (Table A-1).

TABLE A-1. Countries from the DAC ODA list selected for assessment during Phase 1

Countries from DAC ODA list	Region	Score
Malaysia	ASP	4.7
India	ASP	4.7
Thailand	ASP	4.7
South Africa	Africa	4.5
Indonesia	ASP	4.5
Colombia	LAC	4.5
Dominican Republic	LAC	4.4
Türkiye	ASP	4.2
Viet Nam	ASP	4.2
Brazil	LAC	4.1
Philippines	ASP	4.1

394) World Intellectual Property Organization (WIPO), "Global Innovation Index 2023 – Innovation in the Face of Uncertainty," 2024, www.wipo.int/global_innovation_index/en/2023.

TABLE A-1. Countries from the DAC ODA list selected for assessment during Phase 1 (continued)

Countries from DAC ODA list	Region	Score
Mexico	LAC	4.1
Morocco	Africa	4.0
Argentina	LAC	4.0
Peru	LAC	4.0
Egypt	Africa	3.9
Kenya	Africa	3.9
Cambodia	ASP	3.9
Ecuador	LAC	3.9
Nigeria	Africa	3.8
Mauritius	Africa	3.6
Georgia	ASP	3.5
Jordan	ASP	3.5
Senegal	Africa	3.4
Namibia	Africa	3.4
Tunisia	Africa	3.0
Kazakhstan	ASP	3.0
Tanzania	Africa	2.8
Zambia	Africa	2.8
Bolivia	LAC	1.9

Source: Prepared by the authors.

A.2 METHODOLOGY FOR THE SELECTION OF 9 COUNTRIES FOR PHASE 2

For the Phase 2 analysis, 9 countries were selected out of the list of 30 Phase 1 countries. A comprehensive framework was used to evaluate and rank countries, based on the following criteria:

1. Policy readiness
2. Technology readiness
3. Long-term financial sustainability of technological innovation
4. Knowledge production and sharing.

Each criterion comprises specific indicators that are meticulously analysed using a combination of qualitative and quantitative data sources. They provide a comprehensive understanding of each country's technological innovation landscape, resulting in the selection of 9 countries with the highest potential for technological innovation in the midstream and downstream segments of critical minerals value chains. The 9 countries include the 3 top-ranked countries in each of the 3 regions: Africa, ASP, and LAC. Sections A.2.1 through A.2.4 present the methodologies for calculating each of the four criteria, and Section A.2.5 presents the weighting and aggregation of the final score.

A.2.1 Policy Readiness

The policy readiness score was developed using the following eight policy-related qualitative indicators and one quantitative indicator, jointly serving as a proxy to assess a country's enabling environment for technology innovation in the mid- and downstream segments of the critical minerals value chain:

- Qualitative Indicator 1: Mining frameworks (11.25% weight)
- Qualitative Indicator 2: Renewable Energy Targets (11.25% weight)
- Qualitative Indicator 3: Environmental protection (11.25% weight)
- Qualitative Indicator 4: Circular economy and recycling (11.25% weight)
- Qualitative Indicator 5: Technology Innovation and R&D support (11.25% weight)
- Qualitative Indicator 6: Critical Minerals processing and refining (11.25% weight)
- Qualitative Indicator 7: Assembling and manufacturing (11.25% weight)
- Qualitative Indicator 8: Waste management (11.25% weight)
- Quantitative Indicator 1: World Governance Indicator 2022 (10% weight)

Qualitative Indicator 1 considers general mining frameworks of a country and assesses mining codes, laws, and frameworks that influence the whole mining value chain, including extraction, processing, and beneficiation of critical minerals. This indicator is important, considering how mining policies, especially related to the critical minerals value chains, contribute to broader socioeconomic development goals in each country.

Qualitative Indicator 2 considers renewable energy targets and energy decarbonisation, analysing how countries integrate energy decarbonisation strategies to their policies, laws, and regulations, and how these can influence the mid- and downstream segments of critical minerals value chains.

Qualitative Indicator 3 considers environmental protection policies, laws, and regulations throughout mining value chains.

Qualitative Indicator 4 considers the integration of circular economy principles in policy, legal, and regulatory frameworks, including regulations on recycling, recovery of critical minerals from manufactured products in different industries such as electronics and automotive, and regulations that promote resource efficiency.

Qualitative Indicator 5 considers policies, laws, and regulations that support research and development (R&D), as well as technological innovation, particularly in the midstream and downstream segments of critical minerals value chains. It also considers policies that include financial mechanisms that incentivise technological innovation in the midstream and downstream segments of critical minerals value chains, such as tax incentives, subsidies and grants, national and international funds, and partnerships.

Qualitative Indicator 6 considers policies, laws, and regulations that promote the processing and refining of critical minerals, adding value beyond extraction.

Qualitative Indicator 7 considers policies, laws, and regulations encouraging the production of end-products derived from processed critical minerals, such as electric vehicles (EVs), lithium-ion batteries, and renewable energy components.

Qualitative Indicator 8 considers policies, laws, and regulations that govern waste management in the midstream and downstream segments of critical minerals value chains.

The source for Qualitative Indicators 1–8 is an extensive internal analysis of primary data that includes over 550 policies, laws, and regulations, as documented in the Policy Tracker Spreadsheet, available upon request. A score from 1 to 3 was assigned to each qualitative indicator, with 1 indicating low support, 2 indicating medium support, and 3 indicating high support, based on the degree to which the country's policies and regulations align with and promote each qualitative indicator.

Quantitative Indicator 1 considers the World Bank's WGIs,[395] which are a proxy for countries' perceived level and quality of governance and were also used in our methodology for the selection of 30 countries for Phase 1 (see section A.1 above). The averages of each country's score in the six aggregate governance indicators in 2022 were ranked. Then, the score was scaled across countries by dividing by the highest value across the set of 30 countries.

A.2.2 Technology Readiness

The score for technology readiness was developed using four quantitative indicators that jointly serve as a proxy for demonstrating the most pertinent technological advancements in critical minerals essential for the clean energy transition within the defined TRLs:

- Indicator 1: Technology Readiness Level (TRL) (1–10) (50% weight)
- Indicator 2: Mineral Supply and Scarcity (25% weight)
- Indicator 3: Renewable Energy per Capita (12.5% weight)
- Indicator 4: Mineral Processing Research
- Publications (12.5% weight)

Indicator 1 considers a country's ability to develop, adopt, and implement technologies across key sectors. It reflects the country's capacity for innovation and its potential to contribute to the global technological landscape, offering insights into future economic and industrial development in general and not limited to the critical mineral and metal industry. To calculate the TRL scores, data was drawn from the World Bank Global Competitiveness Data Set[396] focusing on indicators such as R&D capacity, human capital, and the innovation ecosystem. Key metrics include the Global Competitiveness Index, Capacity for Innovation, Business Sophistication Index, Infrastructure Index, Availability of Engineers & Scientists, Company Spending on R&D, and Innovation Output. These indicators were standardised into two average scores based on their respective scales (1–7 and 0–130), enabling a comparative assessment of technological readiness across different countries.

Countries were then ranked according to these averages, with higher scores indicating greater technological readiness. TRL scores were assigned on a scale from 1 to 10, providing a clear picture of each country's technological capabilities. The score was then scaled across countries by dividing by the highest value across the set of 30 countries. This scaled score was then multiplied by the weight of 50% to contribute to the technology readiness score.

Indicator 2 considers the scarcity of critical minerals supply. Data was primarily sourced from the World Mineral Production Document by the British Geological Survey,[397] which provides comprehensive and granular historical data from 2019 to 2022 across upstream, midstream, and downstream categories. The scarcity factor was calculated as the ratio of midstream/downstream volumes to the total upstream/midstream/downstream capacity. A scarcity factor below 100% indicates that not all mining capacity is utilised for domestic midstream or downstream activities, suggesting significant exports of raw materials. Countries were ranked based on their cumulative midstream/downstream mineral supply capacity, with the highest volume ranked first. Countries with no supply capacity for the identified minerals were assigned a rank of 22.

The score was then scaled across countries by dividing by the largest score across the set of 30 countries. This scaled score was then multiplied by the weight of 25% to contribute to the technology readiness score.

Indicator 3 considers a measure of renewable energy availability relative to population size, offering a straightforward approach to assess how renewable energy resources are distributed among a country's citizens. This indicator focuses purely on the capacity available per individual, and was calculated as follows:

395) "Home: Worldwide Governance Indicators." *World Bank*, World Bank Group, January 23, 2024, http://www.worldbank.org/en/publication/worldwide-governance-indicators.

396) "WEF Global Competitiveness Index 4.0," Prosperity Data 360, *World Bank Group*, July 17, 2023, https://prosperitydata360.worldbank.org/en/dataset/WEF+GCI.

397) BGS Press, "World Mineral Production 2018 to 2022," *British Geological Survey*, September 4, 2024,

Energy per Capita	=	Renewable Energy Capacity (MW) / Population (millions)

By isolating the impact of population on renewable energy capacity, this approach allows for more accurate comparisons between countries with varying economic and demographic profiles. It assesses how effectively renewable energy capacity is distributed among its citizens, thus providing insight into the equitable distribution of energy resources. This indicator contributes to a deeper understanding of the global landscape of renewable energy, supporting the transition towards sustainable and equitable energy solutions.

The score was scaled across countries by dividing by the highest value across the set of 30 countries. This scaled score was then multiplied by the weight of 12.5% to contribute to the technological readiness score.

Indicator 4 considers a country's ranking based on the number of mineral processing research publications in leading academic journals. The primary journals included in this assessment were Minerals Engineering, Journal of the Southern African Institute of Mining and Metallurgy, Mining, Metallurgy & Exploration, and Minerals. The score was then multiplied by the weight of 12.5% to contribute to the technology readiness score.

A.2.3 Long-Term Financial Sustainability of Technological Innovation

The score for long-term financial sustainability of technological innovation was developed using three quantitative indicators that jointly serve as a proxy for the existence of a supportive financial and investment environment for technological innovation across the 30 countries in scope:

- Indicator 1: Research and development expenditure (% of GDP) (2018–2022 unless otherwise indicated) (50% weight)
- Indicator 2: Grants, excluding technical cooperation (BoP, current US$) / avg GDP 2018–2022 (25% weight)
- Indicator 3: Investment in energy with private participation (current US$) / GDP (25% weight)

Indicator 1 considers the R&D expenditure across the 30 countries as a percentage of the country's GDP. The purpose of this calculation was to generate an average across a period of 2018 to 2022 for both the World Bank R&D expenditure data (via UNESCO Institute for Statistics)[398] and the World Bank GDP dataset.[399] In cases where 2018–2022 data was not available, the most recent available figures were used.

The score was then scaled across countries by dividing by the highest value across the set of 30 countries. This scaled score was then multiplied by the weight of 50% to contribute to the financial sustainability score.

Indicator 2 provides a view of countries that are receiving grants, where this information is represented in the form of grants in USD as a percentage of the country's average GDP. The calculation used averages across 2018–2022 for both the World Bank Grants data[400] and the World Bank GDP dataset.[401]

Grants are defined as legally binding commitments that obligate a specific value of funds available for disbursement, typically in the form of transfers made in cash, goods, or services, for which there is no repayment requirement.[402] The data compiles flows of official and private financial resources from OECD DAC members to developing countries.

---

https://www.bgs.ac.uk/news/world-mineral-production-2018-to-2022-is-now-available.

398) "Research and Development Expenditure (% of GDP)," UIS.Stat Bulk Data Download Service, *World Bank Group*, April 4, 2024, https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS.

399) "World Development Indicators," *World Bank Group*, June 28, 2024, https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.MKTP.CD&country=&_gl=1*17lwg20*_gcl_au*MTk3NDA5MzQxOS4xNzE3MDA0MDU3.

400) "Grants, Excluding Technical Cooperation (BoP, current US$)," International Debt Statistics, *World Bank Group*, December 13, 2023, https://data.worldbank.org/indicator/BX.GRT.EXTA.CD.WD.

401) "World Development Indicators," *World Bank Group*, June 28, 2024, https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.MKTP.CD&country=&_gl=1*17lwg20*_gcl_au*MTk3NDA5MzQxOS4xNzE3MDA0MDU3.

The score was then scaled across countries by dividing by the largest score across the set of 30 countries. This scaled score was then multiplied by the weight of 25% to contribute to the financial sustainability score.

Indicator 3 provides information on investment in energy (with private participation) based on the World Bank Private Participation in Infrastructure Project Database.[403] In line with the approach for indicators 1 and 2 above, the calculation used an average across a period of 2018 to 2022 for both the World Bank PPIP database and the World Bank GDP dataset.[404]

This indicator covers commitments to infrastructure projects in electricity and natural gas that have reached financial closure and directly or indirectly serve the public, meaning that its focus is broader than just clean energy investment. Although its inclusion was due to data availability, it is nevertheless an indicator for available funds in the country for energy-related investment.

The score was scaled across countries by dividing by the highest value across the set of 30 countries. This scaled score was then multiplied by the weight of 25% to contribute to the financial sustainability score.

A.2.4 Knowledge Production and Sharing

The domestic and international knowledge sharing score was developed using three quantitative indicators that jointly serve as a proxy for the extent to which knowledge development and knowledge transfer is occurring across the 30 countries in scope:

- Indicator 1: Total patent grants (direct and Patent Cooperation Treaty [PCT] national phase entries) / GDP (40% weight)
- Indicator 2: IP Payments as a % of Total Trade (30% weight)
- Indicator 3: Patent Cooperation Treaty Signatory (30% weight)

Indicator 1 considers the total number of patents granted in the country across a 10-year period. Data across the 30 countries on "Total patent grants (direct and PCT national phase entries)," for the period 2013–2022,[405] was extracted from WIPO's IP Statistics Data Centre.[406]

The sum of patents granted in the 10-year period was divided by the country's average GDP for the same period, calculated using World Bank data.[407] The score was then scaled across countries by dividing by the highest value across the set of 30 countries. This scaled score was then multiplied by the weight of 40% to contribute to the final knowledge-sharing score.

Indicator 2 consists of the proportion that payments for the use of IP make up of a country's total annual trade figures. The calculations for this indicator used 2023 data for charges for the use of intellectual property and total trade.

The WTO Stats Dashboard provides data on charges for the use of intellectual property. Data for 2023 was used for most countries.[408]

Per the Global Innovation Index methodology (Appendix III., 5.3.1),[409] total trade is defined as the

402) "Metadata Glossary: Grants, Excluding Technical Cooperation (BoP, current US$)," International Debt Statistics, *World Bank Group*, December 13, 2023, https://databank.worldbank.org/metadataglossary/world-development-indicators/series/BX.GRT.EXTA.CD.WD.

403) "Investment in energy with private participation (current US$)," Private Participation in Infrastructure Database, *World Bank Group*, 2023, https://data.worldbank.org/indicator/IE.PPI.ENGY.CD?view=chart.

404) "World Development Indicators."

405) Note regarding Nigeria: The country did not disclose data on patent grants in this period;, this may be due to Nigeria not being a receiving state for PCT patent applications. Nigeria has consistently not reported on patents or received a score of ~0 in Global Innovation Index rankings. Only the patents granted in 2022 have been included in this assessment.

406) "WIPO IP Statistics Data Center," *World Intellectual Property Organization*, December, 2023, https://www3.wipo.int/ipstats/ips-search/search-result?type=IPS&selectedTab=patent&indicator=23&reportType=13&fromYear=2013&toYear=2022&ipsOffSelValues=&ipsOriSelValues=AR,BO,BR,KH,CO,DO,EC,EG,GE,IN,ID,JO,KZ,KE,MY,MU,MX,MA,NA,NG,PE,PH,SN,ZA,TH,TN,TR,TZ,VN,ZM&ipsTechSelValues=910.

407) "World Development Indicators."

408) "Commercial Services, Exports, 2023," WTO Stats Dashboard, *World Trade Organization*, 2024, https://stats.wto.org/dashboard/services_en.html#. Exceptions are Egypt, Kenya, Mexico, Namibia, Tanzania, and Tunisia, for which 2022 data was used, and Viet Nam and Senegal, where 2014 and 2021 data was used, respectively (based on latest data availability).

409) Dutta et al., "Global Innovation Index 2023: Innovation in the face of uncertainty," *World Intellectual Property Organization*, September 27, 2023, https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2023-en-global-innovation-index-2023-16th-edition.pdf.

sum of total imports of code G goods and code SOX commercial services (excluding government goods and services not included elsewhere) plus total exports of code G goods and code SOX commercial services (excluding government goods and services not included elsewhere), divided by 2. WTO statistics on trade across commercial services and goods-related services were used to gather import and export trade figures for 2023 across the 30 countries.[410]

The country score for this indicator was calculated by taking the average of charges for the use of IP (import plus export divided by 2), and dividing this by the total trade per country for the year 2023. The score was then scaled across countries by dividing by the largest score across the set of 30 countries. This scaled score was then multiplied by a weight of 30% to contribute to the final knowledge-sharing score.

Indicator 3 shows the extent to which a country has ratified relevant intellectual property–related patent treaties. In the calculation of this indicator, the following five treaties administered by WIPO were considered:

- Patent Cooperation Treaty (PCT): Assists applicants in seeking international patent protection, supports patent offices to grant decisions, and facilitates public access to technical information related to patents.[411]
- Patent Law Treaty (PLT): Harmonises and streamlines formal patent and application procedures more user-friendly.[412]
- The Hague Agreement: Governs the international registration of industrial designs.[413]
- The Stockholm Act (1967): Latest revision of the Paris Convention, which applies to industrial property (including patents, trademarks, industrial designs, utility models, service marks, trade names, geographical indications, and the repression of unfair competition) to ensure protection of intellectual property in other countries.[414]
- Strasbourg Agreement: Establishes the International Patent Classification, making retrieval possible for authorities, R&D units, and others concerned with the application or development of technology.[415]

The calculation of the indicator involved assessing whether or not each treaty was in force in the country (value 1 for treaty in force, value 0 for treaty not in force for a given country), taking an average across the five treaties. This indicator was weighted at 30% of the overall knowledge-sharing score.

A.2.5 Data Processing and Final Scoring

Each criterion was assigned a weight reflecting its perceived importance in the overall assessment:

- Policy Readiness: 1/3 weight
- Technology Readiness: 1/3 weight
- Long-term financial sustainability of technological innovation: 1/6 weight
- Knowledge Production and Sharing: 1/6 weight.

The weighted scores for each criterion were aggregated to calculate an overall score for each country. This score determined the country's rank in the overall evaluation.

410) "Trade in Commercial Services," Global Services Trade Data Hub, *World Trade Organization*, July 31, 2024, https://www.wto.org/english/res_e/statis_e/gstdh_commercial_services_e.htm.

411) "Patent Cooperation Treaty," WIPO Lex, *World Intellectual Property Organization*, July 9, 2024, https://www.wipo.int/wipolex/en/treaties/ShowResults?search_what=C&treaty_id=6.

412) "Patent Law Treaty," WIPO Lex, *World Intellectual Property Organization*, July 9, 2024, https://www.wipo.int/wipolex/en/treaties/ShowResults?search_what=C&treaty_id=4.

413) "Hague Agreement," WIPO Lex, *World Intellectual Property Organization*, July 9, 2024, https://www.wipo.int/wipolex/en/treaties/ShowResults?search_what=C&treaty_id=9.

414) "Stockholm Act (1967)," WIPO Lex, *World Intellectual Property Organization*, July 9, 2024, https://www.wipo.int/wipolex/en/treaties/ShowResults?search_what=A&act_id=31.

415) "Strasbourg Agreement Concerning the International Patent Classification," *World Intellectual Property Organization*, https://www.wipo.int/treaties/en/classification/strasbourg.

The underlying data and formulas used for the scoring and ranking are available upon request. The resulting list of 9 countries for Phase 2 includes the top 3 countries in each of the three developing country regions:

Region: Africa

- Namibia
- South Africa
- Zambia

Region: ASP

- India
- Indonesia
- Türkiye

Region: LAC

- Argentina
- Brazil
- Mexico

APPENDIX B

Policy, Legal, and Regulatory References

This appendix provides the list of legal instruments and other references consulted for the preparation of the policy, legal, and regulatory frameworks summaries for the 30 Phase 1 countries (Section 2.1) and of the deep-dive narratives of the policy, legal, and regulatory frameworks of the 9 Phase 2 countries (Section 3.2 for African countries, Section 3.3 for ASP countries, and Section 3.4 for LAC countries). The list is alphabetically ordered by region and, within each region, by country.

Region: AFRICA

Agreement Establishing the African Continental Free Trade Area (AfCFTA), adopted 21 March 2018, entered into force 30 May 2019, https://au.int/en/treaties/agreement-establishing-african-continental-free-trade-area

Draft Protocol to the Agreement Establishing the African Continental Free Trade Area on Intellectual Property Rights, January 2023, https://www.bilaterals.org/IMG/pdf/en_-_draft_protocol_of_the_afcfta_on_intellectual_property_rights.pdf.

Protocol on Investment to the Agreement Establishing the African Continental Free Trade Area (AfCFTA), adopted February 2023, https://www.bilaterals.org/IMG/pdf/en_-_draft_protocol_of_the_afcfta_on_investment.pdf.

Protocol on Energy in the Southern African Development Community, signed 24 August 1996, https://www.sadc.int/document/protocol-energy.

Protocol on Mining in the Southern African Development Community, signed 8 September 1997, https://www.sadc.int/document/protocol-mining-1997.

Protocol on Finance and Investment, signed 18 August 2006, amended 4 July 2019, https://www.sadc.int/document/protocol-finance-and-investment-2006, https://www.sadc.int/document/agreement-amending-annex-1-cooperation-investment-protocol-finance-investment-english-2016.

Protocol on Science Technology and Innovation, signed 17 August 2008, https://www.sadc.int/document/protocol-science-technology-and-innovation-2008.

EGYPT

Egypt, Mineral Resources Law, Law No. 198 (2014), https://www.petroleum.gov.eg/en/mineral-resources/lstmineralresourceslawandregulations/Mineral%20Resources%20Law%20No%20198%20of%202014.pdf.

Egypt, Investment Law, Law No. 72 (2017), https://investmentpolicy.unctad.org/investment-laws/laws/167/egypt-investment-law-.

Egypt, Renewable Energy Law, Decree No. 203 (2014), https://www.iea.org/policies/6104-egypt-renewable-energy-law-decree-no-2032014.

Egypt, Egypt Renewable Energy Tax Incentives, Presidential Decree No. 17 (2015), https://www.iea.org/policies/6105-egypt-renewable-energy-tax-incentives-presidential-decree-no-172015.

Egypt, Prime Minister Decree No. 964 - Amendment of Executive Regulation of Law 4/1994 (2015), https://www.iea.org/policies/14821-prime-minister-decree-no-964-of-2015-amendment-of-executive-regulation-of-law-41994.

Egypt, Egypt Vision 2030 (2016), https://arabdevelopmentportal.com/sites/default/files/publication/sds_egypt_vision_2030.pdf.

Egypt, Decree No. 330 (2015), https://manshurat.org/sites/default/files/docs/pdf/008075.pdf.

KENYA

Kenya, National E-Waste Management Strategy (2019–2024), https://repository.kippra.or.ke/handle/123456789/1687

Kenya, Mining Act No. 12 (2016), https://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/MiningAct_No12of2016.pdf.

Kenya, VAT Act (2013), https://www.iea.org/policies/6007-tax-incentives-for-renewable-energy.

Kenya, VAT (Amendment) Act (2014), https://www.iea.org/policies/6007-tax-incentives-for-renewable-energy.

Kenya, Mining and Minerals Policy (2016), https://www.idlo.int/sites/default/files/pdfs/highlights/Kenya%20Mining%20Policy%20Popular%20Version-LowRes.pdf.

Kenya, Mining Outlook 2023 (2023), https://bowmanslaw.com/insights/kenyas-mining-outlook-2023-current-status-future-possibilities/.

Kenya, Draft Mining (Royalty Collection and Management) Regulations (2023), https://www.mining.go.ke/sites/default/files/documents/RIA-2023%20-%20Royalty%20Collection.pdf.

Kenya, Draft Mining (Mineral Royalty Sharing) Regulations of (2023), https://www.mining.go.ke/sites/default/files/Mining/mining%20documents/Mining(Mineral%20Royalty%20Sharing)%20Regulations%2C2023.pdf.

MAURITIUS

Mauritius, Minerals Act of 1966 (1966), https://www.a-mla.org/en/country/pdf/43.

Mauritius, Long-Term Energy Strategy 2009–2025 (2009), https://sustainabledevelopment.un.org/content/documents/1245mauritiusEnergy%20Strategy.pdf.

Mauritius, Mauritius Renewable Energy Agency (MARENA) (2016), https://www.iea.org/policies/6428-mauritius-renewable-energy-agency-marena.

Mauritius, Green Energy Scheme for Cooperatives (2017), https://www.iea.org/policies/6432-green-energy-scheme-for-cooperatives.

MAROCCO

Morocco, Law No. 33-13 Related to Mines (2015), https://www.a-mla.org/en/country/pdf/570.

Morocco, Moroccan General Tax Code (2021), https://www.gide.com/sites/default/files/mining_in_morocco_overview_w-018-41231.pdf.

Morocco, Law 57.09 Moroccan Agency for Solar Energy "MASEN" (2009), https://www.iea.org/policies/5521-moroccan-agency-for-solar-energy-masen-law-5709.

Morocco, National Strategy for Sustainable Development 2030 (2017), https://www.iea.org/policies/8568-national-strategy-of-sustainable-development-2030.

Morocco, Law 47-09 on Energy Efficiency (2011), https://www.amee.ma/sites/default/files/2019-07/Loi%2047-09.pdf.

Morocco, Circulation Tax Exemption (2017), https://www.iea.org/policies/6993-circulation-tax-exemption-morocco.

Morocco, Municipal Solid Waste Management Programme (2006), https://www.worldbank.org/content/dam/Worldbank/document/Climate/Climate-Finance-Projects-briefs/Morocco-Municipal-Solid-Waste-Management.pdf.

Morocco, Solid Waste Management Law 28-00 (2006), https://www.sante.gov.ma/Reglementation/GESTIONETELIMINATIONDESDECHETS/28-00.pdf.

Morocco, EU–Morocco Green Partnership (2022), https://neighbourhood-enlargement.ec.europa.eu/news/eu-and-morocco-launch-first-green-partnership-energy-climate-and-environment-ahead-cop-27-2022-10-18_en.

NAMIBIA

Namibia, National Renewable Energy Policy (2017), https://www.mme.gov.na/files/publications/03f_National%20Renewable%20Energy%20Policy%20-%20July%202017.pdf.

Namibia, Minerals (Prospecting and Mining) Act 33 (1992), https://www.a-mla.org/en/country/pdf/22.

Namibia, Minerals (Prospecting and Mining) Amendment Act (2008), https://www.a-mla.org/en/country/pdf/1348.

Namibia, Minerals Development Fund of Namibia Act 19 (1996), https://www.a-mla.org/en/country/pdf/131.

Namibia, State-owned Enterprises Governance Act 2 (2006), https://www.a-mla.org/en/country/pdf/131.

Namibia, Energy Policy White Paper (1998), https://www.iea.org/policies/5892-energy-policy-white-paper-1998.

Namibia, Feed-in Tariff (2015), https://www.iea.org/policies/5746-namibia-feed-in-tariff.

Namibia, Concentrated Solar Power Technology Transfer for Power Generation in Namibia (2014), https://www.iea.org/policies/5897-concentrated-solar-power-technology-transfer-for-power-generation-in-namibia.

Namibia, Solar Revolving Fund (SRF) (2011), https://www.iea.org/policies/5894-solar-revolving-fund-srf.

Namibia, National Energy Fund (NEF) (1990), https://www.iea.org/policies/5896-national-energy-fund-nef.

Namibia, Minerals Beneficiation Strategy (2021), https://mit.gov.na/documents/41692/88507/Mineral%2BBeneficiation%2BStrategy%2Bfor%2BNamibia%2B2021.pdf.

Namibia, Namibia–EU Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen (2022), https://single-market-economy.ec.europa.eu/system/files/2022-11/MoU-Namibia-batteries-hydrogen.pdf.

Namibia, Ban on Export of Unprocessed Critical Minerals (2023), https://www.reuters.com/markets/commodities/namibia-bans-export-unprocessed-critical-minerals-2023-06-08/.

Namibia, Ministry of Environment and Tourism (MET), National Solid Waste Management Strategy, http://the-eis.com/elibrary/sites/default/files/downloads/literature/National%20solid%20waste%20management%20strategy.

NIGERIA

Nigeria, Circular Economy Roadmap, https://climateaction.africa/nigeria-circular-economy-sustainable-future.

Nigeria, National Environmental (Electrical/Electronic Sector) Regulations (2011), https://www.nesrea.gov.ng/wp-content/uploads/2020/02/Electrical_Electronics.pdf

Nigeria, National Minerals and Metals Policy (2008), https://www.a-mla.org/en/country/pdf/1007.

Nigeria, Nigerian Minerals and Mining Act (2007), https://www.a-mla.org/en/country/law/3.

Nigeria, Nigeria Renewable Energy Master Plan (2011), https://www.iea.org/policies/4974-nigeria-renewable-energy-master-plan.

Nigeria, Feed-in Tariff for Renewable Energy Sourced Electricity (2015), https://www.iea.org/policies/5974-nigeria-feed-in-tariff-for-renewable-energy-sourced-electricity.

Nigeria, Finance Act (2020), https://www.a-mla.org/en/country/pdf/1835.

Nigeria, Mining and Metal Sector Investment Promotion Brochure (2017), https://www.a-mla.org/en/country/pdf/1008.

SENEGAL

Senegal, Law No. 2016-32 (2016), https://www.a-mla.org/en/country/law/988.

Senegal, VAT Exemption for Renewable Energy Equipment (2020), https://www.iea.org/policies/17768-vat-exemption-for-renewable-energy-equipment.

Senegal, The General Tax Code of Senegal (2012), https://www.iisd.org/system/files/publications/senegal-mining-policy-framework-assessment-en.pdf.

Senegal, Programme for the Promotion of Renewable Energies, Rural Electrification and Sustainable Supply in Domestic Fuel (PERACOD) (2004), https://www.iea.org/policies/4965-program-for-the-promotion-of-renewable-energies-rural-electrification-and-sustainable-supply-in-domestic-fuel-peracod.

Senegal, Renewable Energy Law (2010), https://www.iea.org/policies/5423-renewable-energy-law.

Senegal, Law No. 2020-31 (2020), https://www.minmidt.cm/en/the-national-mining-corporation-sonamines-created-by-the-president-of-the-republic.

Senegal, Model Mining Convention (2012), https://www.iisd.org/system/files/publications/senegal-mining-policy-framework-assessment-en.pdf.

Senegal, Emerging Senegal Plan (2012), https://www.senegal-emergent.com/en/the-pse.

SOUTH AFRICA

South Africa, Special Economic Zones (SEZ) Act No. 16 of 2014 (2014), https://www.thedtic.gov.za/sectors-and-services-2/industrial-development/special-economic-zones/.

South Africa, Industrial Development Corporation Act (1940), https://www.gov.za/sites/default/files/gcis_document/201505/act-22-1940.pdf.

South Africa, The Mineral and Petroleum Resources Development Act (MPRDA) (2002), https://unctad.org/system/files/non-official-document/cstd2023-24_g_c14_southafrica_en.pdf.

South Africa, Beneficiation Strategy of 2011 (2011), https://www.gov.za/sites/default/files/gcis_document/201409/beneficiation-strategy-june-2011-final-30.pdf.

South Africa, National Development Plan (NDP) 2030 (2023), https://unctad.org/system/files/non-official-document/cstd2023-24_g_c14_southafrica_en.pdf.

South Africa, National Environmental Management Act (NEMA), No. 107 (1998), https://www.gov.za/sites/default/files/gcis_document/201409/a107-98.

South Africa, Strategic Framework for Implementing Sustainable Development in the South African Minerals Sector (2009), https://www.gov.za/sites/default/files/gcis_document/201409/sd-strategic-framework-minerals-april-2009.pdf.

South Africa, Department of Science and Innovation, Science, Technology, and Innovation Decadal Plan 2022–2032, https://www.dst.gov.za/index.php/documents/strategies-and-reports/189-sti-decadal-plan/file.

South Africa, Mining Charter, Act No. 28, (2018), https://www.gov.za/sites/default/files/gcis_document/201809/41934gon1002.pdf.

South Africa, Broad-based Socio-economic Empowerment Charter for the Mining and Minerals Industry (2018), https://www.gov.za/sites/default/files/gcis_document/201809/41934gon1002.pdf.

South Africa, National Waste Management Strategy (2020), https://www.dffe.gov.za/sites/default/files/docs/2020nationalwaste_managementstrategy1.pdf.

South Africa, Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (2011), https://www.iea.org/policies/5393-renewable-energy-independent-power-producer-programme-reippp.

South Africa, Second-Hand Goods Act (2009), https://www.saps.gov.za/resource_centre/acts/downloads/juta/shg_act_6_2009.pdf

South Africa, Waste Act, 2008 (Act No. 59 of 2008), https://www.dffe.gov.za/sites/default/files/legislations/nema_amendment_act59.pdf

South Africa, Mining Charter, Act No. 28, (2018), https://www.gov.za/sites/default/files/gcis_document/201809/41934gon1002.pdf.

South Africa, Waste Act, Extended Producer Responsibility Regulations (2020), https://lawlibrary.org.za/akn/za/act/gn/2020/1184/eng@2021-05-05

South Africa, South Africa Just Energy Transition Partnership (JETP) Investment Plan (2023), https://www.climatecommission.org.za/south-africas-jet-ip.

South Africa, South Africa–Japan Cooperation on Mineral Technology Transfer (2022), https://www.jogmec.go.jp/english/news/release/news_10_00003.html.

South Africa, United Kingdom–South Africa Partnership on Minerals for Future Clean Energy Technologies (2022), https://www.gov.uk/government/publications/uk-south-africa-joint-statement-on-partnering-on-minerals-for-future-clean-energy-technologies/uk-and-south-africa-working-in-partnership-on-minerals-for-future-clean-energy-technologies.

TANZANIA

Tanzania, Mining Act (2010), https://www.a-mla.org/en/country/pdf/8.

Tanzania, Mining Act (Amendment) Regulations (2012), https://www.a-mla.org/en/country/pdf/573.

Tanzania, Mining Act Revised Edition of 2018 (2018), https://www.a-mla.org/en/country/pdf/1435.

Tanzania, 2019 Minerals Yearbook (2019), https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/myb3-2019-tanzania.pdf.

Tanzania, Natural Wealth and Resources Act (2017), https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/myb3-2019-tanzania.pdfhttps:/d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/myb3-2019-tanzania.pdf.

Tanzania, Mining (Mineral Beneficiation) Regulations (2018), https://www.a-mla.org/en/country/pdf/2165.

Tanzania, Mining (Value Addition) Regulations (2020), https://www.a-mla.org/en/country/pdf/2048.

Tanzania, Mining (Local Content) Regulations (2018), https://www.a-mla.org/en/country/pdf/1427.

Tanzania, The Scaling up Renewable Energy Programme for Tanzania (SREP Tanzania) (2013), https://www.iea.org/policies/5637-scaling-up-renewable-energy-programme-for-tanzania-srep-tanzania.

Tanzania, Tanzanian Energy Development Access Programme (TEDAP) (2008), https://www.iea.org/policies/4963-tanzanian-energy-development-access-programme-tedap.

Tanzania, Value Added Tax Act of 2019 (2019), https://www.a-mla.org/en/country/pdf/1862.

TUNISIA

Tunisia, Renewable Energy Law for Electricity Production (No.74/2013) (2015), https://www.iea.org/policies/5873-renewable-energy-law-for-electricity-production-no742013.

Tunisia, Tax Exemptions for the Import of Renewable Energy and Energy Efficiency Equipment Materials (2010), https://www.iea.org/policies/110-tax-exemptions-for-the-import-of-renewable-energy-and-energy-efficiency-equipment-materials.

Tunisia, Decree 2009/362 on Renewable Energy and Energy Efficiency Premiums (2009), https://www.iea.org/policies/4934-decree-2009362-on-renewable-energy-and-energy-efficiency-premiums.

Tunisia, 2016 Investment Law (2023), https://www.state.gov/reports/2023-investment-climate-statements/tunisia/.

Tunisia, Tax Incentive Law (2017), http://www.finances.gov.tn/sites/default/files/reglementaire_fr/Loi2017_8.pdf/.

Tunisia, Tunisian Solar Plan (PST) 2010-2016 (2009), https://www.iea.org/policies/4936-tunisian-solar-plan-pst-2010-2016.

Tunisia, National Energy Efficiency Programme 2008-2011 (2008), https://www.iea.org/policies/4938-national-energy-efficiency-program-2008-2011-renewable-energy-provisions.

Tunisia, The Law 2009-7 on Energy Efficiency: Renewable Energy Provisions (2009), https://www.iea.org/policies/4937-law-2009-7-on-energy-efficiency-renewable-energy-provisions.

Tunisia, Law 2005-82 on Energy Efficiency Fund (FNME) (2006), https://www.iea.org/policies/4939-law-2005-82-on-energy-efficiency-fund-fnme.

Tunisia, Decree on Rules of Selling Renewable Electricity to the Tunisian Company of Electricity and Gas (STEG) (2009), https://www.iea.org/policies/5331-decree-on-rules-of-selling-renewable-electricity-to-the-tunisian-company-of-electricity-and-gas-steg.

ZAMBIA

Zambia, Mines and Minerals Development Act No. 11 (2015), https://www.a-mla.org/en/country/pdf/862.

Zambia, The Mines and Minerals Development Act No. 7 (2015),

Zambia, The Mines and Minerals Development (Amendment) Act No. 18 (2018).

Zambia, Mines and Minerals Development (General) Regulations of 2016 (2016), https://www.a-mla.org/en/country/pdf/995.

Zambia, Zambia Development Agency Act (2006), https://www.zda.org.zm/wp-content/uploads/2020/12/ZDA-Act-2006-1.pdf.

Zambia, Zambia Vision 2030 (2006), https://www.zambiaembassy.org/sites/default/files/documents/Vision_2030.pdf.

Zambia, National Policy on Environment (2007), https://www.iea.org/policies/5837-the-national-policy-on-environment-2007.

Zambia, National Energy Policy (2008), https://www.iea.org/policies/5909-national-energy-policy-2008.

Zambia, Solid Waste Regulation and Management (2018), https://www.parliament.gov.zm/sites/default/files/documents/acts/The%20Solid%20Waste%20Regulation%20and%20Management%20Act%2C%202018.pdf.

Zambia, Environmental Management (Amendment) Act No.8 (2023), https://faolex.fao.org/docs/pdf/zam219945.pdf.

Zambia, Partnership on Sustainable Raw Materials Value Chains Between the European Union and The Republic of Zambia (2023), https://single-market-economy.ec.europa.eu/system/files/2023-11/MoU_CRM_EU-Zambia_26_10_2023_signed.pdf.

Zambia, European Union's Global Gateway Strategy (2023), https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/stronger-europe-world/global-gateway_en.

Zambia, Zambia's Critical Minerals Strategy, https://www.mmmd.gov.zm/?p=3161.

Region: ASP

CAMBODIA

Cambodia, Law on Mineral Resource Management and Exploitation (2001), https://leap.unep.org/en/countries/kh/national-legislation/law-mineral-resource-management-and-exploitation.

Cambodia, Law on Environmental Protection and National Resource Management (1996), https://leap.unep.org/en/countries/kh/national-legislation/law-environmental-protection-and-natural-resource-management.

Cambodia, National Policy in Mineral Resources 2018–2028 (2018), http://www.mme.gov.kh/documents/255/MME_National_Mineral_Policy-EN.pdf.

Cambodia, National Energy Efficiency Programme (NEEP) (2022), https://www.iea.org/policies/17464-national-energy-efficiency-programme-neep.

Cambodia, Power Development Masterplan (PDP) (2022-2040) (2022), https://climate-laws.org/document/power-development-master-plan-2022-2040-0f75.

Cambodia, Sub decree 16 Management over Electrical Equipment and Electronic Waste (2016), https://www.eurocham-cambodia.org/legal_directory_index/detail/332.

GEORGIA

Georgia, Georgia Country Strategy 2021–2026: Georgian Mining Code (2019), https://www.ebrd.com/georgia-strategy.pdf.

Georgia, Law of Georgia on Environmental Protection No. 519 (2016), https://faolex.fao.org/docs/pdf/geo42013ENG.pdf.

Georgia, Long-Term Low Emission Development Strategy 2050 (2023), https://www.undp.org/georgia/publications/georgia-low-emission-development-strategy-2050.

Georgia, Integrated National Energy and Climate Plan of Georgia (NECP) (2023), https://www.energy-community.org/dam/jcr:4dfd3e00-78c0-47a8-a2d9-01ec62459010/National__Energy_and_Climate_Plan_of_Georgia_(DRAFT)%20(2).pdf.

Georgia, Law of Georgia on Energy and Water Supply (2009), https://matsne.gov.ge/en/document/download/4747785/4/en/pdf.

Georgia, Georgia Innovation and Technology Agency (GITA), https://gita.gov.ge/en.

Georgia, The Law on Science, Technology and Their Development (1994), https://leap.unep.org/en/countries/ge/national-legislation/law-georgia-science-technology-and-their-development-no-603-1994.

Georgia, The Law on Grants (1996), https://www.mof.ge/images/File/laws/B-Law-Law-on-Grants-ENG.pdf.

Georgia, The Law on Higher Education (2004), https://matsne.gov.ge/ru/document/download/32830/53/en/pdf.

Georgia, The Law on Education Quality Improvement (2010), https://matsne.gov.ge/en/document/download/93064/5/en/pdf.

Georgia, The Law on Innovations (2016), https://matsne.gov.ge/en/document/download/3322328/0/en/pdf.

Georgia, Resolution No. 426 of 2015 of Georgian Government on Determining List and Classifying Waste according to Types and Characteristics (2015), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC166716/.

Georgia, Special Requirements for Collection and Treatment of Hazardous Waste No. 145 (2016), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC166695.

Georgia, Georgian Government Decree on Rules for Collection and Treatment of Municipal Waste No. 159 (2016), https://leap.unep.org/en/countries/ge/national-legislation/resolution-no-159-2016-georgian-government-rules-collection-and.

Georgia, Waste Management Code (2015), https://faolex.fao.org/docs/pdf/geo166634ENG.pdf.

Georgia, Georgian Government Decree No. 421 on Arrangement, Operation, Closure, and Post-care of Landfill (2015), https://waste.gov.ge/ka/wp-content/uploads/2015/07/FINAL-Landfill-Bylaw-RES_421_ENG_20150713.pdf.

Georgia, Technical Regulation No. 326 (2021), https://ewastemonitor.info/wp-content/uploads/2021/11/REM_2021_CISGEORGIA_WEB_final_nov_11_spreads.pdf.

Georgia, Resolution No. 324 of May 25, 2020 on 'Approval of Technical Regulation on Batteries and Battery Waste Management (2020), https://www.sgs.com/en/news/2020/07/safeguards-09820-georgia-announces-technical-regulation-on-batteries-and-battery-waste-management.

INDIA

India, Battery-Waste Management Rules (2022), https://cpcb.nic.in/uploads/hwmd/Battery-WasteManagementRules-2022.pdf.

India, National Mineral Policy (2019), https://mines.gov.in/admin/storage/app/uploads/64352887bcfa41681205383.pdf.

India, Production Linked Incentive (PLI) Schemes (2020), https://www.investindia.gov.in/production-linked-incentives-schemes-india.

India, Prospective Critical Minerals Policy (2024), https://www.argusmedia.com/en/news-and-insights/latest-market-news/2569898-india-to-launch-policy-to-boost-critical-mineral-supply.

India, National Programme on High Efficiency Solar PV Modules (2021), https://www.investindia.gov.in/team-india-blogs/availing-benefits-under-pli-scheme-high-efficiency-solar-pv-modules.

India, New Electric Vehicle (EV) Policy (2024), https://www.india-briefing.com/news/indias-new-ev-policy-to-attract-investments-boost-imports-31667.html/.

India, *A Review of State Government Policies for Electric Mobility* (2021), https://www.wricitiesindia.org/sites/default/files/Full_report_EV_State_Policy.pdf.

India, Special Economic Zone Act (2005), https://www.nsez.gov.in/Resources/SEZ%20Act,%202005.pdf.

India, Special Economic Zones Rules (2006), https://nsez.gov.in/Resources/SEZ%20Rule,%202006.pdf.

India, E-Waste (Management) Rules (2022), https://cpcb.nic.in/uploads/Projects/E-Waste/e-waste_rules_2022.pdf.

INDONESIA

Indonesia, Mining Law No. 3 (2020), https://www.iea.org/policies/16957-mining-law-no-32020.

Indonesia, Energy Ministry Decree regarding National Planning on Mineral and Coal 2022-2027 (2022), https://www.iea.org/policies/17994-energy-ministry-decree-regarding-national-planning-on-mineral-and-coal-2022-2027.

Indonesia, Decree Regarding Classification of the Critical Minerals Lists (2023), https://www.iea.org/policies/17998-energy-ministry-decree-regarding-classification-of-the-critical-minerals-lists.

Indonesia, Statement Regarding EV Batteries During 2023 National Coordination Meeting of Regional Heads (2023), https://en.antaranews.com/news/269706/indonesia-to-become-largest-ev-battery-producer-in-2027-minister.

Indonesia, AEML Electric Vehicles Outlook (2023), https://acv.vc/wp-content/uploads/2023/07/Report-Indonesias-Electric-Vehicle-Outlook-Supercharging-Tomorrows-Mobility_NEW.pdf.

Indonesia, Tax Incentives for Special Economic Zones (2022), https://www.aseanbriefing.com/news/tax-incentives-for-special-economic-zones-in-indonesia/.

Indonesia, Super Tax Deductions for R&D (2024), https://www2.deloitte.com/content/dam/Deloitte/id/Documents/tax/id-tax-info-jun2024-en.pdf.

Indonesia, National Research and Innovation Agency, https://www.brin.go.id/en/page/5/pengantar.

Indonesia, Government Regulation (GR) No. 4 (2009), https://pubs.usgs.gov/myb/vol3/2019/myb3-2019-indonesia.pdf.

Indonesia, Prohibition of the Export of Nickel Ore (2020), https://www.iea.org/policies/16084-prohibition-of-the-export-of-nickel-ore.

Indonesia, 2023 Local Content Decree (2023), https://jdih.setkab.go.id.

Indonesia, Governmental Regulation No. 27 of 2020 on Specific Wastes Management (2020), https://setkab.go.id/en/govt-issues-regulation-on-specific-waste-management.

JORDAN

Jordan, Natural Resources Law (2018), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC200530.

Jordan, Environmental Protection Law No. 6 (2017), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC173241/.

Jordan, Regulation No. 85 of 2020 - Environmental Information and Control System for Waste Management (2020), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC207679.

Jordan, National Mining Strategy (2020), https://petra.gov.jo/Include/InnerPage.jsp?ID=58840&lang=en&name=en_news.

Jordan, Economic Modernisation Vision, https://www.jordanvision.jo/img/vision-en.pdf.

Jordan, Renewable Energy & Energy Efficiency Law No. 13 (2012), https://www.memr.gov.jo/ebv4.0/root_storage/en/eb_list_page/renewable_energy__energy_efficiency_law_-_english.pdf.

Jordan, Exemptions on Import and Registration Taxes (2021), https://jordanexports.jo/mobility.

KAZAKHSTAN

Kazakhstan, Guidelines to Boost the Production of Eco-friendly Automotive Vehicles in Kazakhstan (2015), https://asiantransportoutlook.com/documents/193/Kazakhstan_emobilityprofile.pdf.

Kazakhstan, ST RK 3753-2021 National Standard for the Treatment of Hazardous Waste (2023), https://ewastemonitor.info/wp-content/uploads/2023/07/National_E-waste_Monitor_Kazakhstan_2023_final_web.pdf.

Kazakhstan, Subsoil and Use of Subsoil Code (2023), https://documents1.worldbank.org/curated/en/099081823001539573/pdf/P17674501063760b08b290a4ae6547845d.pdf.

Kazakhstan, Joint Order of I.O. of the Minister of Ecology, Geology and Natural Resources of the Republic of Kazakhstan and Minister of the Industry and Infrastructure Development of the Republic of Kazakhstan, Law No. 400 (2021), https://cis-legislation.com/document.fwx?rgn=133832.

Kazakhstan, Strategic Development Plan of the Republic of Kazakhstan until 2025 (2024), https://primeminister.kz/ru/documents/gosprograms/stratplan-2025.

Kazakhstan, Presidential Decree Validating the Strategic Development Plan of the Republic of Kazakhstan until 2025, Decree No. 636, https://www.fao.org/faolex/results/details/en/c/LEX-FAOC191496.

Kazakhstan, Environmental Code of the Republic of Kazakhstan, Law No. 400-VI (2021), https://www.iea.org/policies/12917-environmental-code-of-the-republic-of-kazakhstan-400-vi-as-amended.

Kazakhstan, Memorandum of Understanding Between the Republic of Kazakhstan and the European Union on a Strategic Partnership on Sustainable Raw Materials, Batteries and Renewable Hydrogen Value Chains (2022), https://single-market-economy.ec.europa.eu/system/files/2022-11/EU-KAZ-MoU-signed_en.pdf.

MALAYSIA

Malaysia, The 1987 Environmental Quality Order (1987), https://prod.iea.org/policies/16961-the-1987-environmental-quality-order.

Malaysia, National Mineral Industry Transformation Plan 2021-2030 (2021), https://www.iea.org/policies/16794-national-mineral-industry-transformation-plan-2021-2030.

Malaysia, Eleventh Malaysia Plan 2016–2020 (2016), https://www.pmo.gov.my/dokumenattached/RMK/RMKe-11Book.pdf.

Malaysia, Green Technology Master Plan Malaysia 2017-2030 (2017), https://www.pmo.gov.my/wp-content/uploads/2019/07/Green-Technology-Master-Plan-Malaysia-2017-2030.pdf.

Malaysia, National Automotive Policy (2014), https://www.maa.org.my/pdf/NAP_2014_policy.pdf.

Malaysia, National Automotive Policy (2020), https://www.miti.gov.my/index.php/pages/view/nap2020.

Malaysia, National Policy on Industry 4.0 (Industry4WRD) (2018), https://www.miti.gov.my/index.php/pages/view/4832.

Malaysia, Domestic Investment Strategic Fund (DISF), https://www.bankislam.com/business-banking/sme-banking/disf.

Malaysia, Twelfth Malaysia Plan 2021–2025 (2021), https://faolex.fao.org/docs/pdf/mal210617.pdf.

PHILIPPINES

Philippines, Philippine Mining Act of 1995, Republic Act No. 7942 (1995), https://www.iea.org/policies/16252-philippine-mining-act-of-1995-republic-act-no-7942.

Philippines, Revised Implementing Rules and Regulations of R.A. 7942, Philippine Mining Act of 1995, DENR Administrative Order 2010-21 (2010), https://www.iea.org/policies/16274-revised-implementing-rules-and-regulations-of-ra-7942-philippine-mining-act-of-1995-denr-administrative-order-2010-21.

Philippines, Philippine Environmental Impact Statement Law (2021), https://emb.gov.ph/wp-content/uploads/2021/03/Philippine-Environmental-Impact-Statement-System-Brochure.pdf.

Philippines, The Philippine Clean Air Act, Republic Act No. 8749 (1999), https://faolex.fao.org/docs/pdf/phi45271.pdf.

Philippines, An Act to Control Toxic Substances and Hazardous and Nuclear Wastes, Providing Penalties for Violations Thereof, and for Other Purposes, Republic Act No. 6969 (2015), https://emb.gov.ph/wp-content/uploads/2015/09/RA-6969.pdf.

Philippines, Ecological Solid Waste Management, Law Act No. 9003 (2000), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC045260/.

Philippines, The Philippine Clean Water Act, Republic Act No. 9275 (2004), https://faolex.fao.org/docs/pdf/phi70789.pdf.

Philippines, Institutionalizing and Implementing Reforms in the Philippine Mining Sector Providing Policies and Guidelines to Ensure Environmental Protection and Responsible Mining in the Utilisation of Mineral Resources, Executive Order No. 79 (2012), https://www.officialgazette.gov.ph/2012/07/06/executive-order-no-79-s-2012/.

Philippines, Philippine Development Plan 2023-2028 (2023), https://pdp.neda.gov.ph/wp-content/uploads/2023/01/PDP-2023-2028.pdf.

Philippines, The Electric Vehicle Industry Development Act, Republic Act No. 11697 (2022), https://ltoportal.ph/evida-law-electric-vehicle-industry-development-act/#google_vignette.

Philippines, Technical Guidelines on the Environmentally Sound Management of WEEE (2020), https://emb.gov.ph/wp-content/uploads/2020/12/NATIONAL-POLICY-REGULATORY-FRAMEWORK-ALREADY-IN-PLACE-FOR-E-WASTE-MANAGEMENT-EMB-ANNOUNCED.pdf.

THAILAND

Thailand, Minerals Act, B.E. 2560 (2017), https://policy.asiapacificenergy.org/sites/default/files/Minerals%20Act%2C%20B.E.%202560%20%282017%29.pdf.

Thailand, Energy Efficiency Revolving Fund (EERF) (2003), https://www.iea.org/policies/283-energy-efficiency-revolving-fund-eerf.

Thailand, National Renewable Energies Development Plan 2008–2022 (REDP) (2009), https://www.iea.org/policies/4803-renewable-energy-development-plan-redp-2008-2022.

Thailand, ESCO Fund (2008), https://www.iea.org/policies/702-esco-fund.

Thailand, Eastern Economic Corridor Act (2018) https://investmentpolicy.unctad.org/investment-policy-monitor/measures/3216/thailand-passes-the-eastern-economic-corridor-act.

TÜRKIYE

Türkiye, Mining Law No. 3213 (1985), https://policy.asiapacificenergy.org/node/2311.

Türkiye, Eleventh Development Plan 2019-2023 (2019), https://www.iea.org/policies/17867-eleventh-development-plan-2019-2023.

Türkiye, Ministry of Energy and Natural Resources, Strategic Plan 2019-2023 (2019), https://www.iea.org/policies/17644-ministry-of-energy-and-natural-resources-strategic-plan-2019-2023.

Türkiye, National Energy Plan (2022), https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/TUEP/Türkiye_National_Energy_Plan.pdf

Türkiye, Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) Strategic Plan 2022-2026 (2022), https://www.iea.org/policies/17646-turkish-energy-nuclear-and-mineral-research-agency-strategic-plan-2022-2026.

Türkiye, Supply Procurement Strategy Action Plan 2017-2019 (2017), https://www.iea.org/policies/17866-supply-procurement-strategy-action-plan-2017-2019.

Türkiye, Accelerating to Zero Coalition, https://acceleratingtozero.org/.

Türkiye, Global Commercial Vehicle Drive to Zero MoU (2021), https://globaldrivetozero.org/mou-nations/.

VIET NAM

Viet Nam, 2010 Mineral Law, Law No. 60/2010/QH12 (2010), https://vbpl.vn/TW/Pages/vbpqen-toanvan.aspx?ItemID=10501.

Viet Nam, Law on Environmental Protection (2014), https://www.iea.org/policies/11906-law-on-environmental-protection-2014.

Viet Nam, Law on Environmental Protection, Law No. 72/2020/QH14 (2020), https://www.iea.org/policies/18356-law-no-722020qh14-on-environmental-protection.

Viet Nam, Master Plan on Exploration, Exploitation, Processing, Use of Mineral Resources (2023), https://en.vietnamplus.vn/master-plan-on-exploration-exploitation-processing-use-of-mineral-resources-approved-post262901.vnp.

Viet Nam, Decision 334/QD-TTg 2023 Strategy for Geology, Minerals and Mining Industry Through 2030 (2023), https://english.luatvietnam.vn/tai-nguyen/decision-334-qd-ttg-2023-strategy-for-geology-minerals-mining-industry-through-2030-248174-d1.html.

Viet Nam, Vietnam Energy Green Transport (2021), https://www.trade.gov/market-intelligence/vietnam-energy-green-transport.

Viet Nam, Decree No. 57/2020/ND-CP (2016), https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer.

Region: LAC

ARGENTINA

Argentina, Mining Code, Law No. 1919 (1886), https://www.argentina.gob.ar/normativa/nacional/ley-1919-43797/actualizacion.

Argentina, Mining Code, Law No. 24,196 (1993), https://www.argentina.gob.ar/normativa/nacional/ley-24196-594/actualizacion.

Argentina, Large Investment Incentive Scheme (RIGI) (2024), https://www4.hcdn.gob.ar/dependencias/dsecretaria/Periodo2024/PDF2024/TP2024/0018-D-2024.pdf

Argentina, Resolution No. 47 (2020), https://www.argentina.gob.ar/normativa/nacional/resoluci%C3%B3n-47-2020-340707/texto.

Argentina, Mining Code, Law No. 24.585 (1995), https://www.argentina.gob.ar/normativa/nacional/ley-24585-30096/texto.

Argentina, National Promotion System for the use of Renewable Energy Sources for the Production of Electrical Energy, Law No. 27.191 (2015), https://servicios.infoleg.gob.ar/infolegInternet/anexos/250000-254999/253626/norma.htm.

Argentina, National Strategic Plan for Mining Development (2021), https://www.argentina.gob.ar/sites/default/files/plan_estrategico_para_el_desarrollo_minero_argentino.pdf.

Argentina, National Lithium Roundtable (2021), https://litioargentina.com/desarrollo/mesa-nacional-del-litio-que-es-y-por-que-es-clave-para-cuidar-el-recurso-en-el-pais.

Argentina, Draft Law on the Industrial Development of Lithium (2023), https://www4.hcdn.gob.ar/dependencias/dsecretaria/Periodo2023/PDF2023/TP2023/2856-D-2023.pdf.

Argentina, EU–Argentina Partnership on Sustainable Raw Materials Value Chains (2023), https://single-market-economy.ec.europa.eu/system/files/2023-07/MoU_EU_Argentina_20230613.pdf.

Argentina, National Strategy for the Circular Economy (2024), https://www.argentina.gob.ar/sites/default/files/ambiente-plan-estrategico-provincial-gestion-residuos.pdf.

BOLIVIA

Bolivia, Mining Law, Law No. 535 (2014), https://mineria.gob.bo/juridica/20140528-13-6-11.pdf.

Bolivia, Law No. 1333 (1992), https://sea.gob.bo/digesto/CompendioII/N/129_L_1333_01.pdf.

Bolivia, National Development Plan (PND) 2021-2025 (2021), https://observatorioplanificacion.cepal.org/sites/default/files/plan/files/PDES_2021-2025a_compressed_0.pdf.

Bolivia, Law 928 (2017), https://www.lexivox.org/norms/BO-L-N928.xhtml.

Bolivia, Supreme Decree Nº 3227 (2017), https://www.lexivox.org/norms/BO-DS-N3227.html.

Bolivia, Bolivian Tax Code, Law No. 2492 (2003), https://www.oas.org/juridico/spanish/mesicic3_blv_codtribut.pdf.

Bolivia, Law 466 (2009), https://www.oas.org/es/sla/dlc/mesicic/docs/mesicic5_nic_resp_ane_5.pdf.

Bolivia, Law No. 755 (2015), https://sea.gob.bo/digesto/CompendioII/N/142_L_755.pdf.

Bolivia, National Plan for Integral Solid Waste Management (PNGIRS) 2016–2020 (2016), https://redcompostaje.mmaya.gob.bo/files/biblioteca/05%20PLANIF%20NORMATIVA/03%20Gu%C3%ADa%20Formulaci%C3%B3n%20PMGIRS.pdf.

BRAZIL

Brazil, Bill No. 2780 (2024), https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=2447259.

Brazil, Mining Code, Decree-Law No. 227 (1967), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC112289.

Brazil, Law No. 13.575 (2017), https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/l13575.htm.

Brazil, Approved Regulatory Agenda of the National Mining Agency, Resolution No. 20/2019 (2019), https://anmlegis.datalegis.net/action/ActionDatalegis.php?acao=abrirTextoAto&link=S&tipo=RES&numeroAto=00000020&seqAto=000&valorAno=2019&orgao=ANM/MME&cod_modulo=351&cod_menu=6675.

Brazil, Law No. 6938 (1981), https://www.planalto.gov.br/ccivil_03/leis/l6938.htm.

Brazil, Bill No. 2780 (2024), https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=2447259.

Brazil, Mining Code, Decree-Law No. 227 (1967), https://www.fao.org/faolex/results/details/en/c/LEX-FAOC112289.

Brazil, Law No. 13.575 (2017), https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/l13575.htm.

Brazil, Approved Regulatory Agenda of the National Mining Agency, Resolution No. 20/2019 (2019), https://anmlegis.datalegis.net/action/ActionDatalegis.php?acao=abrirTextoAto&link=S&tipo=RES&numeroAto=00000020&seqAto=000&valorAno=2019&orgao=ANM/MME&cod_modulo=351&cod_menu=6675.

Brazil, Law No. 6938 (1981), https://www.planalto.gov.br/ccivil_03/leis/l6938.htm.

Brazil, Law No. 10.165 (2000), https://www.planalto.gov.br/ccivil_03/leis/l10165.htm.

Brazil, National Mining Plan 2030, Ordinance No. 121 (2011), https://www.iea.org/policies/17864-ordinance-no-121-national-mining-plan-2030.

Brazil, National Strategic Pro-Minerals Policy, Decree 10.657 (2021), https://www.gov.br/mme/pt-br/acesso-a-informacao/legislacao/decretos/2021/decreto-n-10-657-2021.pdf/view.

Brazil, Investment Partnership Programme, Law No. 3,334 (2016), https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2016/lei/l13334.htm.

Brazil, National Mining Plan 2050 (2011), https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/pnm-2050/sobre-o-pnm-2050.

Brazil, Ordinance GM/MDIC nº 162 (2023), https://www.gov.br/mdic/pt-br/composicao/se/cndi/arquivos/decretos-e-portarias/arquivos/dou_2023-06-19-portaria-gm-mdic-no-162-de-16-de-junho-de-2023-designacao-membros-cndi-sociedade-civil/view

Brazil, Law No. 11.196 (2005), https://www.planalto.gov.br/ccivil_03/_ato2004-2006/2005/lei/l11196.htm.

Brazil, Growth Acceleration Programme (PAC) (2023), https://www.gov.br/mre/pt-br/embaixada-praia/nova-versao-do-programa-de-aceleracao-do-crescimento-pac.

Brazil, Decree No. 11.120 (2022), https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/decreto/d11120.htm.

Brazil, National Solid Waste Policy (PNRS), Law No. 12.305 (2010) https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm.

Brazil, Automotive Sector Policy (Rota 2030), Law No. 13.755 (2018), https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/lei/l13755.htm.

Brazil, Law 12.546 (2011), https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2011/lei/l12546.htm.

COLOMBIA

Colombia, Mining Code, Law 685 (2001), https://www.anm.gov.co/sites/default/files/ley_685_2001_0.pdf.

Colombia, Decree 1073 (2015), https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=77887.

Colombia, National Development Plan (PND) 2022–2026 (2022), https://colaboracion.dnp.gov.co/CDT/Prensa/Publicaciones/plan-nacional-de-desarrollo-2022-2026-colombia-potencia-mundial-de-la-vida.pdf.

Colombia, Green Growth Policy, CONPES 3934 (2018), https://colaboracion.dnp.gov.co/CDT/Conpes/Econ%C3%B3micos/3934.pdf.

Colombia, Law 2250 (2022), https://www.suin-juriscol.gov.co/viewDocument.asp?ruta=Leyes/30044431.

Colombia, Law 1715 (2014), https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=57353.

Colombia, Decree 2041 (2014), https://www.suin-juriscol.gov.co/viewDocument.asp?id=1389917.

Colombia, Law 1672 (2013), https://www.minambiente.gov.co/wp-content/uploads/2021/06/ley-1672-2013.pdf.

Colombia, National Circular Economy Strategy (ENEC) (2018), https://www.minambiente.gov.co/asuntos-ambientales-sectorial-y-urbana/estrategia-nacional-de-economia-circular/.

Colombia, Resolution 1407 (2018), https://www.minambiente.gov.co/documento-normativa/resolucion-1407-de-2018/.

Colombia, Law 2069 (2020), https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=160966.

Colombia, Law 1286 (2009), https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=34850.

Colombia, Law 1508 (2012), https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=45329.

Colombia, Mining Law for the Just Energy Transition, National Reindustrialisation, and Mining for Life (2024), https://www.minenergia.gov.co/documents/11475/2024_02_16_BORRADOR_ARTICULADO_NLM.pdf.

DOMINICAN REPUBLIC

Dominican Republic, Mining Law No. 146 (1971), https://faolex.fao.org/docs/pdf/dom44855.pdf.

Dominican Republic, National Development Strategy 2030, Law No. 1-12 (2012), https://www.iea.org/policies/16739-law-no-1-12-that-establishes-the-national-development-strategy-2030.

Dominican Republic, General Law on Environment and Natural Resources, Law No. 64-00 (2000), https://observatorioplanificacion.cepal.org/sites/default/files/instrument/files/2000.%20Ley%2064%20General%20sobre%20medio%20ambiente%20y%20recursos%20naturales.pdf.

Dominican Republic, Incentive for Renewable Energy and Special Regimes, Law No. 57-07 (2007), https://www.cne.gob.do/wp-content/uploads/2015/11/Ley-No.-57-07-Sobre-Incentivos-al-Desarrollo-de-Energ--as-Renovables.pdf.

Dominican Republic, Law on Competitiveness and Industrial Innovation, Law No. 392-07 (2007), https://dgii.gov.do/legislacion/leyesTributarias/Documents/Leyes%20de%20Incentivos%20y%20Fomentos/392-07.pdf.

Dominican Republic, Draft Reform of the Mining Law (2017), https://presidencia.gob.do/noticias/ministerio-de-energia-y-minas-presenta-detalles-anteproyecto-de-reforma-de-la-ley-minera.

Dominican Republic, General Law on Comprehensive Waste Management and Co-processing, Law No. 225-20 (2020), https://dgii.gov.do/legislacion/leyestributarias/documents/leyes%20de%20instituciones%20y%20fondos%20de%20terceros/225-20.pdf.

ECUADOR

Ecuador, Mining Law (2009, amended in 2013 and 2018), https://www.gob.ec/sites/default/files/regulations/2018-09/Documento_Ley-de-Miner%C3%ADa.pdf.

Ecuador, Environmental Management Law (1999), https://www.ambiente.gob.ec/wp-content/uploads/downloads/2012/09/LEY-DE-GESTION-AMBIENTAL.pdf.

Ecuador, National Development Plan (2018), https://www.gob.ec/sites/default/files/regulations/2018-10/Plan%20Nacional%20de%20Desarrollo%20Toda%20Una%20Vida%202017%20-%202021.pdf.

Ecuador, National Plan for the Mining Sector Development (2020), https://www.recursosyenergia.gob.ec/wp-content/uploads/2020/10/Plan-Nacional-de-Desarrollo-del-Sector-Minero-2020-2030.pdf.

Ecuador, National Circular Economy Strategy (2021), https://youtopiaecuador.com/estrategia-economia-circular-lista-ecuador/.

Ecuador, General Law on the Inclusive Circular Economy (2021), https://www.lexis.com.ec/biblioteca/ley-organica-economia-circular-inclusiva.

Ecuador, Ministerial Agreement No. 026 (2014), https://www.ambiente.gob.ec/wp-content/uploads/downloads/2014/05/AM-026-Procedimientos-Registro-generadores-desechos-peligrosos.pdf.

Ecuador, Ministerial Agreement No. 190 (2013), https://www.ambiente.gob.ec/wp-content/uploads/downloads/2013/01/Acuerdo-Ministerial-190-Pol%C3%ADtica-Nacional-de-Post-Consumo-de-Equipos-El%C3%A9ctricos-y-Electr%C3%B3nicos.pdf.

Ecuador, Ministerial Agreement No. 191 (2014), https://www.ambiente.gob.ec/wp-content/uploads/downloads/2014/05/AM-191-Intructivo-para-reciclaje-para-celulares_final.pdf.

MEXICO

Mexico, General Mining Law (2023), https://www.diputados.gob.mx/LeyesBiblio/pdf/LMin.pdf.

Mexico, Decree by Which Various Provisions of the Mexican Mining Law (and Others) are Amended, Added, and Repealed (2023), https://www.dof.gob.mx/nota_detalle.php?codigo=5688050&fecha=08/05/2023#gsc.tab=0.

Mexico, Energy Transition Law (2015), https://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf.

Mexico, Mining Reforms (2022), https://www.dof.gob.mx/nota_detalle.php?codigo=5649533&fecha=20/04/2022#gsc.tab=0.

Mexico, Lithium for Mexico, Decree DOF 23/08/22 (2023), https://www.diputados.gob.mx/LeyesBiblio//norma/estatuto/est083_17mar23.pdf.

Mexico, General Law for Equality Between Women and Men, latest amendment 29 December 2023, https://www.diputados.gob.mx/LeyesBiblio/pdf/LGIMH.pdf.

Mexico, NOM-157-SEMARNAT-2009 (2009), https://www.profepa.gob.mx/innovaportal/file/6665/1/nom-157-semarnat-2009.pdf.

PERU

Peru, General Mining Law, Law No. 109 (1992), https://www.leyes.congreso.gob.pe/Documentos/DecretosLegislativos/00109.pdf.

Peru, Supreme Decree No. 014-92-EM (1992), https://cdn.www.gob.pe/uploads/document/file/900996/DS-014-92-EM.pdf?v=1593565033.

Peru, Supreme Decree No. 040-2014-EM (2014), https://cdn.www.gob.pe/uploads/document/file/5279522/4743960-d-s-040-2010-em.pdf?v=1697233763.

Peru, Promotion for the Investment of Electricity from Renewable Energy, Law No. 1002 (2008), https://cdn.www.gob.pe/uploads/document/file/893170/DL-1002.pdf?v=1593214541.

Peru, National Plan for Science, Technology, and Innovation for Competitiveness and Human Development (PNCTI 2006-2021) (2006), https://portal.concytec.gob.pe/images/stories/images2012/portal/areas-institucion/pyp/plan_nac_ctei/plan_nac_ctei_2006_2021.pdf.

Peru, Productive Diversification National Plan (PNDP), https://pndp.produce.gob.pe/.

Peru, Law that Promotes Scientific Research, Technological Development, and Technological Innovation, Law No. 30309 (2015), https://cdn.www.gob.pe/uploads/document/file/1066464/Ley_30309.pdf?v=1596051992.

Peru, Mining Royalty Law, Law No. 28.258 (2004), https://www2.congreso.gob.pe/sicr/cendocbib/con4_uibd.nsf/1002BCF7DCFACAE705257C200052B47B/$FILE/28258.pdf.

Peru, Law By Which the Exploration, Exploitation and Industrialisation of Lithium and its Derivates are Determined as Public Necessity, National Interest, and Strategic Resources for the Country, Law No. 31.283 (2021), https://leyes.congreso.gob.pe/Documentos/2016_2021/ADLP/Normas_Legales/31283-LEY.pdf.

Peru, General Law on Solid Waste Management, Decree-Law No. 1278 (2017), https://www.minam.gob.pe/wp-content/uploads/2017/04/Decreto-Legislativo-N%C2%B0-1278.pdf.

Peru, Circular Economy Roadmap 2030 (2024), https://www.gob.pe/institucion/minam/noticias/950449-peru-impulsa-hoja-de-ruta-nacional-de-economia-circular-al-2030.

APPENDIX C

Stakeholders Interviewed

This appendix lists the names, affiliations, and stakeholder groups of the individuals interviewed during Phase 2 of the market assessment, along with the date of their interviews.

TABLE C-1. Stakeholders Interviewed on Phase 2

Name	Afiliation	Stakeholder Group	Date
Isaac Elizondo Garcia; Luis Janeiro	International Renewable Energy Agency (IRENA)	International Organization	26 August 2024
Tatiana Aguilar	World Economic Forum (WEF)	International Organization	27 August 2024
Mark Mistry	Nickel Institute	Industry Association	28 August 2024
Cinthia Rodrigues; Claudia Dias	Brazil Mining Association (IBRAM)	Industry Association	4 September 2024
Steven Kukoda	International Copper Association (ICA)	Industry Association	5 September 2024
Rob Dunne	Consultant, Perth, Australia; Formerly with Newmont, Denver	Private Sector	5 September 2024
Wei Huang	Asian Infrastructure Investment Bank (AIIB)	International Organization	5 September 2024
Gyubin Hwang; Alexandra Hegarty; Joyce Raboca	International Energy Agency (IEA)	International Organization	6 September 2024
Carlos Rebolledo Ibacahe	Ecometales	Private Sector	6 September 2024
Margreth Tadie	Stellenbosch University	Academia	10 September 2024
Tom Krumins	Vale	Private Sector	10 September 2024
Tom Moerenhout	Columbia University School of International and Public Affairs (SIPA) / International Institute for Sustainable Development (IISD)	Academia	12 September 2024
Jacob Jin	Austin Elements	Private Sector	12 September 2024
Anthony Anyimadu	Amira Global	Private Sector	13 September 2024
Dennis Vega	Sustainable Minerals Institute - International Centre of Excellence - Chile	Academia	13 September 2024
Matthew Taylor	Synesqo	Private Sector	13 September 2024
Jim Kennedy	Three Consulting	Private Sector	13 September 2024
Carlos Cuburu; Emiliano Cisneros	Ministry of the Economy, Mining Secretariat, and SEGEMAR, Argentina	Government	16 September 2024
Ana Cristina Alonso Soria; Ganesh Rasagam; Mariem Malouche; Tania Priscilla Begazo Gomez	World Bank	International Organization	16 September 2024
Ludwig John Hidalgo Pascual	Metdev	Private Sector	17 September 2024
Darshit Jaju	Hindalco	Private Sector	18 September 2024

TABLE C-1. Stakeholders Interviewed on Phase 2 (continued)

Name	Afiliation	Stakeholder Group	Date
Abdul Rashid Sesay' Solomon Tucker	Casila Mining & Engineering Services	Private Sector	19 September 2024
Natascha Nunes da Cunha	Inter American Development Bank (IDB)	International Organization	19 September 2024
Nishchay Chadha	Ace Green Recycling	Private Sector	19 September 2024
Ardhi Wardhana; Muhammad Habib	Centre for Strategic and International Studies (CSIS)	International Organization	20 September 2024
John Lindberg; Dana Cartwright	ICMM	International Organization	23 September 2024
Anurag Awasthi	India Electronics & Semiconductor Association	Industry Association	24 September 2024
Oliver Siegel	Magmatic Bio	Private Sector	24 September 2024
Dr. P. Pradip	Tata Consultancy Services	Private Sector	25 September 2024
Alejandro López Valdivieso	Universidad Autónoma de San Luis Potosí	Academia	25 September 2024
Marcelo Oscar Marzocchini; Diego Alejandro Galeano	Innovation, Science and Technology Secretariat, Argentina	Government	27 September 2024
Mehmet Ali Recai Onal	Genomines	Private Sector	1 October 2024
Paulo de Sá	Independent consultant	Private Sector	3 October 2024
Eudy Mabuza; Beeuwen Gerryts	Department of Science and Innovation, South Africa	Government	8 October 2024
Mehdi Safari	Mintek	Private Sector	13 October 2024

Source: Prepared by the authors.

APPENDIX D

Project Pipeline

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
France; early stages in South Africa.	Genomines.[416] [417] [418]	Engineered hyper-accumulator plants for critical minerals extraction.	Utilising synthetic biology to enhance plants' ability to extract critical minerals from soil and mining tailings, thus remediating the land.	Advanced bioleaching techniques through optimised plant growth and microbiome enhancement.	Project TRL 6. It secured USD 2.2 million in seed funding from BPI France.	Potential for projects in developing countries focusing on critical mineral recovery from tailings using bioengineered plants. No public information exists on project timelines.	This project aligns with SDG 15 (Life on Land) by restoring degraded lands and removing toxic metals from contaminated soils, promoting healthier ecosystems. It also supports SDG 12 (Responsible Consumption and Production) by enabling the recovery of critical minerals from these plants, fostering a circular economy, and reducing the need for traditional, environmentally damaging mining methods. Furthermore, the project contributes to SDG 9 (Industry, Innovation, and Infrastructure) by advancing biotechnological research and creating sustainable solutions for resource recovery, thus supporting the transition toward greener industrial processes. When implemented in a developing country, it has the potential to impact SDG 1 (eradicating poverty) and 5 (gender equality) by providing a safer, greener alternative to artisanal mining, which is often unsafe, uncontrolled, and unregulated.

416) https://www.genomines.com/post/genomines-mining-nickel-absorbed-by-plants-on-polluted-land.

417) https://www.genomines.com/post/green-metals-and-mining-the-race-to-decarbonise.

418) https://www.sciencedirect.com/science/article/abs/pii/S1360138598012837.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Australia, Namibia, United Arab Emirates	Lepidico.[419]	Proprietary L-Max® and LOH-Max® technologies to extract lithium from lepidolite and other lithium micas.	Ore from the brownfield, open-pit Karibib mines in Namibia is initially processed using conventional flotation technology, producing a lepidolite-rich concentrate (upstream). This concentrate is then transported to the United Arab Emirates, where patented, non-thermal conversion technologies (unlike those used for spodumene) are employed (midstream). The resulting lithium hydroxide is subsequently supplied to customers under a binding offtake agreement with Traxys.	The patented, non-thermal (unlike those used for spodumene), conversion technologies L-Max® and LOH-Max® technologies enable lithium extraction from diverse sources, including lepidolite, other lithium-rich mica minerals, and high-grade lithium phosphate mineral amblygonite. These technologies offer an attractive alternative to the current lithium supply chain from traditional extraction from spodumene and brine.	TRL 8–9. Financing completed and construction commenced in 2023.	The company is a vertically integrated lithium developer with a patented set of clean technologies that also produce other critical minerals from mica minerals. Concentrate commissioning & production chemical plant commissioning and production is expected in 2025. Potential for application at the site of upstream extraction in Namibia.	The company's approach aligns with SDG 12 (Responsible Consumption and Production) by enabling the efficient use of previously untapped mineral resources, reducing waste, and minimising the environmental impact of lithium extraction. Additionally, Lepidico supports SDG 9 (Industry, Innovation, and Infrastructure) by advancing innovative extraction methods that offer a more sustainable alternative to traditional hard-rock and brine lithium sources. The company's technology also contributes to SDG 13 (Climate Action) by providing essential materials for EVs and renewable energy storage, which are key to reducing global carbon emissions.

419) https://lepidico.com/technology.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
South Africa	Cwenga Lib.[420] [421]	Lithium-ion battery recycling process: modular technology using safer chemicals and processes.	This is the first lithium-ion battery recycling company in South Africa. Modular recycling stations.	Disassembly, sorting, hydrometallurgy, and products.	Project TRL 9; recently implemented.	Significant impact on both mid- and downstream processing. South Africa is a top producer of PGMs, with significant mid- and downstream PGM processing infrastructure. Battery recycling is a significant milestone for the region for other critical minerals. The attractive feature of Cwenga technology is that it is modular and uses safer chemicals.	By focusing on the recovery of critical minerals like lithium, cobalt, and nickel from used batteries, the program aligns with SDG 12 (Responsible Consumption and Production), promoting a circular economy and reducing the need for new resource extraction. Additionally, the program supports SDG 13 (Climate Action) by minimising the environmental impact of battery waste, lowering greenhouse gas emissions through the reuse of materials, and reducing the carbon footprint associated with new mining activities. Moreover, it contributes to SDG 8 (Decent Work and Economic Growth) by fostering sustainable jobs in the recycling industry and supporting green economic activities. As this recycling technology grows it will begin to have a positive impact on SDG 1 (No Poverty) and SDG 5 (Gender Equality) because of its modular nature and safer process.

420) https://medium.com/@colinwindell/first-li-ion-recycling-plant-opens-in-south-africa-9113a2c82d74.

421) https://recyclinginternational.com/technology/technology-news/south-africa-gears-up-battery-recycling/51657.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
India	Amara Raja.[422] [423] [424] [425] [426]	Advanced cell technologies, battery cell manufacture, battery recycling, and e-waste recycling.	Collaboration with Gotion High-Tech for licensing advanced Lithium Iron Phosphate (LFP) technology for manufacturing lithium-ion cells in cylindrical and prismatic forms. Also battery packs and charging solutions for light EVs and the telecom industry.	Downstream operations include the Manufacture of lithium-ion cells and battery packs. It is one of the first companies to invest in lithium-ion technologies in India, with a state-of-the-art Gigafactory inaugurated in 2024.	Project TRL 8–9.	Gigafactory capacity to increase from 16 GWh to over 25 GWh annually. The project's first phase, with a capacity of 2 GWh, is expected to be operational soon. Cell types: lithium iron phosphate (LFP) cells and NMC-based 2170 cylindrical cells primarily for two-wheelers. Partnerships: Gotion High-Tech and InoBat to access cell performance and production efficiency improvements. MOU with Piaggio Vehicles to develop and supply lithium batteries and EV chargers for Piaggio India EVs. Customer Qualification Plant (CQP) operational in 2025–2026.	The company actively promotes, monitors, and supports SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 5 (Gender equality), SDG 6 (Clean water and sanitation), SDG 7 (Affordable and clean energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (climate action). The company has won many awards and accolades for its efforts. The company is engaged in a wide range of clean energy solutions and recycling technologies.

422) https://www.amararaja.com/press_release/amara-raja-announces-strategic-technology-collaboration-with-gotion-inobat-batteries-gib.

423) https://www.equitymaster.com/detail.asp?date=08/14/2024&story=3&title=Will-Amara-Raja-Cash-in-on-the-EV-Boom-Through-an-IPO.

424) https://timesofindia.indiatimes.com/business/india-business/amara-raja-breaks-ground-for-customer-qualification-plant-for-ev-cell-manufacturing-eyes-lead-acid-battery-plant-up-north/articleshow/112448426.cms.

425) https://economictimes.indiatimes.com/industry/renewables/amara-raja-batteries-plans-1-billion-capex-in-5-7-years-to-focus-more-on-new-age-energy-storage-systems/articleshow/85176696.cms?from=mdr.

426) https://www.amararajaeandm.com/images/certificates/ARE&ML%20Sustainability%20Report%20FY23%20Low%20Resolution.pdf.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
India	Attero.[427] [428] [429] [430] [431]	Battery-grade salts from recycled lithium-ion batteries and e-waste.	Attero has developed an advanced, eco-friendly recycling process for lithium-ion batteries and eWaste, combining mechanical and hydrometallurgical technologies to recover lithium, nickel, cobalt, and graphite at high efficiency, while minimising CO2 emissions. Attero aspires to establish leadership in responsible e-waste management in India.	Mechanical and hydrometallurgical recycling technologies.	In progress TRL 7. Extraction of 22 critical minerals important for green chemistry with purity greater than 99.5%. Efficiency of 98% in extracting critical minerals from e-waste and lithium-ion batteries.	Current capacity: 250,000 tons annually, with plans to increase to 1 million tons by 2030.	The company actively promotes, monitors, and supports SDGs and has received many certifications. Its battery recycling e-waste recycling operations to recover critical minerals align with SDG 12 (Responsible Consumption and Production), promoting a circular economy and reducing the need for new resource extraction, SDG 13 (Climate Action) by minimising the environmental impact of battery and e-waste, lowering greenhouse gas emissions through the reuse of materials, and reducing the carbon footprint associated with new mining activities. Overall, the company contributes to SDG 8 (Decent Work and Economic Growth) by fostering sustainable jobs in clean energy technologies including recycling, and supporting green economic activities. As its technology grows, it will begin to have a positive impact on SDG 1 (No Poverty) and SDG 5 (Gender Equality).

427) https://attero.in/about-us.

428) https://www.amararaja.com/press_release/amara-raja-announces-strategic-technology-collaboration-with-gotion-inobat-batteries-gib.

429) https://attero.in/edge/li-ion-battery-recycling.

430) https://attero.in/Lithium-ion-battery-management.

431) https://attero.in/sustainability.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
India	Tata Chemicals.[432] [433] [434] [435] [436] [437] [438] [439] [440]	Battery recycling and recovery of critical minerals; production of nickel hydroxide cake; battery energy storage systems.	Providing battery storage solutions and recycling lithium-ion batteries for the recovery of valuable materials and metals such as lithium carbonate (Li_2CO_3). Collaborating with Indian R&D centres, including ISRO, CSIR-CECRI, and CMET, to support the indigenous development of battery materials, cell production, and recycling technologies Innovation Centre in Pune working on multiple chemistries as well as cell design and active manufacturing technologies. launched recycling operations to recover key materials.	Lithium Carbonate Recovery, Recycling of Lithium-Ion Batteries.	Project TRL 8–9.	Lithium-ion cell manufacturing factory: In June 2023, Tata Chemicals signed an MOU with the Gujarat government to build a factory in Sanand, Gujarat, with an initial capacity of 20 GWh with the potential for doubling capacity. Tata Chemicals has also launched its new recycling process line for Lithium-ion battery, the Battery Pack Engineering Centre in Pune, and the Innovation Centre to develop cell and active manufacturing technologies. Reduce dependency on virgin lithium mining and promote sustainable battery production.	The company, adhering to Tata Group's sustainability ambition, has very strong SDGs and they actively promote, monitor and support SDGs 1 (Eradicating poverty), 5 (Gender equality), 6 (Clean water and sanitation), 7 (Affordable and clean energy), 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable cities and communities), 12 (Responsible Consumption and Production), 13 (climate action), 14 (Life below water), and 15 (Life on Land). The company has won awards for their efforts. By focusing on the recovery of valuable metals like lithium, cobalt, and nickel from used batteries, the program aligns with SDG 12 (Responsible Consumption and Production), promoting a circular economy and reducing the need for new resource extraction. Additionally, the program supports SDG 13 (Climate Action) by minimising the environmental impact of battery waste, lowering greenhouse gas emissions through the reuse of materials, and reducing the carbon footprint associated with new mining activities. Moreover, it contributes to SDG 8 (Decent Work and Economic Growth) by fostering sustainable jobs in the recycling industry and supporting green economic activities. As this recycling technology grows, it will begin to have a positive impact on SDG 1 (No Poverty) and SDG 5 (Gender Equality) because of its modular nature and safer process.

432) https://www.tatachemicals.com/applications/Lithium-ion-dry-cell-and-other-batteries.

433) https://www.ndtvprofit.com/markets/tata-chemicals-shares-gain-the-most-in-eight-months-on-plans-to-build-ev-battery-plant.

434) https://www.reuters.com/business/autos-transportation/indias-tata-group-signs-16-bln-ev-battery-plant-deal-2023-06-02.

435) https://www.equitymaster.com/detail.asp?date=09/20/2023&story=3&title=Tata-Groups-Next-Big-Leap-in-the-EV-Battery-Sector.

436) https://ir.tatachemicals.com/2019-20/material-sciences-and-energy-sciences.php.

437) https://ir.tatachemicals.com/2022-23/environmental-towards-a-sustainable-future.php.

438) https://www.tatachemicals.com/news-room/articles/green-chemistry-for-sustainability.

439) https://www.tatachemicals.com/news-room/press-release/tata-chemicals-awarded-sustainable-plus-world%27s-first-sustainability-label.

440) https://www.tatachemicals.com/Asia/News-room/Press-release/tata-chemicals-promotes-sustainable-development-while-empowering-communities.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
India, Singapore, United States (Texas)	Ace Green Recycling.[441]	Battery materials from recycled batteries.	Innovative battery recycling technology platform offering sustainable end-of-life solutions. Some R&D and plants in India; bulk of R&D in the United States and Singapore.	ACE's LithiumFirst process to extract battery metals.	TRL 8–9. ACE's lithium battery recycling technology has been assessed and validated by global consulting firm Arthur D Little.	Implementing Scope 1 emissions-free technology to efficiently recycle diverse chemistries of lead and lithium batteries across sectors such as electronics, automotive, and energy storage. This approach aims to minimise environmental impact while recovering critical materials for reuse. Plans are underway to expand the battery recycling facility in Taiwan, equipping it with the capability to process up to 20,000 tons of lead batteries annually, further strengthening regional circular economy efforts and reducing dependency on new raw material sources.	The company aligns with SDG 12 (Responsible Consumption and Production) by promoting a circular economy, minimising waste, and reducing the environmental footprint of battery disposal through its innovative, pollution-free recycling processes. Ace Green Recycling also supports SDG 9 (Industry, Innovation, and Infrastructure) by investing in advanced, eco-friendly technologies for battery recycling, which enhance resource recovery efficiency and reduce the need for primary extraction. Additionally, their efforts contribute to SDG 13 (Climate Action) by ensuring that critical materials are reused in a way that lowers carbon emissions compared to traditional recycling methods. Their operation in India positively impacts SDG 5 (Gender Equality).

441) https://www.acegreenrecycling.com.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
China (GEM), Indonesia (QMB; PT QMB New Energy Materials), South Africa.	PT QMB, PT QMB New Energy Materials, and GEM – Green Eco Manufacture. [442] [443] [444]	Battery grade nickel, cobalt and manganese salts from laterite ores.	PT QMB operation involves laterite processing (upstream) and production of battery grade products (midstream) which will eventually be used in planned domestic battery cell manufacture (downstream). PT QMB is located in Qingshan Park, China-Indonesia Comprehensive Industrial Park, Morowali, Central Sulawesi; the Operation is 63% Chinese-owned, while the rest is owned by Indonesia, Japan, and South Korea. GEM has significant activity in South Africa	Advanced HPAL (high pressure acid leaching) technology for nickel laterite processing (upstream) and production of Ni-Co MHP (mixed hydroxide precipitate) andhigh-purity nickel, cobalt and manganese sulphate crystals.	Project TRL 9; recently implemented.	PT QMB and GEM have already deployed this technology since 2021; design capacity of 96,000 tons of nickel metal equivalent. The Ni-Co-Mn products will eventually be used domestically when the battery cell plant is commissioned.	These projects have a significant impact on SDG 9 (Industry, innovation, and infrastructure) and SDG 12 (Responsible Consumption and Production) by strengthening and expanding production of battery-grade Ni and Co materials from the country's rich Ni ore resources, and by promoting the recovery and recycling of valuable metals such as gold, silver, and rare earth elements from discarded electronics, reducing the demand for new raw materials and minimising waste. The projects also support SDG 7 (Affordable and clean energy) by strengthening midstream and promoting downstream processing for clean energy applications. GEM's urban mining efforts also support SDG 11 (Sustainable Cities and Communities) by addressing e-waste challenges in urban areas, reducing pollution, and improving waste management practices. Additionally, the projects contribute to SDG 13 (Climate Action) by lowering the carbon footprint associated with traditional mining and refining processes, as recycling requires significantly less energy. The company also has a role in SDG 8 (Decent Work and Economic Growth) by providing employment opportunities and contributing to the local economy. The huge infrastructure development leading to additional midstream and downstream processing support SDG 5 (Gender equality) and SDG 1 (Eradicating poverty).

442) https://en.gem.com.cn/Products/list.aspx?lcid=268.

443) https://en.gem.com.cn/About/index.aspx.

444) http://en.gemindonesia.com/gsjs/index.aspx.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Indonesia, China	Liqin Nickel (Hamahera) Co., Ltd. (Indonesia),[445] [446] Ningbo Liqin (China), and Halida Group Indonesia.	Battery-grade nickel-cobalt compounds from laterites.	Hydrometallurgical nickel laterites processing (upstream) to produce battery-grade nickel, cobalt, and nickel-cobalt products (midstream processing). The project (in Obi Island, Indonesia) has an annual design capacity of 120,000 metal tons of nickel-cobalt compounds including 14,250 metal tons of cobalt.	HPAL (high pressure acid leaching) of laterites; production of nickel-cobalt Mixed Hydroxide Precipitate (MHP), refined nickel sulphate and cobalt sulphate from leach solutions.	Commissioned in 2021 with two lines. Now 6 lines are operating with a total capacity of 120000 metal tons per year.	A significant positive impact on both midstream and downstream processing. Two nickel-cobalt compound production lines with a total design capacity of 37,000 metal tons were put into operation at the end of 2021. Second phase was completed at the end of 2022. Third phase was completed at the end of 2023 with a capacity of 65,000 metal tons of nickel-cobalt compounds.	These projects have a significant impact on SDG 9 (Industry, innovation, and infrastructure) and SDG 12 (Responsible Consumption and Production) by strengthening and expanding production of battery-grade nickel and cobalt materials from the country's rich nickel ore resources. The projects also support SDG 7 (Affordable and clean energy) by strengthening midstream and promoting downstream processing for clean energy applications. The huge infrastructure development leading to additional midstream and downstream processing support SDG 5 (Gender equality) and SDG 1 (Eradicating poverty).

445) https://www.lygend.com/industries/5.html.

446) https://www.lygend.com/product.html.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Indonesia	PT Freeport Indonesia.[447]	Copper smelting and refining to produce high-purity cathode copper.	PT Freeport Indonesia launched the Gresik Smelter & Refinery (majority owned by Indonesia) in Java in June 2024 with a design capacity of processing 1.7 million metric tons of copper concentrate, from PTFI operations in Papua, to produce 650,000 tons of copper cathode and 50 to 60 tons of gold. Smelting uses Mitsubishi continuous process technology and refining uses ISA technology to produce LME Grade A copper (99.99% pure). Byproducts such as slag and sulphuric acid will be used locally.	Downstream operations to process copper concentrate using Mitsubishi continuous smelting and converting process to produce anode copper and ISA technology for refining to produce high-purity cathode copper (LME Grade A).	Project TRL 9.	This new smelter is a major milestone for Indonesia to build midstream and downstream processing capabilities and is the result of the country's ban of exports of all raw minerals from June 2023. This facility will have a significant impact on several SDGs. The Mitsubishi smelter meets the environmental regulatory limit of 280 ppm of SO_2 stack emission with a sulphur capture level of approximately 97%. Another new smelter may likely be built in Papua, close to the mine site. The valuable and useful byproducts from this facility are sulfuric acid, copper slag, gypsum, anode slime, and copper telluride, all of which can be used or further processed in Indonesia.	The company's activities are significant for SDG 9 (Industry, Innovation, and Infrastructure), as it contributes to local infrastructure development and economic growth in the region through job creation and investments in community projects. However, PT Freeport Indonesia faces challenges with SDG 12 (Responsible Consumption and Production), as mining operations can generate significant environmental impacts, including waste management and water use. Addressing these challenges is crucial for improving sustainability in the mining sector. The company also has a role in SDG 8 (Decent Work and Economic Growth) by providing employment opportunities and contributing to the local economy, although maintaining high safety and labour standards is essential for long-term sustainable development.

447) https://www.reuters.com/markets/commodities/freeport-indonesia-launches-37-bln-gresik-copper-smelter-2024-06-27/.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Türkiye	Kalyon PV Group.[448 449]	High-purity silicon ingot, wafer and solar cell production, and solar panel manufacture.	First and only fully integrated R&D and technology starting from the production of high-purity silicon ingot to wafer and solar cell production followed by solar panel manufacture using established and innovative technologies. Obtained quality, performance, and efficiency certificates from internationally recognized institutions for technology and solar PV modules.	Cell Factory: Mono-PERC technology, Bifacial Technology. Commitment to Clean Energy.	TRL 8–9. First integrated plant outside of China, bringing solar energy technology to Türkiye and around the world. Started its operations in 2020; established R&D Centre; completed Phase 3 Production Line in 2023.	Kalyon Holding has realised numerous Photovoltaic Panel Factory and Solar Power Plant investments in Türkiye and the world. Expected to generate clean, green power for two million households in Türkiye, where 20% of total power comes from solar energy. The country expects to eliminate at least 1.5 million tons of annual fossil fuel waste and harmful carbon emissions.	The company's efforts align with SDG 7 (Affordable and Clean Energy) by increasing the availability of solar energy solutions and supporting the transition to clean and sustainable power sources. Kalyon PV also contributes to SDG 9 (Industry, Innovation, and Infrastructure) through its state-of-the-art solar panel manufacturing facility, promoting technological advancement and local production capabilities in the renewable energy industry. Additionally, their projects support SDG 13 (Climate Action) by significantly cutting the reliance on fossil fuels and decreasing greenhouse gas emissions, helping to mitigate climate change.

448) https://kalyonpv.com/en.

449) Multiply Group 2023 ESG Report, Page 11, https://www.kalyonenerji.com/documents/Multiply-Group-ESG-2023-Report.pdf.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
France, Argentina, and Indonesia	Eramet Group.[450]	Lithium extraction from salar brines and production of battery-grade lithium carbonate.	Upstream plus midstream processing. Eramet in association with IFPEN (French Institute of Petroleum and New Energies) and the company Seprosys developed an advanced, highly automated, DLE (Direct Lithium Extraction) process at Centenario, in Salta Province, to produce new battery-grade lithium carbonate. Aluminium-based adsorbent material is used to capture lithium from the brines. Also exploring direct reinjection of the brine into the salt flat to further reduce water consumption. The process also includes nanofiltration and membrane separation (overall efficiency ~87%).	DLE (Direct Lithium Extraction) process to produce new battery-grade lithium carbonate. Aluminium-based adsorbent material is used to capture lithium from the brines. Also exploring direct reinjection of the brine into the salt flat to further reduce water consumption. Unlike other processes, it doesn't use acid, and also can operate at ambient temperature. The whole process also includes nanofiltration and membrane separation (overall efficiency ~87%).	TRL 8-9. Commissioned in July 2024. First production run in November 2024. A feasibility study is underway to achieve production of around 30 additional kilotonnes.	Recently commissioned. 1,600 people working at site; the highest health & safety standards (delivering a TRIR1<2 for roughly 7 million hours of construction activity) and at the highest standards of responsible mining (IRMA guidelines), including all environmental, social and governance aspects. The process, unlike other processes, does not use acid and can operate at ambient temperature with ~90% extraction yield and 60% recycled water. Potential for growth in midstream processing to produce battery-grade materials, and eventually battery manufacture, assembly, and recycling.	The company aligns with SDG 12 (Responsible Consumption and Production) by emphasising sustainable mining practices, including recycling and resource efficiency, to minimise environmental impacts and reduce waste. Eramet also supports SDG 9 (Industry, Innovation, and Infrastructure) through its investment in advanced technologies for extracting and refining minerals, improving efficiency, and reducing the ecological footprint of its operations. Furthermore, the company contributes to SDG 13 (Climate Action) by supplying materials essential for the renewable energy sector, including EVs and energy storage systems, which are crucial for reducing global carbon emissions.

450) https://www.eramet.com/en/news/2024/07/eramet-inaugurates-its-direct-lithium-extraction-plant-in-argentina-becoming-the-first-european-company-to-produce-battery-grade-lithium-carbonate-at-industrial-scale.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Argentina, South Korea	Posco Argentina.[451 452]	Lithium extraction from salar brines and lithium hydroxide production.	Posco Argentina's large lithium extraction project called Sal de Oro is located in Salar del Hombre Muerto, between Salta and Catamarca provinces began operation in 2024. This is Argentina's first commercial lithium hydroxide plant with an annual production capacity of 25,000 tons. The upstream processing produces lithium phosphate, and the downstream operation produces lithium hydroxide.	Lithium phosphate production from salar brines followed by lithium hydroxide production using electrodialysis membrane separation.	TRL 8–9. Posco (South Korea) developed the electrodialysis membrane separation process for the production of lithium hydroxide. The first phase of the operation began operations with an annual production capacity of 25,000 tons. The second phase is expected to be completed in 2025 and will produce an additional 25,000 tons. Posco is considering a third plant with capacity of 50,000 tons enough to make batteries for 1.2 million EVs.	Significant potential for positive impact on both mid- and downstream processing. Implemented in 2023. This operation is one of many in Argentina processing Salars. Potential for growth in midstream processing to produce battery grade materials, and eventually battery manufacture, assembly, and recycling.	The company supports SDG 7 (Affordable and Clean Energy) by supplying high-quality lithium, a key component in lithium-ion batteries that power EVs and renewable energy storage systems. Posco Argentina also aligns with SDG 9 (Industry, Innovation, and Infrastructure) by using innovative direct lithium extraction (DLE) technologies, which aim to increase the efficiency and sustainability of the extraction process. Additionally, the company contributes to SDG 12 (Responsible Consumption and Production) by emphasising resource efficiency and minimising the environmental impact of its operations, particularly concerning water use in sensitive ecosystems.

451) https://koreajoongangdaily.joins.com/news/2024-10-31/business/guestReports/Posco-has-eye-on-supply-with-Argentina-lithium-plant/2167737.

452) http://www.poscoargentina.com/en.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Argentina, China	Lithium Argentina Corp joint venture with Ganfeng Lithium).[453 454]	Battery-grade lithium carbonate salar brines.	Well-known technology for the production of Lithium carbonate from salar brines. Ganfeng Lithium, a leading Chinese lithium producer, is actively involved in downstream processing and aims to integrate Argentina's lithium into its global supply chain.	Salar brine evaporation, impurity removal and battery-grade lithium carbonate precipitation.	TRL 7–9. In 2023, the Cauchari-Olaroz Salt Lake Project was put into operation. As of March 2024, the company has received USD 70 million to expand the project in Argentina.	Significant impact on both mid- and downstream processing. Implemented in 2023. This operation is one of many in Argentina processing salars. Potential for growth in midstream processing to produce battery grade materials, and eventually integrated with battery manufacture, assembly, and recycling.	The company supports SDG 7 (Affordable and Clean Energy) by providing a critical raw material for lithium-ion batteries, which are essential for EVs and renewable energy storage solutions. This, in turn, supports the transition to cleaner energy systems. The company's initiatives also align with SDG 12 (Responsible Consumption and Production) by implementing sustainable mining practices aimed at minimising water use and reducing environmental impacts in their operations. Additionally, the company contributes to SDG 8 (Decent Work and Economic Growth) by creating jobs and promoting economic development in the Jujuy region.

453) https://lithium-argentina.com/our-projects/cauchari-olaroz/default.aspx.

454) https://lithium-argentina.com/our-projects/pastos-grandes-basin/default.aspx.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Multinational company with many locations globally; Argentina	Arcadium Lithium (merger of Allkem and Livent Lithium).[455 456]	Production of lithium metal products from Salar brine: Direct Lithium Extraction and LIOVIX® technology. This midstream technology is for making Lithium metal sheets for batteries.	Development and scale-up of LIOVIX, a lithium product enhancing battery output and lifespan.	Direct Lithium Extraction from salar brines; development and scale-up of LIOVIX, a lithium product enhancing battery output and lifespan.	Direct Lithium Extraction is at TRL 9. Additional projects are the development phase. LIOVIX is at a TRL of 8; it is slowly being integrated commercially.	Lithium carbonate production was about 18000 tons. With additional production from expansion projects the capacity is reported to increase to 40000 tons, and eventually reaching 100,000 tons by 2030.	This process supports SDG 12 (Responsible Consumption and Production) by using fewer raw materials and energy resources, reducing waste, and minimising the environmental impact of lithium extraction. LIOVIX® technology also contributes to SDG 9 (Industry, Innovation, and Infrastructure) by fostering innovation in battery manufacturing, enabling more sustainable and cost-effective solutions for the growing EV market. Additionally, it aligns with SDG 13 (Climate Action) by supporting the expansion of EVs and energy storage solutions, which are critical for reducing greenhouse gas emissions and transitioning to a low-carbon economy.

455) https://arcadiumlithium.com/innovation.

456) https://arcadiumlithium.com/operations-projects.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Brazil, Indonesia.	Vale.[457] [458] [459] [460]	Production of battery-grade nickel and cobalt products from nickel laterites.	Indonesia Growth Project (IGP) Pomalaa nickel laterite processing is being developed by a partnership between Vale Indonesia (supplying the ore) and Zhejiang Huayou Cobalt Company (operating HPAL) in Southeast Sulawesi.	Hydrometallurgical process involving High-Pressure Acid Leach (HPAL), partial neutralisation of leach solution and jarosite precipitation, residual iron removal using lime and air, followed by nickel-cobalt Mixed Hydroxide Precipitate (MHP) using magnesia.	Project TRL 8–9.	Pomalaa plant is expected to produce 120,000 tonnes of nickel and approximately 15,000 tonnes of cobalt contained in MHP product per year by 2026. The project will include solid waste treatment facilities, sedimentation ponds and wastewater treatment, leachate treatment, air emission processing, and toxic and hazardous waste management. The project is expected to generate around 12,000 construction jobs in the area. It will also support further midstream and downstream processes.	Brazilian mining company Vale actively promotes, monitors, and supports these in its global operations. Its nickel operations in Indonesia support SDGs 7 (Affordable and clean energy), 9 (Industry, Innovation, and Infrastructure), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land).

457) https://www.mining-technology.com/news/vale-huayou-huali-nickel-indonesia/?cf-view.

458) https://www.mining.com/web/vale-indonesia-eyes-2026-completion-for-nickel-hpal-plant.

459) https://www.reuters.com/article/markets/currencies/vale-indonesia-eyes-2026-completion-for-nickel-hpal-plant-idUSKBN2G40HU.

460) https://vale.com/pt/esg/nossos-compromissos.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Canada, United States, Brazil	South Star Battery Metals.[461]	Production of flake graphite for battery anodes.	Santa Cruz Graphite Mine in Brazil. Current plan is upstream conventional processing to produce graphite concentrate with a strategy to move into midstream and downstream processing in the future.	Conventional mining and beneficiation to produce graphite concentrate.	Project TRL 8–9.	Brazil is the largest graphite producer of high-quality natural graphite outside of China. Brazil is focused on new mines and growth of graphite production (upstream processing) and is gradually moving on to mid- and downstream processing.	The company's efforts support SDG 9 (Industry, Innovation, and Infrastructure) by developing additional graphite production capacity which can then promote domestic midstream and downstream operations for clean energy transition. Graphite is a crucial material for battery technologies and therefore its production and processing are fully developed, supporting SDG 7 (Affordable and Clean Energy), SDG 5 (Gender Equality).

461) https://www.southstarbatterymetals.com.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Mexico	Bacanora Lithium.[462] [463] [464] [465] [466] [467] [468]	Lithium extraction from clay deposits and production of high-purity lithium carbonate.	Bacanora' s greenfield operations in the Sonora Lithium Project involve extraction of lithium from clay deposits into an aqueous medium (upstream processing) and then midstream processing to produce battery-grade lithium carbonate. They have a strategic partnership with Ganfeng which will play a significant role in the development of the Sonora Lithium Project.	Bacanora's process involves several important unit operations: preconcentration, flotation, sulphation roasting, grinding, leaching, purification, evaporation, ion exchange, and precipitation. The process is a combination of upstream and midstream processing.	TRL 6-8. Bacanora has constructed a lithium carbonate pilot plant in Hermosillo to demonstrate the viability of the developed flow sheet and production of high-quality, battery-grade lithium carbonate samples, which can be distributed to potential customers in Asia as needed. The deposit has significant lithium resources with a low strip ratio, and all necessary permits in place.	The original flow sheet was developed by Ausenco Services in Australia. This has been upgraded to include flotation. The pilot plant plays a crucial role in training local operators in preparation for full-scale operations. In addition to lithium carbonate, the process can generate other byproducts such as cesium-rubidium salt cake and high grade potassium sulphate.	The company supports SDG 12 (Responsible Consumption and Production) in the production of battery-grade Lithium carbonate and subsequently lithium hydroxide from a large Lithium deposit, by promoting the efficient use of natural resources and reducing the environmental footprint. This project aligns with SDG 15 (Life on Land) through the implementation of initiatives and partnerships with local communities and stakeholders, and by promoting continuous monitoring and assessing plans to ensure minimal impact on the environment. The project also contributes to SDG 8 (Decent Work) by fostering sustainable jobs, supporting local planning, commitment to education in the community, and economic development.

462) https://www.ganfenglithium.com.

463) https://www.mining-technology.com/news/bacanora-lithium-project-mexico.

464) https://www.mining-technology.com/news/ganfeng-signs-deal-with-bacanora-for-sonora-lithium-project-in-mexico.

465) https://www.mining.com/bacanora-lithium-to-reopen-plant-at-sonora-project.

466) https://bacanoralithium.com/_userfiles/pages/files/documents/bacanora2020agmqa.pdf.

467) https://dialogue.earth/en/business/58718-mexico-lithium-bacanora-sonora-a-mirage-in-the-desert.

468) https://bacanoralithium.com/sustainability.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Mexico	Grupo México.[469] [470] [471]	Production of refined copper products for various clean energy technologies.	Grupo Mexico is a global conglomerate and is the largest producer of copper in Mexico and the 4th largest in the world. They have operations in Mexico, the United States, Peru, Spain, Argentina, Chile, and Ecuador. Its operations in Mexico include conventional processing copper ores to produce flotation concentrates (upstream processing) and smelting and refining (midstream operations) for production of copper products.	Conventional and mature technologies include flotation, smelting, heap leaching, solvent extraction, electrowinning and electrorefining.	TRL 9.	The copper industry is mature, and plants have been operating for a very long time. Midstream and downstream processing are mature. Mexico is a significant copper producer. The country has excellent infrastructure, and trained workforce, all of which provide a great opportunity to build and grow additional midstream and downstream processing for other critical minerals.	The company has well-developed SDG policies and management. It promotes and supports many of the SDGs in its operations. It promotes SDG 5 (Gender equality) and has a good track record of managing this. The company has contributed significantly to SDG 9 (Industry, Innovation, and Infrastructure) through the development and operation of a massive Cu industry, large-scale infrastructure, green energy production, and adopting innovations in the mature Cu operations. The company makes a large contribution to SDG 8 (Decent Work and Economic Growth) by fostering sustainable jobs and economic growth not only in the communities around operations but also nationwide. Its SDG policies fully support SDG 12 (Responsible Consumption and Production) by actively promoting and monitoring sustainability, health, and safety, natural resource management, environmental impact, and community development. The company also has policies to support SDG 13 (Climate Action) by striving to reduce energy consumption and greenhouse gas emissions associated with conventional extraction techniques, helping to mitigate the impact of mining on climate change. Through their policies regarding respect for the rights of communities and indigenous peoples and environmentally friendly development, they promote and support SDG 15 (Life on Land).

469) https://www.geeksforgeeks.org/electrolytic-refining.

470) https://www.gmexico.com/en/Pages/Politicsds.aspx.

471) https://www.copper.org/publications/newsletters/innovations/2001/08/hydrometallurgy.html.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Australia, Germany, Thailand	Neometals Ltd. & Primobius.[472]	Battery-grade salts from recycled lithium-ion batteries.	Developing projects focused on recycling lithium-ion batteries to recover valuable materials such as lithium, nickel, cobalt, and vanadium. The company is also involved in recovering vanadium from steel slag.	Closed-loop hydrometallurgical recycling processes that enhance material recovery and reduce waste.	Project TRL 9. Neometals is commercially deploying their battery recycling technology with key partners like Mercedes-Benz.	Neometals process was implemented by Primobius in the first recycling plant at Mercedes-Benz in Germany. Primobius has partnership with Neo Mobility Asia for battery recycling business in Thailand and potentially in other parts of the ASP region. Neometals secured USD 3 million for battery recycling expansion.	The company's projects align with SDG 12 (Responsible Consumption and Production) by focusing on recycling lithium-ion batteries and recovering valuable metals like lithium, nickel, and cobalt, reducing the need for new mining. Neometals also supports SDG 9 (Industry, Innovation, and Infrastructure) through innovative technologies for efficient metal recovery, such as vanadium from slag. Additionally, their efforts align with SDG 13 (Climate Action) by providing critical materials for clean energy technologies, supporting the transition to low-carbon solutions.

472) https://www.neometals.com.au/en/business-units/core-divisions/lib.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Belgium	Umicore.[473] [474]	Battery materials, recycling, and critical minerals recovery.	Implementation of advanced recycling processes to recover valuable metals such as cobalt, nickel, and lithium from spent batteries. Umicore's New Business Incubator (NBI) is designed to operate like a start-up to foster innovation and to develop and deploy new technologies.	Umicore has significant activities and a comprehensive portfolio of technologies, both midstream and downstream, in battery materials, recycling, and specialty materials.	Project TRL 9. Technologies already implemented.	There is potential for collaboration with partners in developing countries to enhance local battery recycling capabilities. Their processes are reported to be 20%–30% more cost-efficient with high recovery; over 95% for nickel, copper, and cobalt, and over 70% for lithium. In 2024, Umicore secured a USD 350 million EIB loan to open a recycling factory in Belgium.	By focusing on the recovery of valuable metals like lithium, cobalt, and nickel from used batteries, the program aligns with SDG 12 (Responsible Consumption and Production), promoting a circular economy and reducing the need for new resource extraction. Additionally, the program supports SDG 13 (Climate Action) by minimising the environmental impact of battery waste, lowering greenhouse gas emissions through the reuse of materials, and reducing the carbon footprint associated with new mining activities. Moreover, it contributes to SDG 8 (Decent Work and Economic Growth) by fostering sustainable jobs in the recycling industry and supporting green economic activities.

473) https://www.umicore.com/en.

474) https://www.umicore.com/en/sustainability/sustainable-development-goals.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
Canada	Electra Battery Materials (formerly First Cobalt Corp.).[475]	Cobalt sulphate and other battery materials production.	Midstream and downstream processing to produce battery materials. Building a cobalt refinery to produce cobalt sulphate for the EV market. The project also includes battery recycling to recover lithium, nickel, cobalt, manganese, copper, and graphite. s. Future plan to build a nickel sulphate plant. Recent developements and plans for a battery precursor cathode active materials (PCAM) plant adjacent to cobalt refinery and recycling plant. Also planning to develop a Co-Cu deposit in the U.S (Idaho).	Hydrometallurgical processes for production of battery grade cobalt sulphate and recovery of lithium, nickel, manganese, cobalt,, copper, and graphite from recycled batteries.	Project TRL 7-9. A large-scale cobalt refinery construction in progress in Ontario; estimated operation by 2026. Other plans include a refinery in Quebec, battery materials park with recycling and nickel sulphate production.	When the planned operations are commissioned, they will have a significant positive impact on the North American battery materials supply chain and the EV market. Development of the Co-Cu deposit in Idaho will also have a positive impact in North America.	Electra's initiatives advance SDG 9 (Industry, Innovation, and Infrastructure) through its investment in North America's first fully integrated battery materials park. This facility aims to refine cobalt and nickel and recycle battery materials, strengthening regional supply chain resilience for critical minerals. Additionally, the company's focus on ethically sourced cobalt supports SDG 8 (Decent Work and Economic Growth), ensuring a safe work environment and more responsible sourcing practices compared to traditional mining operations in other regions.

475) https://www.electrabmc.com/projects/projects-overview.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
United States	Allonia.[476 477]	Bioleaching and recovery of critical minerals.	Development of engineered microbes and products including bioleaching and hydrometallurgical processing.	Novel Engineered microbes and products for bioleaching of a variety of feedstocks and critical mineral recovery from leach solutions.	The company has technologies at the TRL 6–8 range. Allonia received USD 30 million Series A Extension funding from Bison Ventures. The current focus is upstream, but can be extended to mid- and downstream processing.	Projects are still in the development stage. The company has Secured partnerships with several mining stakeholders for demonstration of feasibility. One of the outcomes would be the production of higher quality feedstock for mid- and downstream processing. Another outcome would be reducing or eliminating the use of hazardous chemicals and harsh conditions, which could reduce the environmental footprint.	The company's approach aligns with SDG 12 (Responsible Consumption and Production) by promoting resource-efficient mining practices and reducing waste through advanced recovery and recycling technologies by replacing hazardous chemicals. This focus ensures that valuable minerals are extracted more efficiently while minimising environmental impacts. The company also supports SDG 13 (Climate Action) by implementing carbon-reducing technologies and practices that lower the greenhouse gas emissions associated with traditional mining operations, helping to combat climate change. Furthermore, Allonia contributes to SDG 9 (Industry, Innovation, and Infrastructure) by investing in cutting-edge technologies that modernise mining processes, making them more sustainable and resilient. When implemented in a developing country, it has the potential to impact SDG 1 (No Poverty) and 5 (Gender Equality) by providing a safer, greener alternative to artisanal mining, which is often unsafe, uncontrolled, and unregulated.

476) https://allonnia.com/about-us.

477) https://allonnia.com/saff.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
United States	Phoenix Tailings (PT).[478] [479] [480] [481]	Extraction of critical minerals, especially rare earth metals, from tailings and other waste and CO2 GONE Process.	Individual Rare Earth Metal Reduction and domestic Rare Earth Oxide Separation. Zero-waste technology that uses CO2 to extract nickel and magnesium from iron-rich ores.	A proprietary process for separation of REOs and production of rare earth metals through selective halogenation and molten salt electrolysis using mixed halide salts to separate and purify rare earth metals. This process can be powered by renewable energy sources. CO2 GONE Process uses CO2 to extract nickel and magnesium from iron-rich ores. These processes are described as carbon-negative and zero-waste.	In the development and scale-up stage. Focused on U.S. domestic sources and products. Currently producing REEs at a smaller scale. Making efforts to scale up. Also looking at REEs from tailings in Adirondack. "PT CO_2 GONE" process is at TRL 7. It has received USD 39 million in U.S. DOE funding in early 2023.	There is potential for implementation in developing countries with tailings and other waste streams containing rare earth elements. The company has secured funding from several sources and has a strategic partnership with Tridelta Magnetsysteme, a German company, in late 2023 to establish a reliable and sustainable supply chain for their recycled metals. The project timeline is unavailable.	This process contributes to SDG 13 (Climate Action) by capturing and storing CO_2 emissions through a mineralization process that converts carbon dioxide into stable mineral forms, thereby reducing the carbon footprint of industrial activities. It also supports SDG 12 (Responsible Consumption and Production) by using discarded materials from mining tailings as feedstock for the mineralization process, promoting resource efficiency and lowering the dependence on newly sources and raw materials. Additionally, the CO2 GONE process aligns with SDG 9 (Industry, Innovation, and Infrastructure) as it developes cutting-edge technologies that transform mining waste into valuable products, fostering innovation within the resource recovery sector.

478) https://www.phoenixtailings.com.

479) https://www.phoenixtailings.com/products.

480) https://www.accesswire.com/932584/the-massachusetts-startup-leading-the-push-for-domestic-critical-metal-refining.

481) https://www.patch.com/massachusetts/burlington/1-4-million-state-grant-supports-work-burlington-facility.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
United States	Rare Earth Salts Separations & Refining, LLC.[482] [483] [484]	REE separation and recovery from concentrate and recycled materials.	Proprietary technology for REE separation and recovery from concentrate, recycling end-of-life products and industrial waste. The focus is on producing high-purity REEs for use in clean energy technologies.	Advanced recycling processes that recover REEs efficiently from waste streams.	Project TRL 9. The company has commissioned a commercial-scale production of heavy and light REE factories in Nebraska, United States, with U.S DOE funding.	Potential for projects in developing countries focusing on REE recycling and refining. The launch date of the factory is unclear, but likely to occur in 2025. It will specialise in REE recycling.	The company's focus on reducing waste and optimising resource use supports SDG 12 (Responsible Consumption and Production), as it promotes a circular approach to rare earth materials, making the most of limited resources while minimising environmental impact. Its electrochemical process is an innovative technology that reduces process intensity and hazardous steps and supports SDG 9 (Industry innovation, and infrastructure). Additionally, by contributing to a stable supply of REEs crucial for EVs, wind turbines, and other green technologies, the company helps to further SDG 7 (Affordable and Clean Energy), facilitating the transition to a low-carbon economy and the adoption of renewable energy.

482) https://www.rareearthsalts.com/whatwedo.

483) https://www.rareearthsalts.com/ourteam-1-1.

484) https://www.businesswire.com/news/home/20230822581586/en/Rare-Earth-Salts-Announces-Commercial-Scale-Production-of-Heavy-Light-Rare-Earth-Elements-Using-Breakthrough-Technology.

OTHER

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
United States	American Battery Technology Company (ABTC).[485]	Battery metals extraction from recycled lithium-ion batteries.	Recycling, novel extraction, and primary resource development. Proprietary technology for recycling lithium-ion batteries and extracting battery metals such as lithium, cobalt, nickel, and manganese from primary and secondary sources.	Advanced recycling and extraction technologies that improve efficiency and sustainability.	Project TRL 9. The company has established a commercial-scale battery recycling facility and has secured domestic buyers of recycled materials.	Potential for collaboration with developing countries to establish local recycling capabilities. Their commercial recycling plant is in operation as of 2023. Currently expanding recycling operations of black mass refining into critical minerals.	The company's efforts align with SDG 12 (Responsible Consumption and Production) by focusing on the efficient recycling of lithium-ion batteries to recover critical minerals like lithium, nickel, and cobalt, reducing waste and the need for new mining. ABTC also supports SDG 9 (Industry, Innovation, and Infrastructure) through innovative processes that enhance the sustainability of battery materials extraction. By contributing to a domestic supply of these critical materials, ABTC also aids SDG 13 (Climate Action), facilitating the growth of EVs and renewable energy storage, which are essential for reducing carbon emissions and promoting a cleaner energy future.

485) https://www.americanbatterytechnology.com/solutions/Lithium-ion-battery-recycling.

Current location and target developing countries	Company	Technology area or project	Project description	Targeted technologies	Status and expected timelines	Outcomes and impact on the mid- and downstream segments of critical minerals value chains	Impacts on SDG achievement
United States	Maverick Biometals.[486]	Biological extraction of critical minerals from ores.	Development of bioextraction technology using enzymes to break down minerals in ores and concentrates to extract critical minerals such as lithium, nickel, and cobalt.	Proprietary engineered enzymes designed to break down crystal structures of minerals, especially silicate minerals, thereby releasing critical metals; for e.g., breakdown of spodumene, an important lithium silicate mineral, to release lithium. This technology is an alternative to acid-roasting of spodumene, and has the potential to offer high extraction efficiency with minimal environmental impact.	Project TRL 6, in the R&D stage and promising. Its current focus is upstream, but it can be extended to mid- and downstream processing. It has recently received USD 9.6 million in seed funding from VC funds.	Potential for technology transfer and demonstration projects in developing countries. The company is currently trying to secure U.S. DOE SBIR/STTR grants to run a pilot program. No public information exists on timelines.	This initiative supports SDG 12 (Responsible Consumption and Production) by promoting the efficient use of natural resources and reducing the environmental footprint of traditional mining operations. By utilising microorganisms for metal recovery, the project minimises waste generation and enables the recycling of valuable minerals. It also contributes to SDG 13 (Climate Action) by reducing the energy consumption and greenhouse gas emissions associated with conventional extraction techniques, helping to mitigate the impact of mining on climate change. Additionally, the initiative aligns with SDG 9 (Industry, Innovation, and Infrastructure) by promoting and cultivating innovation in biotechnology and creating new, sustainable methods for resource recovery, paving the way for a more eco-friendly and resilient mining industry. When implemented in a developing country, it has the potential to impact SDG 1 (eradicating poverty) and 5 (gender equality) by providing a safer, greener alternative to artisanal mining, which is often unsafe, uncontrolled, and unregulated.

486) https://www.maverickbiometals.com/technology.

Vienna International Centre
Wagramerstr. 5, P.O. Box 300
A-1400 Vienna, Austria

+43 1 26026-0

www.unido.org

A2DFacility@unido.org

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION