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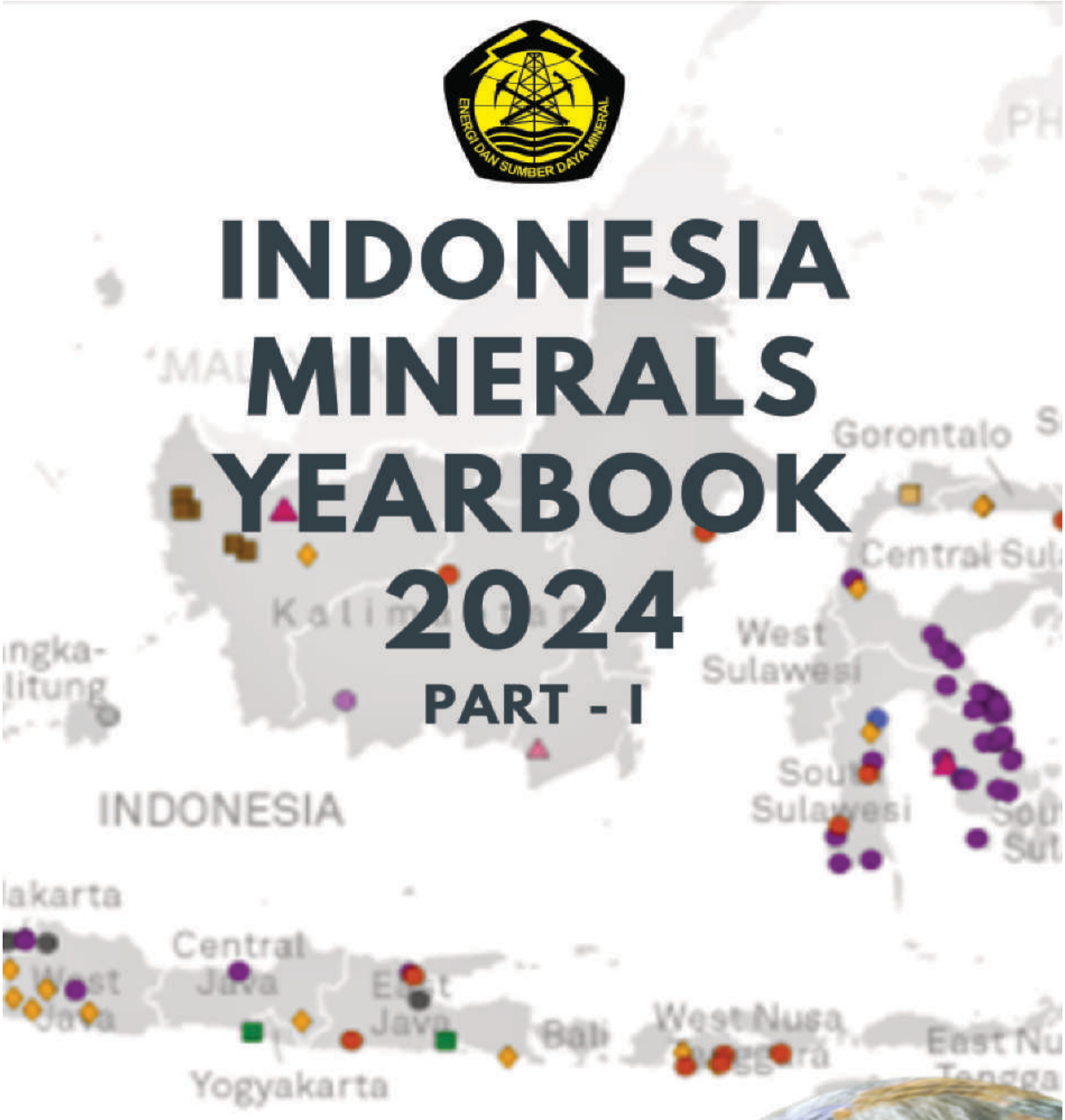
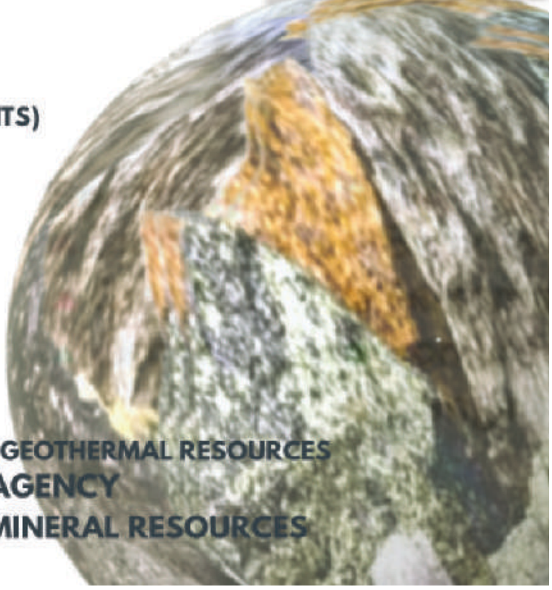
INDONESIA MINERALS YEARBOOK 2024

PART - I



INCLUDING:

- COPPER
- LEAD - ZINC
- GOLD - SILVER
- TIN
- NICKEL - COBALT
- IRON
- BAUXITE
- REE (RARE EARTH ELEMENTS)
- RADIOACTIVE MINERALS
- LITHIUM
- SILICA
- LIMESTONE
- GRAPHITE



CENTER FOR MINERAL, COAL, AND GEOTHERMAL RESOURCES
GEOLOGICAL AGENCY
MINISTRY OF ENERGY AND MINERAL RESOURCES

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INDONESIA MINERALS YEARBOOK 2024

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I Gde Sukadana

Remarks by Minister of Energy and Mineral Resources of Indonesia

Assalamualaikum warahmatullahi wabarakatuh

With deep gratitude to the Almighty God, we are pleased to present the "Indonesia Mineral Yearbook 2024." We extend our heartfelt appreciation to all parties who contributed to the compilation of this book. As minerals are non-renewable natural resources, their utilization must be managed wisely and sustainably. This yearbook serves as a central repository of data and information, supporting mining sector planning, mineral resource management policies, investment opportunities, and international statistical needs.

President Prabowo Subianto has consistently emphasized his commitment to "AstaCita 5," urging us to further downstream processing and develop industries based on natural resources to enhance domestic value-added benefits. This book underscores Indonesia’s dedication to the global energy transition, aiming for net zero emissions by 2060.

The "Indonesia Mineral Yearbook 2024" provides a comprehensive overview compiled from the latest data, covering resources and reserves, production, supply and demand, as well as trends and strategic issues concerning critical minerals.

We acknowledge that achieving the goal of downstream processing and fostering natural resource-based industries with increased domestic value requires robust cross-sectoral coordination, both within the government and with business entities. Therefore, we welcome all stakeholders to contribute their insights to this yearbook.

The ultimate objective of mineral resource management in Indonesia is to enhance the quality and quantity of national human resources, reinforce self-sufficiency, secure reserves, strengthen economic contributions, and ultimately improve the welfare and prosperity of the people, in alignment with the 1945 Constitution.

In conclusion, I hope this book serves as a valuable reference, offering deeper insights into the challenges and opportunities in managing critical and strategic minerals in Indonesia. Let us work together to maximize our natural resources and build a sustainable green economy that ensures prosperity for all Indonesians. Thank you.

Wassalamualaikum warahmatullahi wabarakatuh
Jakarta,   December 2024
Minister of Energy and Mineral Resources
of the Republic of Indonesia
Bahlil Lahadalia

Remarks by Head of Geological Agency

Assalamualaikum warahmatullahi wabarakatuh

We express our deepest gratitude to the Almighty God for His blessings, which have enabled us to complete the "Indonesia Mineral Yearbook 2024." This edition serves as an update to the "Indonesia Mineral Yearbook 2018," aiming to: a) Centralize Data and Information with comprehensive details on resources, reserves, production, supply-demand trends, exports-imports, prices, and mineral stocks; b) Support Mining Sector Planning and Policy Development; c) Promote Transparency and Accountability; d) Encourage Investment Growth; e) Monitor Sustainability Efforts; f) Meet International Statistical Standards; and g) Enhance Knowledge and Education.

As the world undergoes an energy transition, Indonesia, with its vast mineral wealth, has a crucial role in contributing to the global net zero emission target by 2060. This shift presents both challenges and opportunities, particularly in optimizing mineral resources that support green energy and advanced technology. The "Indonesia Mineral Yearbook 2024" highlights key issues regarding critical and strategic minerals essential for global energy transition and national resource resilience, including: a) Supply Risks of Critical Minerals, b) Downstream Processing and Value Enhancement, c) High Technology and Green Energy Development, and d) Exploration Strategies for Resource and Reserve Optimization

Accordingly, the "Indonesia Mineral Yearbook 2024" covers Strategic and Critical Minerals, including Copper, Lead-Zinc, Gold-Silver, Tin, Nickel-Cobalt, Iron, Rare Earth Elements (REE), Bauxite, Radioactive Minerals, Lithium, Silica, Limestone, and Graphite.

We hope that this yearbook proves beneficial for stakeholders in the mining sector and contributes to increased investment in Indonesia’s mineral resources industry.

Wassalamualaikum warahmatullahi wabarakatuh
Bandung, December 2024
Head of Geological Agency,
Ministry of Energy and Mineral Resources of the Republic of Indonesia

Muhammad Wafid A.N.

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EXECUTIVE SUMMARY

The National Industrial Development Plan (RIPIN) has outlined a comprehensive roadmap for the Base Metal and Non-Metallic Mineral Industries for the period 2015-2035, emphasizing three key national industrial objectives:

Processing and Refining Iron and Steel – Enhancing domestic value-added production and reducing reliance on imports.

Processing and Refining Non-Ferrous Base Metals – Expanding the refining capacity for metals such as aluminium, copper, and nickel.

Development of the Precious Metals Industry, Rare Earth Elements (REE), and Nuclear Fuel – Strengthening Indonesia's strategic position in critical minerals essential for advanced technologies.

Since 2019, the Indonesian government has been actively promoting the Battery Electric Vehicle (BEV) program, aligning with Presidential Regulation No. 55 of 2019, which aims to accelerate the transition towards electric mobility. This ambitious initiative has significantly boosted the demand for essential mineral raw materials such as:

Nickel – A key component in lithium-ion batteries and stainless-steel production.

Cobalt – Vital for battery cathodes, ensuring energy density and longevity.

Rare Earth Elements (REEs) – Essential for high-performance magnets used in EV motors and wind turbines.

Lithium – A crucial element for energy storage in EV batteries and grid-scale renewable energy storage systems.

To support this industrial transformation, the Ministry of Energy and Mineral Resources has implemented key policies to classify and manage Indonesia's mineral wealth efficiently:

Decree No. 296.K/MB.01/MEM.B/2023 – Classifies 47 mineral commodities as critical minerals, recognizing their importance for national economic and industrial resilience

Decree No. 69.K/MB.01/MEM.B/2024 – Identifies 22 mineral commodities as strategic minerals, ensuring their prioritization in domestic processing, international competitiveness, and national revenue optimization.

These measures are designed to maximize the downstream processing of minerals, enhance Indonesia's industrial competitiveness, and secure a sustainable supply chain for the growing global clean energy economy.

As the world accelerates its transition to clean energy to combat climate change, the demand for critical minerals is expected to rise exponentially. According to a recent International Energy Agency (IEA) report, the need for key minerals will experience substantial growth by 2040 under the Net

Zero Emissions (NZE) scenario, which aims to limit global warming to 1.5°C.

Among the most essential minerals driving this transition are copper, lithium, nickel, cobalt, graphite, and rare earth elements (REEs), each playing a pivotal role in renewable energy technologies and electric vehicles (EVs).

Lithium – The most dramatic increase is expected, with demand projected to rise 8.7 times by 2040 compared to 2023 levels. This surge is primarily driven by its indispensable role in lithium-ion batteries, which power electric vehicles (EVs) and energy storage systems. The proportion of lithium used in clean energy applications is anticipated to grow from 56% in 2023 to 91% in 2040, underscoring its importance in decarbonizing transportation and energy sectors.

Graphite – Demand is set to increase 3.9 times, largely due to its essential function as an anode material in lithium-ion batteries. The share of graphite utilized in clean energy technologies will surge from 28% in 2023 to 65% in 2040, reflecting the rapid expansion of EV and battery storage industries.

Rare Earth Elements (REEs) – Essential for high-performance magnets used in wind turbines and EV motors, REE demand is projected to rise 1.9 times. Their use in clean energy applications will expand from 18% to 41% by 2040, reinforcing their critical role in renewable energy generation and electric mobility.

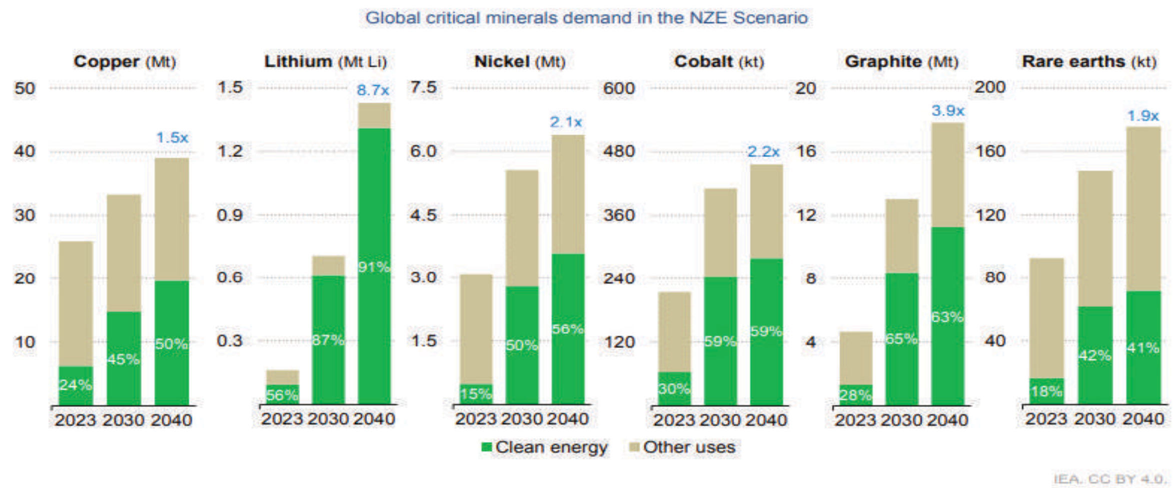
Nickel – A crucial material in battery production, nickel demand is expected to grow 2.1 times by 2040. Its utilization in clean energy technologies will rise from 15% to 56%, primarily due to the increasing demand for high-nickel cathodes in EV batteries, which enhance energy density and battery lifespan.

Cobalt – Another vital component in battery manufacturing, cobalt demand is forecasted to increase 2.2 times, with its use in clean energy applications growing from 30% to 59%. Cobalt is essential for stabilizing lithium-ion battery chemistry, ensuring longer-lasting and more efficient energy storage solutions.

Copper – As the backbone of electrical infrastructure, copper demand is set to increase 1.5 times, driven by its widespread application in electrical wiring, renewable energy systems, and EV motors. The proportion of copper used in clean energy sectors is projected to climb from 24% to 50% by 2040, solidifying its role as a foundational material for global electrification efforts.

The rapid expansion of renewable energy, electric mobility, and energy storage systems is creating an unprecedented demand for critical minerals. With lithium, graphite, nickel, cobalt, copper, and REEs at the core of these emerging industries, ensuring stable and sustainable supply chains will be essential to meeting global climate goals. Nations rich in these minerals—like Indonesia, Australia, and China—are poised to become key players in the clean energy revolution, shaping the future of sustainable development and technological innovation.

Limiting global warming to 1.5 °C, as in the NZE Scenario, means very rapid growth in demand for key minerals



Notes: The figures for copper are based on refined copper. Those for rare earth elements are for magnet rare earth elements only. Growth rates (in blue) are between 2023 and 2040.

As a key initiative under the National Industrial Development Plan (RIPIN) 2015–2035, the Downstream Investment Strategic Roadmap (2023–2045) has been developed to accelerate the growth and value-added processing of Indonesia's rich mineral resources. This roadmap serves as a comprehensive framework to enhance the country's mineral downstream sector, strengthening its industrial base, economic resilience, and global competitiveness.

The roadmap establishes long-term targets for the downstream processing and refining of critical and strategic minerals, including:

Copper – Essential for electrical infrastructure, renewable energy systems, and high-tech industries.

Tin – A key material in electronics, soldering, and energy storage applications.

Bauxite – The primary ore for aluminium production, crucial for aerospace, automotive, and construction industries.

Iron – A fundamental component in steel manufacturing, driving infrastructure and industrial development.

Gold & Silver – High-value metals used in electronics, renewable technologies, and financial markets.

By 2045, Indonesia aims to significantly expand its mineral processing capabilities, reduce reliance on raw material exports, and position itself as a leading global hub for refined metals and advanced material production. This initiative aligns with the nation's broader vision for sustainable industrialization, economic diversification, and technological advancement in the global mineral economy.

The United States Geological Survey (2024) has recognized Indonesia's crucial role in the global mining industry due to its significant production and reserves of several critical mineral commodities, including:

Commodity	Metal Reserves (Tons)	World Percentage	Production (Tons)	World Percentage	Information
Copper	24,000,000	2.4%	800,000	5%	The 9th largest reserves in the world
Gold	3,420	6%	110	4.4%	The 6th largest reserves in the world
Silver	42.7	7%			The 6th largest reserves in the world
Tin	1,387,194	24.26%			The largest reserves in the world
Nickel	55,000,000	40%	1,800,000	50%	The 1st Reserves and Production
Iron	3,655,000,000 (*)	1.92%			The 8th largest reserves in the world
Bauxite	2,800,000,000 (*)	8.8%			4th in World Reserves

(*) Ore reserve

A comprehensive list of essential commodities, categorized as either Strategic or Critical Minerals, can be found in the *Mineral Yearbook 2024*. This book examines key commodities central to Indonesia's downstream program, including bauxite and base metals such as copper, nickel, tin, and iron. It also covers precious metals like gold and silver, while providing in-depth information on critical minerals such as lithium, silica, limestone, graphite, and rare earth elements.

Copper

Copper Reserves and Strategic Importance

As of December 2023, the Mineral Resources and Reserves Balance (Geological Agency, 2024) reports that Indonesia holds 21.4 million tons of copper metal reserves and 2.8 billion tons of copper ore reserves. Meanwhile, the United States Geological Survey (2024) estimates Indonesia’s total copper metal reserves at 28 million tons, underscoring the country’s strategic role in the global copper market.

Key Copper Mining Regions and Producers

Indonesia’s largest copper reserves are found in West Nusa Tenggara and Central Papua. The Batu Hijau mine, operated by PT Amman Mineral Nusa Tenggara, and the Grasberg mine, managed by PT Freeport Indonesia, are among the world's most significant copper producers, contributing to both domestic processing and global exports.

Production and Sustainability of Copper Reserves

According to the 2024 report from the Ministry of Energy and Mineral Resources, Indonesia produced 132 million tons of copper in 2023. Over the past five years (2019–2023), domestic demand for copper cathodes has surged, particularly from PT Smelting in 2022.

At the current annual extraction rate, Indonesia’s copper ore reserves are projected to last until 2044. However, increasing demand and future exploration could impact resource longevity.

Global Copper Demand and Future Growth

The global copper market is experiencing steady growth, driven by infrastructure expansion, renewable energy adoption, and green technologies. According to the Global Copper Long-Term Outlook 2020 (Wood Mackenzie):

- Global copper consumption is projected to grow by 1.7% annually from 2026 to 2040.
- By 2040, worldwide copper demand is expected to reach 33 million tons, with China consuming nearly 50% of the total supply.
- Demand for copper in renewable energy and EV technologies is forecasted to rise by 40%, reinforcing its role in energy transition and sustainable infrastructure.

Conclusion

Indonesia’s significant copper reserves and strong mining sector establish the country as a key global supplier. With rising demand for clean energy technologies, investments in sustainable mining, exploration, and downstream processing will be essential to prolong reserves, enhance economic value, and solidify Indonesia’s role in the global copper supply chain.

Lead-Zinc

Strategic Reserves and Economic Importance

Indonesia holds substantial lead and zinc resources, positioning itself as a key supplier in global markets. The country's reserves support industries such as automotive manufacturing, battery production, construction, and electronics. As of 2024, Indonesia's lead ore resources total 2.6 billion tons, with proven reserves of 75.5 million tons, while zinc ore resources stand at 3.8 billion tons, with proven reserves of 67.9 million tons.

Production Trends and COVID-19 Impact (2016–2022)

Indonesia’s lead and zinc production fluctuated between 2016 and 2020, with the COVID-19 pandemic causing a severe decline in 2020. Lead ore output dropped to 16.4 thousand tons, while refined lead metal production reached 11.9 thousand tons, and domestic consumption stood at 11.7 thousand tons. In contrast, 2019 marked peak production, with 17 thousand tons of lead ore output, 12.3 thousand tons of refined metal, and 12.2 thousand tons in domestic demand.

By 2021–2022, production rebounded as global industries recovered, infrastructure investments increased, and demand for lead-acid batteries, galvanized steel, and alloy manufacturing surged.

Rising Lead and Zinc Prices in 2024

Strong demand and supply constraints have driven a sharp price increase in 2024. According to the Ministry of Trade (October 2024), zinc prices rose by 10.82% to USD 760.10 per ton, while lead prices increased by 0.72% to USD 826.18 per ton. These trends align with London Metal Exchange (LME) data, reflecting market volatility, supply chain disruptions, and strong demand from manufacturing and construction sectors.

Conclusion: Strengthening Indonesia's Position in the Global Market

With abundant reserves, recovering production, and rising global demand, Indonesia is set to solidify its role in the international lead and zinc market. By investing in downstream processing, refining capacity expansion, and market adaptation, the country can maximize economic benefits from its mineral wealth while supporting global industrial growth.

Gold-Silver

Strategic Importance of Gold and Silver Resources

Indonesia is endowed with vast gold and silver resources, found in primary hydrothermal deposits and secondary placer deposits. These mineral reserves play a crucial role in economic growth, industrial development, and global supply chains.

Types of Gold and Silver Deposits

Indonesia hosts a diverse range of gold and silver deposits, including epithermal, porphyry, skarn, orogenic, and volcanogenic massive sulphides (VMS) deposits, as well as sedimentary exhalative (SEDEX) and Carlin-type formations. Placer and alluvial gold deposits, formed through erosion and sedimentary transport, are also present but typically contain lower-grade resources.

Gold and Silver Resource and Reserve Estimates

According to Indonesia's Mineral Resources and Reserves 2023 (Geological Agency, 2024), the country holds 15.5 billion tons of gold ore resources and 12,000 tons of gold metal resources, with 3.6 billion tons of gold ore reserves and 3,400 tons of gold metal reserves. The largest gold reserves are concentrated in Papua and West Nusa Tenggara. Indonesia also possesses 150 tons of gold metal reserves and 64.4 million tons of alluvial gold ore reserves.

Key Exploration and Discovery: The Hu'u Copper-Gold Deposit

One of the most significant discoveries is the Hu'u deposit in West Nusa Tenggara, managed by PT Sumbawa Timur Mining (STM). The Onto Copper-Gold Deposit contains an estimated 2.1 billion tons of total mineral resources, with an average gold content of 0.48 g/t and copper content of 0.86%. This discovery strengthens

Indonesia's position as a global copper-gold producer.

Gold Production and Market Trends

In 2022, Indonesia produced 105.5 tons of gold, with 37.08 tons allocated to the domestic market and 43.53 tons exported. With an extraction rate of 13.16 million tons per year, the country's gold ore reserves could sustain production for up to 268 years.

Over the past five years, gold prices surged by 68.08%, averaging an annual growth of 8.51% (2018–2023) due to rising global demand, inflation hedging, and increased investment interest.

Outlook and Sustainability

To ensure long-term sustainability and economic stability, Indonesia must prioritize:

Exploration and Development – Expanding resource assessments and unlocking new deposits.

Downstream Processing – Enhancing refining capacity for greater domestic value addition.

Sustainable Resource Management – Implementing environmentally responsible mining practices.

Industrial Applications – Strengthening gold and silver use in automotive, electronics, and advanced technologies.

Conclusion

With substantial reserves, rising exploration efforts, and increasing global demand, Indonesia is poised for continued growth in the gold and silver mining sector. By leveraging its mineral wealth, adopting advanced mining technologies, and strengthening global market positioning, Indonesia can maximize its role as a key player in the global precious metals industry.

Nickel-Cobalt

Dominance in Nickel Reserves and Production

Indonesia has cemented its position as the world's largest holder of nickel reserves and leading global producer, according to the United States Geological Survey (USGS, 2023). With vast deposits and a robust downstream processing industry, the country plays a pivotal role in supplying nickel for electric vehicles (EVs), stainless steel production, and energy storage technologies. As of 2023, Indonesia's nickel reserves stood at 55 million metric tons, the highest globally, and the country accounted for 50% of global nickel production, reaching 1.8 million metric tons annually.

Nickel and Cobalt Resource Distribution

According to the Geological Agency of the Ministry of Energy and Mineral Resources (2023), Indonesia possesses 18.6 billion tons of nickel ore resources, with 5.3 billion tons classified as reserves. The country also holds 185 million tons of nickel metal resources, with 56.1 million tons confirmed as reserves. Additionally, Indonesia is rich in cobalt, a key material for high-performance lithium-ion batteries, with 3.3 billion tons of cobalt ore resources and 9.2 million tons of cobalt metal resources.

Nickel Ore Classification and Processing Technologies

Indonesia's nickel deposits range from 0.4% to 2.73% Ni, influencing the refining processes. High-grade saprolite ores (>1.5% Ni), rich in nickel and low in iron, are ideal for pyrometallurgical processing, producing ferronickel and nickel pig iron (NPI). Low-grade limonite ores (<1.5% Ni), with higher iron and cobalt content, are processed using hydrometallurgical methods (HPAL) to extract nickel and cobalt for battery production.

Nickel Supply Sustainability and Processing Capacity

Indonesia's total nickel resources stand at 185 million tons, with nearly 49% classified as high-grade (>1.5% Ni), making them suitable for domestic smelters. Of the 56.1 million tons of nickel reserves, about 70% contain a nickel grade above 1.5%, ensuring a stable supply for the refining industry, while 30% are lower-grade reserves, essential for battery-grade nickel production.

Nickel Production and Future Demand Projections

In 2023, Indonesia extracted 176 million tons of nickel ore, supporting 130 operational nickel smelters. By 2026, nickel ore demand is projected to reach 387 million tons annually, with 87 million tons required from low-grade (<1.5% Ni) deposits. High-grade nickel ore reserves (>1.7% Ni) are expected to last until 2029, while reserves above 1.5% Ni are projected to remain sustainable until 2033.

Conclusion: Indonesia's Future in the Nickel Market

With unmatched nickel reserves, industry-leading production, and an expanding downstream processing sector, Indonesia is positioned to meet rising global demand for stainless steel, EV batteries, and clean energy technologies. Strategic resource classification ensures efficient utilization, reinforcing Indonesia's dominance in the global nickel market and supporting long-term industrial growth.

Bauxite

Strategic Reserves and Global Positioning

According to the U.S. Geological Survey (2023), Indonesia holds 2.8 billion tons of bauxite ore reserves, accounting for 9% of the world's total bauxite resources, which stand at 31.3 billion tons. This positions Indonesia among the top global bauxite producers, alongside Australia, Guinea, and China.

Bauxite Resources and Reserves

Based on the 2023 Mineral Resources Balance (Geological Agency, 2024), Indonesia's bauxite and alumina resources include 7.5 billion tons of crude bauxite resources, with 3.8 billion tons classified as washed bauxite. The country also holds 1.2 billion tons of alumina (Al_2O_3) resources, 531.4 million tons of alumina reserves, and 1.4 billion tons of washed bauxite reserves. These figures underscore Indonesia's potential for long-term aluminium production and global supply chain stability.

Bauxite Quality and Refining Suitability

Bauxite in Indonesia is classified based on Al_2O_3 content, determining its suitability for refining and smelting. Low-grade bauxite (≤38.5% Al_2O_3) requires extensive processing, while high-grade bauxite (>46% Al_2O_3) is ideal for high-purity alumina production. Medium-to-high-grade bauxite (42%-46% Al_2O_3) is efficient for aluminium refining and requires less energy-intensive processing.

Projected Sustainability and Future Outlook

Assuming all bauxite smelters operate at full capacity in 2024, and production continues at 41.3 million tons annually, Indonesia's 2.8 billion tons of reserves could sustain supply until 2092. Strategic investments in exploration, refining technology, and sustainable resource management will be critical to maintaining Indonesia's leadership in the global aluminium industry.

Conclusion

With extensive bauxite reserves, a growing downstream processing capacity, and a secure long-term supply, Indonesia is poised to strengthen its role in the global bauxite and aluminium market. Enhancing exploration, refining efficiency, and sustainable mining practices will ensure the country remains a key player in global industrial development and trade.

Iron

Strategic Role of Iron Ore in Indonesia

Indonesia holds vast iron ore reserves, playing a crucial role in steel production, infrastructure development, and industrial growth. The country's iron ore deposits, primarily composed of magnetite (Fe_3O_4) and hematite (Fe_2O_3), are found in skarn formations, hydrothermal veins, lateritic weathering zones, and sedimentary deposits. Economic grades typically exceed 40% total Fe, making these resources highly valuable.

Types of Iron Ore Deposits

Indonesia's iron ore resources fall into four main categories. Primary iron ore deposits, mainly found in skarn formations and hydrothermal veins, contain high iron grades and are among the most desirable for steel production. Iron sand deposits, rich in titanomagnetite, accumulate along coastal plains and are used in pig iron production. Iron laterite deposits, derived from nickel laterite weathering, are abundant but require intensive refining due to complex mineralogy. Sedimentary iron deposits, including banded iron formations (BIFs), consist of thin iron oxide layers formed through mechanical weathering and chemical reactions.

Iron Ore Resources and Reserves

According to Indonesia's 2023 Mineral Resources and Reserves Report, the country's total iron ore resources are estimated at 20.1 billion tons, with 3.6 billion tons classified as reserves. Primary iron ore accounts for 7.8 billion tons of resources and 1.2 billion tons of reserves, while iron laterite contributes 7.9 billion tons of resources and 1.6 billion tons of reserves. Iron sand deposits make up 4.4 billion tons of resources, with 782.4 million tons of reserves. While iron laterite dominates in volume, its low reserve-to-resource ratio indicates that much of it remains uneconomical for extraction due to processing and infrastructure challenges.

Challenges and Opportunities

Indonesia's iron ore industry faces significant hurdles in resource-to-reserve conversion, as only 18% of total resources are classified as reserves. Logistical, technological, and investment constraints limit the economic viability of many deposits. Primary iron ore deposits are preferable for direct processing, while iron laterite and iron sand deposits require improved processing efficiency to enhance their viability. Large-scale extraction presents environmental challenges, including deforestation, ecosystem disruption, and shoreline erosion, requiring stronger regulations and sustainable mining practices. Investment in infrastructure and refining facilities is critical, with opportunities for foreign direct investment (FDI) and public-private partnerships (PPPs) to optimize extraction and processing.

Outlook

To maximize its iron ore potential, Indonesia must prioritize advanced exploration techniques, expand domestic refining capacity, and improve processing methods for lower-grade ores. Strengthening sustainable mining practices and attracting strategic investment partnerships will be key to securing Indonesia's role in the global steel industry. With 20.1 billion tons of total resources and 3.6 billion tons of reserves, Indonesia could enhance domestic industrial growth and solidify its position as a major global supplier of iron ore.

Rare Earth Elements (REE)

Strategic Importance of REEs

Rare Earth Elements (REEs) are critical minerals essential for renewable energy systems, electric vehicles (EVs), aerospace components, and high-performance electronics. Given the global concentration of REE supply, Indonesia's exploration and development of these resources have become a national priority for technological and industrial growth.

REE Composition and Classification

REEs comprise 17 elements, including 15 lanthanides, yttrium (Y), and scandium (Sc). They are further classified into Light REEs (LREEs), such as lanthanum to europium, and Heavy REEs (HREEs), including gadolinium to lutetium.

Global REE Supply and Market Leaders

According to the 2024 USGS report, China dominates 70% of global REE production and holds 33.85% of global reserves. Other key producers include the United States, Australia, Myanmar, and Russia, which are emerging as alternative sources.

Indonesia’s REE Deposits and Distribution

Indonesia's REE deposits are primarily found in tin mining by-products, lateritic soils, and placer sediments. Key regions include West Sulawesi, Kalimantan, Bangka-Belitung, and North Sumatra. The country’s estimated REE resources total 136.2 million tons of ore, containing approximately 118.7 thousand tons of REE metal.

Exploration and Resource Estimates

Indonesia’s REE resources are mainly in xenotime and monazite, both by-products of tin mining. The 2022 Mineral Resources and Reserves Balance estimates 186.7 tons of monazite and 20.7 tons of xenotime. Additional explorations in 2022 identified significant prospects in West Sulawesi, South Bangka, Belitung, and Sisoding Pamornangan, with millions of tons of REE ore and thousands of tons of REE metal.

Challenges and Future Development

Low Reserve Classification and Exploration Needs

Most REE resources remain unverified for economic viability, requiring detailed surveys, exploration drilling, and feasibility studies.

Infrastructure and Processing Limitations

Unlike China, which has advanced REE refining and separation technologies, Indonesia lacks large-scale processing facilities and must invest in solvent extraction and ion exchange methods.

Environmental and Regulatory Challenges

REE mining generates radioactive waste due to uranium and thorium content, necessitating strict environmental safeguards and sustainable mining practices.

Global Supply Chain Integration

With increasing geopolitical tensions affecting REE markets, Indonesia has the potential to diversify the global supply chain by partnering with global tech firms and battery manufacturers.

Conclusion

Indonesia’s vast REE potential provides an opportunity to strengthen its role in the global rare earth industry. However, challenges in classification, processing capacity, and environmental impact must be addressed. By investing in exploration, infrastructure, and sustainable mining, Indonesia can unlock its REE resources, contributing to renewable energy, EV production, and high-tech industries worldwide.

Radioactive Minerals

Strategic Importance of Radioactive Minerals

Radioactive minerals are essential for nuclear energy, advanced medical technologies, and high-tech industrial applications. These minerals primarily contain uranium (U) and thorium (Th), found in silicates, phosphates, and oxides. With the growing demand for clean energy and rare nuclear materials, Indonesia's uranium and thorium deposits present a significant opportunity for resource development.

Geological Occurrence and Resource Distribution

Indonesia's uranium and thorium deposits are associated with metamorphic rocks, volcanic formations, black shale deposits, and granitic intrusions. Key uranium-bearing regions include North Sumatra (Aloban Sector), West Kalimantan (Pinoh Metamorphic Group - PMG), West Sulawesi (Adang Volcanic Formation - Mamuju), Bangka-Belitung Islands, and Central and East Kalimantan, Riau Islands. West Kalimantan holds Indonesia's largest uranium reserves (28 million tons), while West Sulawesi contains the country's largest thorium deposits (9.85 million tons).

Current Resource Estimates (2023 Data)

According to Indonesia's 2023 mineral resource assessments, the country holds 28 million tons of uranium and 10.5 million tons of thorium, with the largest thorium deposits in West Sulawesi and Bangka-Belitung.

Challenges and Development Opportunities

Exploration and Reserve Classification - Most uranium and thorium deposits remain unclassified for economic viability, requiring further geological surveys, remote sensing, and feasibility studies.

Environmental and Regulatory Considerations - Stringent safety and environmental regulations are necessary to manage radiation exposure and waste disposal, ensuring responsible mining practices.

Global Energy Demand and Strategic Positioning - Uranium is a key fuel for nuclear power plants, while thorium is being explored for next-generation nuclear reactors (Molten Salt Reactors - MSRs). As global energy security concerns rise, Indonesia has an opportunity to become a major supplier of radioactive minerals.

Need for Domestic Processing Capabilities - Indonesia lacks uranium enrichment facilities and processing infrastructure. Strategic partnerships with global nuclear technology firms can help develop domestic refining capacity to increase economic value.

Conclusion

Indonesia's abundant uranium and thorium resources provide a unique opportunity to strengthen its role in the global nuclear industry. However, challenges in exploration, regulation, and processing must be addressed. By investing in advanced exploration, sustainable extraction, and strategic partnerships, Indonesia can unlock the full economic and strategic value of its uranium and thorium deposits, securing its place in the global energy transition and high-tech sectors.

Lithium

Introduction

The global demand for lithium is surging, driven by the rapid expansion of electric vehicles (EVs), renewable energy storage, and high-tech industries. Indonesia, with its diverse lithium occurrences in pegmatite, mudstone, and geothermal brines, has the potential to become a key player in the global lithium supply chain and support its battery manufacturing and clean energy ambitions.

Geological Distribution of Lithium in Indonesia

Lithium-rich pegmatite-granite formations contain valuable minerals such as spodumene and lepidolite, found across Sumatra, Kalimantan, Sulawesi, and Papua. Geothermal brine deposits, particularly in Bledug Kuwu and Bledug Cangkring, show promising lithium concentrations, while traditional salt mining operations have revealed high lithium levels, indicating extraction potential. Mudstone formations, notably in East Java's Sidoarjo Mud Volcano System, present an unconventional but promising lithium source.

Strategic Importance of Indonesia’s Lithium

Indonesia's lithium could support the growing EV battery industry, leveraging the country’s existing nickel resources to develop an integrated battery materials supply chain. Lithium-ion energy storage systems are essential for renewable power grids, with Indonesia’s geothermal lithium offering a sustainable alternative. As China, Australia, and South America dominate lithium production, Indonesia’s emergence as a supplier would enhance supply chain resilience and reduce dependency on limited markets.

Challenges and Development Strategies

Most of Indonesia’s lithium remain in occurrence types, requiring further geological surveys and feasibility studies. Processing pegmatite lithium demands high-temperature refining, while brine and geothermal extraction necessitate advanced direct lithium extraction (DLE) technologies. Sustainable mining policies and eco-friendly processing methods will be critical in minimizing environmental impact. Strategic investments and partnerships with global battery manufacturers and mining firms are needed to accelerate development and attract foreign and domestic investors.

Conclusion

Indonesia’s potential lithium resources offer a significant opportunity to establish the country as a global supplier in clean energy industries. However, success depends on technological innovation, investment, and sustainable extraction practices. With rising demand in EV batteries, energy storage, and high-tech applications, Indonesia has the potential to play a major role in the future of lithium production and clean energy solutions.

Silica

Introduction

Silica minerals are vital industrial materials with widespread applications in glass manufacturing, electronics, construction, metallurgy, and advanced technologies. Indonesia is endowed with vast silica resources, primarily in the form of quartz sand, quartz rock, and quartzite, positioning the country as a key player in the global silica industry. With abundant reserves and rising global demand for high-purity silica-based products, Indonesia has significant opportunities for domestic processing and export potential.

Quartz Sand: Geological Formation and Industrial Applications

Quartz sand consists predominantly of silica (SiO_2) crystals formed through the weathering of feldspar- and quartz-rich rocks over geological timescales. The accumulation and deposition of quartz grains are influenced by weathering, erosion, sedimentation, and hydrodynamic conditions in diverse geological environments. Although quartz sand contains natural impurities such as iron oxides, calcium oxides, alkali oxides, and organic material, its high purity makes it indispensable in glassmaking, construction, electronics, and metallurgy. It is commonly known as white sand due to its bright appearance.

Indonesia hosts vast quartz sand deposits, with significant reserves across Java, Nusa Tenggara, Sulawesi, Sumatra, Kalimantan, and Papua. As of 2023, Indonesia's quartz sand resources were estimated at 13.5 billion tons, with 3.4 billion tons classified as reserves. On a global scale, silica sand production reached 402.6 million tons in 2023, growing at an annual rate of 4.92% from 2019 to 2023. Indonesia ranks as the 19th-largest producer, contributing 0.8% of global output. The country's rich silica deposits and strategic location provide significant potential for industry growth and exports.

Quartz Rock: Formation and Economic Potential

Quartz rock is a valuable mineral resource formed through sedimentation, crystallization, and chemical transformations over time. This durable mineral has widespread industrial applications in glass production, electronics, metallurgy, and construction. Its unique geological formation contributes to its purity and strength, making it highly sought after in industrial processes.

Indonesia is home to substantial quartz rock deposits, with estimated total resources of 28.3 million tons and reserves of 2.1 million tons. This significant resource base offers promising opportunities for industrial extraction and commercial utilization. With increasing global demand for quartz-based products, sustainable mining practices, responsible quarrying, and advanced refining technologies are essential to ensure long-term resource availability and environmental protection.

Quartzite: Metamorphic Transformation and Industrial Significance

Quartzite is a dense, non-foliated metamorphic rock composed predominantly of quartz (90% to 99%). It forms through the metamorphism of quartz-rich sandstone under intense heat, pressure, and chemical activity. These geological forces result in the transformation of sandstone into a highly resistant and durable material with extensive industrial applications.

Indonesia is rich in quartzite reserves, with major deposits in Aceh, West Sumatra, Lampung, and East Nusa Tenggara. In 2023, 16 identified locations across these regions contained an estimated 264.5 million tons of quartzite resources and reserves. Quartzite-derived quartz sand plays a crucial role in the upstream industry, with a utilization rate of 65.32%. It is processed into silica sand for glassmaking and construction, silica flour for specialized applications, and resin-coated sand for foundries and molding industries.

Under the supervision of the Ministry of Industry, 21 companies operate quartz sand processing facilities with a combined unintegrated capacity of 738.5 thousand tons per year. Japan remains one of the largest consumers of Indonesian quartz sand, heavily utilizing it in the glass, cement, ceramics, and cement product industries. As demand for high-purity silica-based materials continues to grow, Indonesia's quartzite reserves present a strategic opportunity for industrial expansion, export growth, and economic development.

Conclusion

With abundant quartz sand, quartz rock, and quartzite reserves, Indonesia holds immense potential in the global silica market. By leveraging sustainable mining practices, investing in refining and processing technologies, and strengthening industrial infrastructure, the country can enhance its competitiveness in high-value silica-based industries. As global demand rises, Indonesia is well-positioned to become a leading supplier of high-quality silica materials, supporting domestic industrial growth and international trade.

Limestone

Formation and Composition

Limestone is a widely occurring sedimentary rock primarily composed of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and aragonite ($CaCO_3$). It forms over millions of years through chemical precipitation, biological accumulation from marine organisms, and mechanical compaction of sediments. These geological and biological processes occur in marine and terrestrial environments, creating extensive natural deposits.

Industrial Importance and Cement Production

Limestone, commonly known as calcium carbonate ($CaCO_3$), is the primary raw material in cement manufacturing. It serves as the main source of calcium oxide (CaO), a crucial ingredient in clinker production, which is the key intermediate in cement formation. The chemical composition of limestone directly influences the quality, strength, and durability of cement, with high-grade limestone typically containing over 90% $CaCO_3$ and minimal silica (SiO_2) and magnesium oxide (MgO). Excessive impurities, such as silica, iron oxides, or magnesium, can disrupt clinker formation, affecting cement performance and production efficiency.

Global Production and Indonesia's Limestone Reserves

According to the U.S. Geological Survey (Mineral Commodity Summaries, January 2024), global limestone production reached an estimated 430 billion tons in 2024, underscoring its importance in construction, infrastructure, and industrial applications worldwide.

Indonesia holds vast limestone reserves, with 227.6 billion tons of total resources and 21.1 billion tons of proven reserves, distributed across 193 districts in 31 provinces. These deposits position Indonesia as a key supplier of high-quality limestone, supporting industries such as cement production, steel manufacturing, construction, and chemical processing.

Conclusion

Limestone remains one of the most essential raw materials in the global industrial landscape, particularly in cement production. With its abundant reserves and growing demand for construction materials, Indonesia plays a pivotal role in infrastructure development and economic growth. The country's vast limestone resources not only contribute to domestic industries but also hold significant potential for international supply chains, reinforcing its importance in sustaining global industrial progress.

Graphite

Properties and Industrial Significance

Graphite is a naturally occurring allotropic form of carbon, composed of carbon atoms arranged in a hexagonal crystalline lattice. It is the most thermodynamically stable form of pure carbon under standard conditions. This unique structure gives graphite exceptional electrical and thermal conductivity, lightweight efficiency, and chemical inertness, making it ideal for use in batteries, electronics, and high-performance industrial applications. It is iron-black to gray with a metallic luster, has low hardness (1–2 on the Mohs scale), and is known for its softness and lubricity due to weak van der Waals forces between its layers.

Types and Formation

Graphite occurs in three primary forms, each with distinct industrial value. Vein graphite, the purest and rarest form, is highly valued for high-tech applications. Amorphous graphite, formed through the metamorphism of coal seams, is commonly used in lubricants, paints, and refractories. Flake graphite, resulting from high-temperature metamorphism, is essential in lithium-ion batteries, graphene production, and electronics.

Indonesia's Graphite Resources

According to CMCGR's 2023 Non-Metallic Mineral Resource Balance, Indonesia holds significant graphite resources, particularly in Southeast Sulawesi and West Kalimantan. These resources position the country as a potential emerging supplier for industries such as energy storage, metallurgy, and advanced materials manufacturing.

Industrial Applications

Graphite is widely used in steel manufacturing, battery production, aerospace and defence, electronics, medical implants, lubricants, and nuclear reactors due to its high thermal stability, conductivity, and mechanical resilience. It plays a crucial role in crucibles, refractory linings, fuel cells, graphene sheets, and corrosion-resistant coatings.

Conclusion

Graphite is a versatile and high-value mineral with applications in renewable energy, semiconductors, and industrial technologies. As global demand for graphite-based innovations grows, Indonesia could become a key player in the international supply chain, supporting advancements in energy storage, high-performance materials, and next-generation technologies.

1

INTRODUCTION

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Indonesia's industrial development follows a structured roadmap outlined in the National Industrial Development Master Plan (RIPIN) 2015-2035. This long-term strategy aims to transform Indonesia into a resilient and competitive industrial nation by leveraging its natural resources, strengthening industrial capacity, and fostering technological innovation. The roadmap is divided into three distinct stages, each with strategic priorities designed to support sustainable and inclusive industrial growth (Figure 1.1).

Stage I: Foundation for Industrial Growth (2015-2019)

The first phase of RIPIN focused on enhancing the value of Indonesia's abundant natural resources. The emphasis was placed on improving industrial capacity by investing in human resources and advancing technological capabilities. Additionally, this stage aimed to ensure equitable industrial development across all regions of Indonesia, reducing disparities and fostering inclusive economic growth. By laying a strong foundation, Indonesia sought to establish a more sustainable and diversified industrial sector.

Stage II: Strengthening Competitiveness (2020-2024)

Building upon the initial phase, the second stage of RIPIN is dedicated to achieving a competitive advantage in the global market while maintaining environmental sustainability. This phase prioritizes the strengthening of Indonesia's industrial structure, enabling industries to become more integrated and self-sufficient. The mastery of technology plays a critical role, as Indonesia seeks to increase the adoption of advanced manufacturing techniques and digitalization. Furthermore, the development of high-quality human resources is a key objective, ensuring that the workforce is equipped with the skills and expertise necessary for a more advanced and innovation-driven industrial sector.

Stage III: Becoming a Resilient Industrial Nation (2025-2035)

The final phase of RIPIN envisions Indonesia as a globally competitive and resilient industrial nation. This stage focuses on deepening the national industrial structure, fostering greater integration between upstream and downstream industries. High global competitiveness is a key target, with Indonesia aiming to position itself as a major player in international trade and industrial production. Additionally, innovation and technology will serve as the foundation for future industrial development, driving advancements in research, automation, and sustainable manufacturing practices.

The national industrial development strategy is closely linked to the advancement of upstream and intermediate industries, focusing on natural resource utilization, export control of energy and raw materials, and the enhancement of technological expertise. It also prioritizes the development of industrial zones, the expansion of industrial infrastructure, and the promotion of domestic goods to foster a self-sustaining and globally competitive industrial sector.

As part of this vision, the roadmap for the Base Metals and Non-Metallic Minerals Industry has been outlined as a key sector within RIPIN's strategic priorities. This sector plays a critical role in building a robust industrial foundation, ensuring sustainable resource management, and advancing Indonesia's long-term economic growth. (Table 1.1).

The Indonesian government has taken a decisive step toward accelerating the transition to battery-based electric vehicles (EVs) through Presidential Regulation Number 55 of 2019. This policy establishes a comprehensive framework for the development and implementation of electric vehicle programs in road transportation, providing the necessary legal certainty, strategic direction, and foundation for a transformative shift toward sustainable mobility. By facilitating the widespread adoption of electric vehicles, the regulation supports Indonesia's broader energy transition agenda while reinforcing its commitment to reducing carbon emissions and embracing clean energy alternatives.

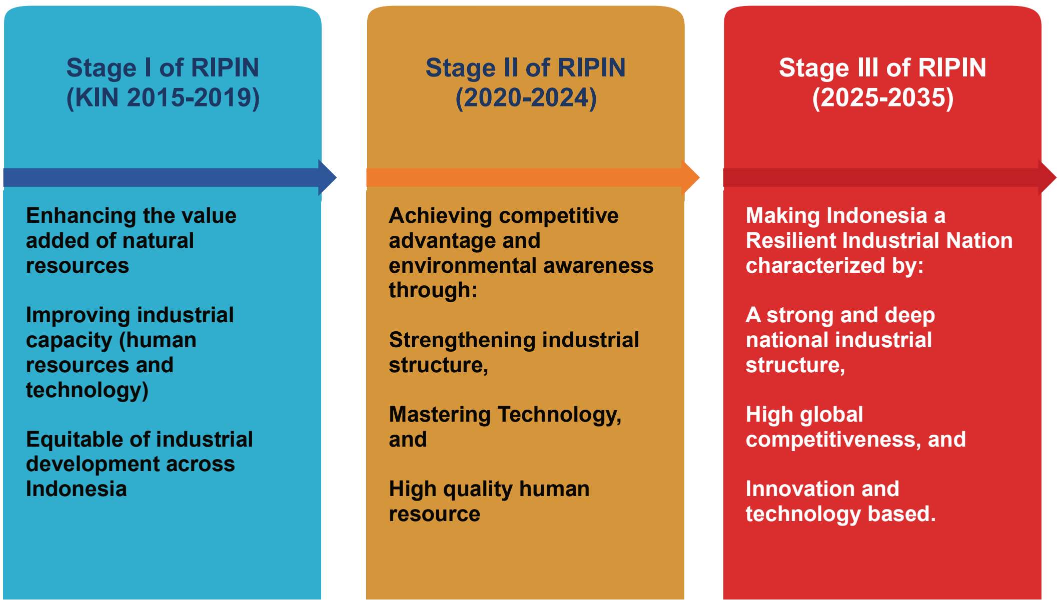


Figure 1.1 Key Stages in Establishing a National Industry (Ministry of Industry, 2015)

Table 1.1. Categorization of Base Metal and Non-Metal Mineral Industries in Strategic Industrial Development Stages (Ministry of Industry, 2015)

PRIORITY INDUSTRIES	TYPE OF INDUSTRY		
	2015-2019	2020-2024	2025-2035
INDUSTRY OF BASIC METAL AND NON-METAL MINING	INDUSTRY OF PROCESSING AND REFINING BASIC IRON AND STEEL		
	1. Iron ore pellet 2. Lumps 3. Fines 4. Sponge iron 5. Pig iron and cast iron 6. Nickel pig iron 7. Ferronickel 8. Ferro alloy 9. Steel for special purposes (health, defence, automotive)	1. Slab, billet, bloom 2. Hot Rolled Coils (HRC), Hot Rolled Plate (HRP), Cold Rolled Coils (CRC), and Wire rod 3. Profile, bar, wire 4. Ferro alloy 5. Stainless steel long and flat products 6. Steel for special purposes (health, defence, automotive)	1. Stainless pipe 2. Ferro alloy 3. Decorative stainless steel 4. Steel for special purposes (health, defence, automotive)
	INDUSTRY OF PROCESSING AND REFINING NON-FERROUS BASE METAL		
	1. Smelter Grade Alumina (SGA) and Chemical Grade Alumina (CGA) 2. Aluminium, aluminium alloy, billet, and slab 3. Nickel matte 4. Copper Cathode 5. Copper/Brass Sheet 6. Nickel hydroxide 7. Fe Ni Sponge, Luppen Fe Ni, and Nugget Fe Ni	1. Aluminium and aluminium alloy 2. Mixed Hydroxide Precipitate (MHP), Mixed Sulphides Precipitate (MSP), and Nickel Metal 3. Copper alloy 4. Copper/Brass Sheet	1. Aluminium and advanced aluminium alloy 2. Nickel electrolytic, Nickel sulphate, and Nickel chloride 3. Copper wire and electronic components
	INDUSTRY OF PRECIOUS METALS, RARE EARTH ELEMENTS AND NUCLEAR MATERIALS		
	1. Precious Metals 2. REE concentrate	1. Precious metals for decoration and jewellery 2. REE	1. Precious metals for electronic components 2. REE for electronic components 3. REE for nuclear fuels

One of the significant implications of this initiative is the growing demand for critical mineral raw materials essential for the energy transition. Key minerals such as nickel, cobalt, rare earth elements (REE), and lithium will play an instrumental role in decarbonizing and electrifying the global economy. These resources serve as fundamental inputs in the production of EV batteries, solar panels, and wind turbines, all of which are integral to replacing fossil fuel-based energy systems with renewable energy sources. As Indonesia embarks on this transition, its strategic mineral reserves are poised to become even more valuable in shaping the future of sustainable energy.

The acceleration of the electric vehicle industry will also drive technological innovation, particularly in the development of advanced materials and mineral combinations that enhance energy storage and efficiency. This technological evolution will be critical in optimizing battery performance, increasing energy density, and extending battery life cycles. As demand for clean energy surges, so too will the need for a broad spectrum of mineral commodities necessary for the modernization and expansion of energy infrastructure.

Global trends further emphasize the increasing importance of these minerals. According to the International Energy Agency (IEA), the demand for minerals used in clean energy technologies is projected to rise substantially by 2040. Copper, nickel, cobalt, rare earth elements, lithium, and graphite will be among the most sought-after commodities as industries strive to meet global Net Zero Emission targets by 2050 and limit temperature rise to 1.5°C (Figure 1.2).

Considering these forecasts, ensuring a stable and sustainable supply of these critical minerals will be paramount. As the global race for essential raw materials intensifies, competition for natural resources is likely to become fiercer. Climate change policies and regulatory shifts favouring low-carbon energy solutions will further amplify demand, making access to these minerals a crucial factor in sustaining the momentum of the energy transition (Figure 1.3). Countries with abundant mineral reserves, such as Indonesia, will play a pivotal role in the evolving global energy landscape, both as key suppliers of strategic resources and as leaders in clean energy innovation.

By fostering the rapid adoption of electric vehicles and supporting the development of a robust supply chain for essential battery materials, Indonesia is positioning itself at the forefront of the global energy transition. This initiative not only strengthens the nation's industrial competitiveness but also reinforces its commitment to environmental sustainability, economic resilience, and technological advancement in the era of decarbonization and digital transformation.

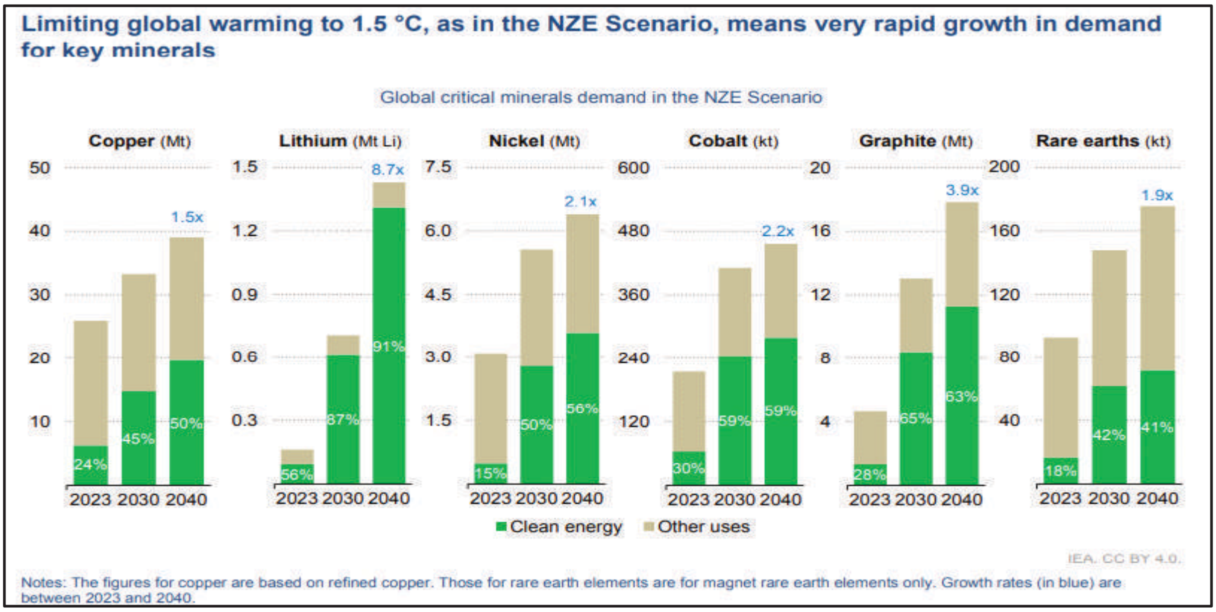


Figure 1.2 Projected Demand Growth for Key Minerals to 2040 in the NZE Scenario (International Energy Agency (IEA), 2024)

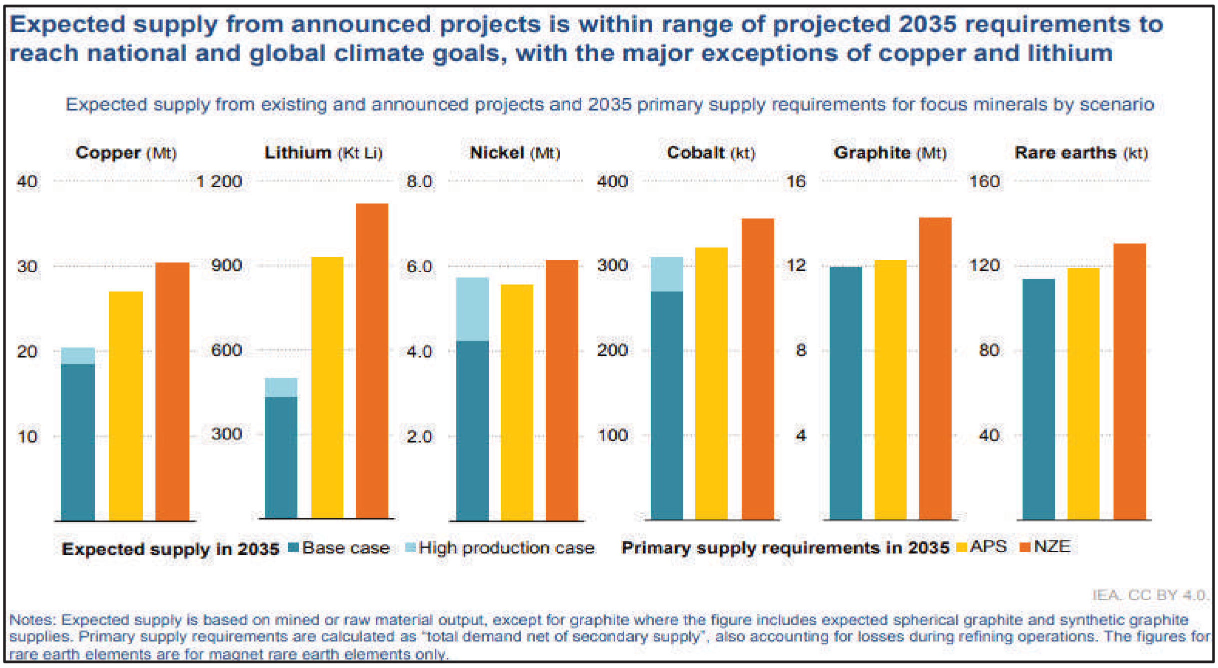


Figure 1.3 Projected Supply and Demand for Key Minerals in 2035 Across Different Scenarios (International Energy Agency (IEA), 2024)

Critical and Strategic Minerals

EU Critical Minerals Classification

The European Union has taken a significant step toward ensuring a secure and sustainable supply of essential raw materials by revising its Critical Raw Material (CRM) Act. This updated framework reflects the growing recognition of raw materials as the backbone of modern industry, clean energy transition, and technological advancement. By reinforcing policies that secure access to critical resources, the EU aims to strengthen economic resilience, reduce dependency on external suppliers, and foster sustainable industrial growth.

At the core of the CRM Act revisions is the identification and classification of raw materials essential for strategic industries, particularly those driving the green and digital transitions. Among the 34 material categories classified as critical, 17 have been designated as strategic raw materials due to their indispensable role in emerging technologies, renewable energy, electric mobility, and defence applications (Figure 1.4). These strategic raw materials are crucial in manufacturing semiconductors, wind turbines, electric vehicle batteries, and other high-tech innovations essential for achieving the EU's sustainability goals (European Commission, 2020).

To facilitate the responsible extraction, processing, and utilization of these critical resources, the revised CRM Act introduces several key measures. It streamlines permitting procedures for mining and refining projects, reducing bureaucratic hurdles and expediting the approval process to accelerate the development of domestic supply chains. Additionally, the act enhances financial support mechanisms, ensuring that enterprises involved in critical raw material extraction and processing have access to funding, investments, and strategic partnerships that bolster supply security.

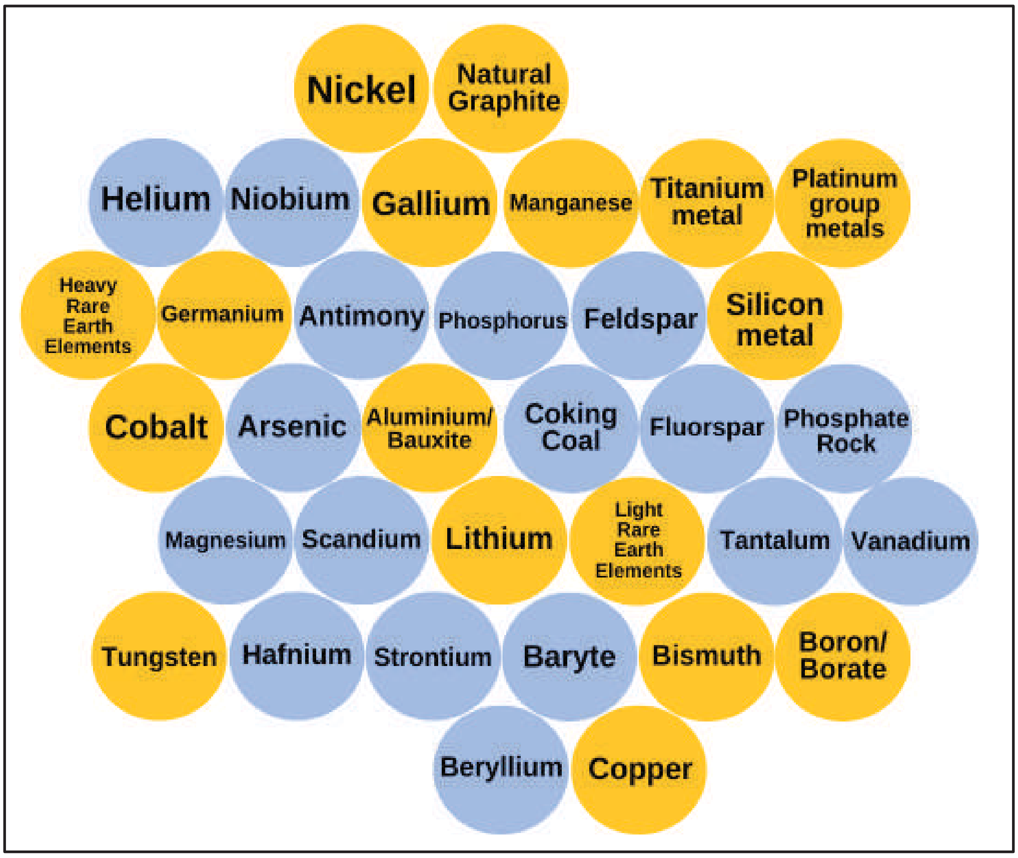


Figure 1.4 European Union (EU) Classification of Critical and Strategic Minerals (*Yellow = Strategic Minerals, Blue = Critical Minerals*) (European Commission, 2020)

A fundamental aspect of the revision is the promotion of sustainability and circularity within the raw materials sector. The EU is actively advancing initiatives to optimize waste recycling and secondary material recovery, reducing reliance on virgin resources while minimizing environmental impact. By fostering a circular economy model, the CRM Act aligns with the broader European Green Deal objectives, emphasizing resource efficiency, carbon neutrality, and sustainable production practices.

As global demand for critical raw materials surges, competition for these resources intensifies, underscoring the importance of supply chain diversification and strategic autonomy. The revised CRM Act strengthens the EU's position in the global raw materials market, reinforcing its ability to secure essential resources while upholding high environmental and social standards. This proactive approach ensures that Europe remains at the forefront of industrial innovation, green technology, and economic sustainability in an increasingly resource-driven world.

Indonesia's Critical and Strategic Minerals Classification

Indonesia has taken a decisive step in securing its mineral resources by issuing Ministry of Energy and Mineral Resources Regulation No. 296.K/MB.01/MEM.B/2023, which governs the classification of critical minerals. This regulation reflects the nation's commitment to strengthening its industrial base, securing supply chains, and ensuring sustainable economic growth by identifying 47 commodities as critical minerals. These minerals play an essential role as raw materials in national strategic industries, contributing significantly to economic development, national security, and technological advancement (Figure 1.5).

Critical minerals are those that fulfil key industrial functions and meet specific criteria, including their necessity in strategic industries, significant economic value, potential supply risks, lack of viable substitutes, and importance in bolstering national defence and security.

The Indonesian government has recognized these minerals as essential to advancing key sectors such as steel production, transportation, electric vehicles, telecommunications, renewable energy, healthcare, and defence. Their classification is based on rigorous qualitative and quantitative assessments that align with global industrial trends and Indonesia's long-term development goals.

Among the 47 commodities identified as critical, key minerals include graphite, aluminium, iron, lithium, nickel, copper, cobalt, and manganese. These elements are particularly vital to produce electric vehicle batteries, a rapidly expanding sector that underpins the global transition toward cleaner energy and reduced carbon emissions. The establishment of a robust domestic supply chain for these materials is expected to enhance Indonesia's position as a leading player in the global battery and electric vehicle market, reinforcing its role in the energy transition and digital economy.

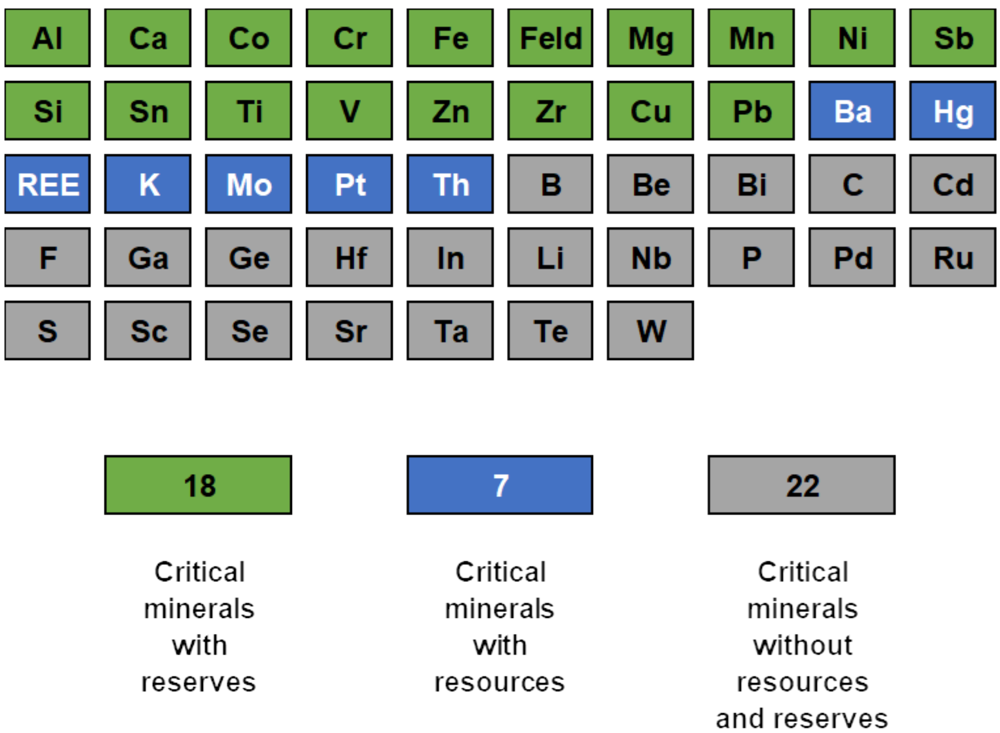


Figure 1.5 Types of critical minerals in Indonesia (Directorate General of Mineral and Coal, 2023)

However, despite Indonesia's vast mineral wealth, not all these critical commodities are currently available in the country. Notably, Indonesia lacks reserves or resources for 23 of the identified critical minerals, including lithium (Li), palladium (Pd), graphite, and gallium (Ga). The absence of these essential materials presents challenges for domestic industries that rely on imports to meet their needs. This dependency underscores the importance of strategic partnerships, international cooperation, and investments in mineral exploration and technological innovation to ensure supply security.

As demand for critical minerals continues to surge globally, Indonesia's regulatory framework aims to balance resource management with sustainable industrial growth. By proactively identifying and classifying critical minerals, the country is positioning itself to leverage its resource potential, reduce import reliance, and strengthen its industrial competitiveness. This initiative aligns with Indonesia's broader economic and environmental strategies, reinforcing its commitment to securing a stable, resilient, and sustainable mineral supply for the future.

While both the EU and Indonesia recognize the strategic importance of critical minerals, their approaches reflect their unique economic and resource landscapes. The EU prioritizes reducing external dependence and sustainability, whereas Indonesia seeks to leverage its resource wealth to strengthen domestic industries and global competitiveness. Collaboration between these two regions could provide mutual benefits, combining the EU's technological and sustainability expertise with Indonesia's mineral resources to build resilient and sustainable supply chains.

Indonesia has taken a structured approach to managing its mineral resources through the classification of critical and strategic minerals, ensuring sustainable industrial development, economic resilience, and global market competitiveness. Under Ministry of Energy and Mineral Resources Regulation No. 296.K/MB.01/MEM.B/2023, commodities classified as critical minerals hold their designation for three years, with the possibility of annual evaluations or earlier revisions if necessary. This adaptive approach enables the government to respond dynamically to shifting economic, technological, and geopolitical factors that influence global supply chains.

In addition to critical minerals, Ministry of Energy and Mineral Resources Regulation No. 69.K/MB.01/MEM.B/2024 further refines Indonesia's mineral policy by identifying 22 commodities as strategic minerals (Table 1.2). These minerals serve as fundamental raw materials for downstream mineral processing, fostering domestic industrial development, economic growth, state revenue, and international trade competitiveness. Their designation underscores Indonesia's commitment to leveraging its mineral wealth to drive national progress while securing a strong foothold in global markets.

Indonesia employs a robust five-point framework to determine whether a mineral qualifies as strategic:

Table 1.2. Classification of Commodities in Strategic Minerals

No.	Strategic Mineral	Mineral Comodity
1	Alluminium (Al)	Bauxite
2	Antimony (Sb)	Antimony
3	Iron (Fe)	Iron Ore, Iron Sand
4	Gold (Au)	Gold
5	Phosphor (P)	Phosphate
6	Galena (Pb)	Galena
7	Cobalt (Co)	Cobalt
8	Chromium (Cr)	Chromite
9	Rare Earth Element (REE)	Rare Earth Element
10	Magensium (Mg)	Magensium
11	Mangan (Mn)	Mangan
12	Molybdenum (Mo)	Molybdenum
13	Nickel (Ni)	Nickel
14	Silver (Ag)	Silver
15	Platinum (Pt)	Platinum
16	Zinc (Zn)	Zinc
17	Silica (Si)	Quartz Sand, Quartize, Quartz Crystal
18	Copper (Cu)	Copper
19	Tin (Sn)	Tin
20	Titanium (Ti)	Titanium
21	Vanadium (V)	Vanadium
22	Zirconium (Zr)	Zircon

Industrial Necessity – Minerals essential for strategic industries, including defence, electric vehicles (EVs), renewable energy (solar panels and batteries), and pharmaceuticals. These industries are pivotal for the nation's long-term industrial and technological advancement.

Market Influence – Minerals that control international markets due to Indonesia's significant resource dominance. By strategically managing these resources, Indonesia can strengthen its position in the global commodity trade.

State Revenue Contribution – Minerals that generate substantial mining revenue for the national economy. A strong mineral sector boosts government funding for infrastructure, social programs, and economic initiatives.

Foreign Exchange Reserves – Minerals that significantly impact the nation's foreign currency earnings through international exports. Securing these reserves stabilizes Indonesia's economic position in global financial markets.

Wide - ranging Industrial Applications – Minerals with extensive uses across multiple strategic industries, supporting industrial diversification, technological innovation, and sustainable economic growth.

By systematically classifying minerals as either critical or strategic, Indonesia is laying the groundwork for an integrated industrial ecosystem that promotes resource security, economic self-sufficiency, and global leadership in key sectors. The prioritization of these minerals aligns with Indonesia's broader Vision 2045, which aims to establish the country as a major industrial and economic powerhouse.

Furthermore, the government's emphasis on domestic downstream processing—rather than exporting raw minerals—ensures that Indonesia maximizes value-added benefits from its resources. By investing in refining and processing industries, the country can produce higher-value materials such as EV batteries, solar panel components, and advanced defence technologies, reducing dependency on imports while fostering economic resilience.

Indonesia's mineral policies position the country as a key player in the global transition to renewable energy and sustainable technologies. The demand for minerals like nickel, cobalt, lithium, and rare earth elements (REEs) is surging due to the rapid growth of electric vehicles, clean energy infrastructure, and digital technologies. As competition for these resources intensifies, Indonesia's policy-driven resource management offers a strategic advantage, making the country an attractive partner for international stakeholders.

By strengthening regulatory frameworks, fostering foreign investment, and promoting sustainable mining practices, Indonesia can secure its place as a leader in the global energy transition and industrial innovation, ensuring long-term prosperity while supporting the world's shift toward a low-carbon future.

Indonesia's Critical and Strategic Mineral Governance Framework

To strengthen mineral governance, sustainable mining practices, and industrial competitiveness, the Indonesian government is in the process of drafting a Government Regulation on the Governance of Critical Minerals and Strategic Minerals. This regulatory framework will provide clear guidelines for mineral trade, investment, and sustainability efforts, ensuring Indonesia's continued leadership in the global energy transition.

This regulation will serve as a key reference for:

Regulations and Policies – Establishing comprehensive mining, processing, and trade regulations for mineral-based industries, including by-products and processing residues.

Business Permits and Licensing – Providing criteria for issuing permits in mineral exploitation and downstream industries, ensuring economic and environmental sustainability.

Exploration Strategies – Enhancing resource and reserve expansion through targeted exploration policies.

Reference Mineral Pricing – Setting benchmark prices for strategic and critical minerals to stabilize the domestic market.

Domestic Prioritization Policies – Ensuring that critical minerals are allocated first for national needs before being exported.

Research and Innovation Acceleration – Strengthening scientific and technological advancements in mining efficiency, sustainability, and mineral processing.

Fiscal Policies in the Mineral Sector – Developing tax incentives, royalties, and fiscal frameworks to optimize mineral sector revenue while encouraging sustainable investments.

International Cooperation – Enhancing strategic partnerships, trade agreements, and geopolitical collaboration in mineral governance.

Indonesia’s Downstream Processing Minerals Roadmap 2023-2045

Recognizing the economic potential of value-added mineral industries, Indonesia has outlined a long-term roadmap (2023–2045) for strategic downstream processing. This initiative focuses on transforming raw materials into high-value products, boosting industrial growth, export revenues, and domestic technological capabilities.

The roadmap emphasizes strategic investments in processing essential commodities such as iron, copper, tin, bauxite, gold, silver, and nickel (Figure 1.6), with the following objectives:

- Enhancing domestic refining capacity to reduce reliance on raw mineral exports.
- Expanding EV battery and renewable energy material production through investments in nickel, lithium, and cobalt refining.
- Establishing advanced metallurgical and alloy industries for automotive, aerospace, and defence applications.
- Developing circular economy models by integrating waste recycling and sustainable mineral extraction technologies.
- Boosting Indonesia’s competitiveness in global mineral supply chains and green technology industries.

By implementing strong governance policies and a structured roadmap, Indonesia is positioning itself as a global leader in the sustainable mineral economy, ensuring that critical and strategic minerals support national industrialization, economic stability, and environmental responsibility.

Regulatory Framework for Mineral and Coal Exploration in Indonesia: Advancing Industrial Development and Resource Sustainability

The Indonesian government has enacted Law No. 3 of 2020, amending Law No. 4 of 2009 on Mineral and Coal Mining, to accelerate the country's industrial development in alignment with the 2015-2035 National Industrial Development Master Plan (RIPIN) and the 2023-2045 Downstream Processing Roadmap. To support national industrial growth, this legislation mandates several priority policies, including comprehensive mining exploration and research across all legal mining areas, the designation of working areas for rock, non-metallic mineral, and mineral mining, and the promotion of value-added activities within the mining sector.

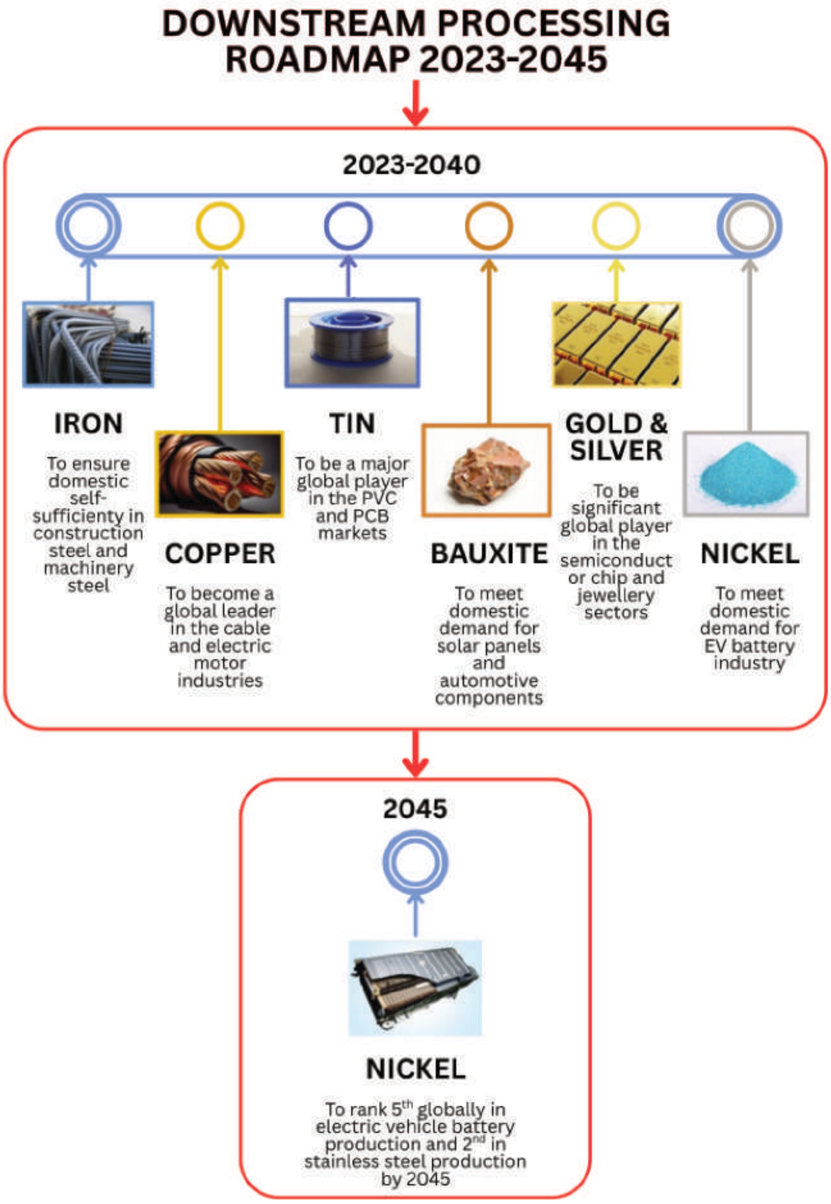


Figure 1.6 Downstream Processing Minerals Roadmap 2023 - 2045 (Coordinating Ministry for Maritime Affairs and Investment, 2024)

To enhance value creation, the Ministry of Energy and Mineral Resources has implemented a downstream processing program through the establishment of mineral processing and refining facilities (smelters). This initiative aims to advance national industrial development, bolster economic resilience, and stimulate economic growth.

As part of the priority policies underpinning the National Industrial Program, the government issued Government Regulation No. 25 of 2023 concerning Mining Areas. This regulation mandates the assignment of exploration and research for the preparation of mineral mining working areas (WIUP) and special coal mining working areas (WIUPK). Additionally, Ministerial Regulation No. 14 of 2023 provides detailed procedures for assigning exploration and research for the preparation of mining areas, WIUP, and WIUPK. It establishes minimum requirements for conducting exploration and research to define and develop these mining areas.

Further technical guidelines are outlined in Ministerial Decree No. 54 of 2023, which specifies criteria for different commodities, work plans, reporting structures, and the duration of exploration assignments. These guidelines ensure a structured and effective approach to mineral exploration and reserve enhancement.

In accordance with these regulations, state-owned enterprises (SOEs) and private companies may apply for exploration and research assignments. These assignments may also be offered to regional-owned enterprises (ROEs) or SOEs for the development of WIUPs. As stipulated in Law No. 3 of 2020 on Mineral and Coal Mining, the exploration and research assignment scheme is expected to yield auctionable areas with sufficient resources to enhance mineral reserves and ensure long-term sustainability of national mineral resources.

Key Strategies for Exploration

The Indonesian government's strategic approach to mineral and coal exploration focuses on regulatory support, technological advancements, and efficient resource management. By strengthening these aspects, the country aims to enhance its mineral reserves, support industrial growth, and ensure long-term economic sustainability (Figure 1.7).

Regulatory Framework

A strong regulatory foundation ensures efficient exploration and resource management. Government Regulation No. 25 of 2023 mandates exploration and research for preparing mining areas (WIUP and WIUPK). Additionally, Ministerial Regulation No. 14 of 2023 defines the procedures for assigning exploration and research, while Ministerial Decree No. 54 of 2023 provides technical guidelines for conducting exploration.

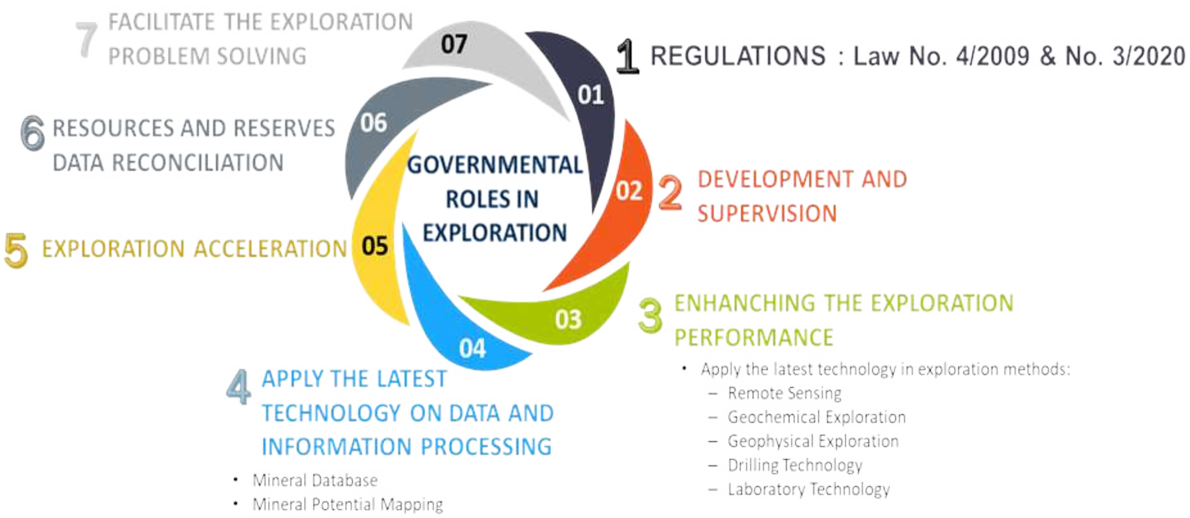


Figure 1.7 Government Roles in Exploration: Key Strategies for Resource Development (Geological Agency, 2024)

Development and Supervision

Government agencies oversee and guide exploration activities to ensure compliance with policies. Supervision plays a crucial role in optimizing resource utilization and preventing environmental degradation.

Enhancing Exploration Performance

To improve exploration outcomes, companies must adopt best practices in resource assessment and management. Efficient planning and systematic execution of exploration programs contribute to better resource identification and extraction.

Application of Advanced Technology

Modern technologies in data processing, remote sensing, and geological modeling enhance the accuracy and efficiency of exploration. The integration of artificial intelligence and big data analytics further optimizes decision-making.

Acceleration of Exploration Efforts

Expediting exploration activities requires streamlined approval processes and efficient collaboration between government agencies and private enterprises. Reducing bureaucratic delays can significantly enhance resource identification and development.

Data Reconciliation of Resources and Reserves

Accurate and updated resource data is essential for informed decision-making. Implementing standardized reporting systems ensures transparency and reliability in mineral and coal resource estimates.

Problem-Solving in Exploration

Addressing challenges in exploration involves strategic planning and risk assessment. Governments and companies must collaborate to resolve issues related to resource depletion, environmental concerns, and economic feasibility.

Global Issues on Mineral Reserves and Production

World Gold Reserves and Production

According to the 2024 United States Geological Survey (USGS) statistics, global gold reserves stand at approximately 59 thousand metric tons (Figure 1.8). Indonesia holds a significant position as a major global supplier of gold, ranking sixth worldwide in terms of gold reserves. According to the December 2023 balance sheet from the Indonesian Ministry of Energy and Mineral Resources, Indonesia's total gold reserves amount to 3.4 thousand metric tons (Nursahan, et al., 2024).

World Silver Reserves and Production

Indonesia is among the top six silver-producing nations globally, possessing 7% of the world's silver reserves. This underscores Indonesia's continued contribution to the global silver supply (Figure 1.9).

World Copper Reserves and Production

Based on 2024 USGS data, the total global copper reserves in 2023 amounted to 1 billion metric tons. Indonesia ranks ninth globally in copper reserves, accounting for 2.4% of the world’s total (Figure 1.10).

According to the U.S. Geological Survey's Mineral Commodity Summaries (January 2024), the world's top copper-producing countries in 2023 were:
Chile, South America – 5 million metric tons
Peru, South America – 2.6 million metric tons
Congo, Africa – 2.5 million metric tons
China, Asia – 1.7 million metric tons
United States, North America – 1.1 million metric tons
Russia, Europe/Asia – 900 thousand metric tons
Australia, Oceania – 800 thousand metric tons
Indonesia, Asia – 800 thousand metric tons
Zambia, Africa – 800 thousand metric tons
Mexico, North America – 700 thousand metric tons

World Nickel Reserves and Production

According to 2024 USGS data, global nickel reserves in 2023 totaled 130 million metric tons (Figure 1.11). Indonesia holds the largest share of the world's nickel reserves, accounting for 42% of the total, with total nickel metallic reserves reaching 56 million metric tons (Nursahan, et al., 2024).

World Bauxite Reserves

As per 2024 USGS data, global bauxite reserves in 2023 stood at 31.8 billion metric tons. Indonesia ranks fourth globally in terms of bauxite reserves, contributing 8.8% of the world’s total (Figure 1.12). This highlights Indonesia’s crucial role in supplying bauxite as a raw material worldwide.

World Tin Reserves

Based on 2024 USGS data, global tin reserves in 2023 were recorded at 5.6 million metric tons. Indonesia leads the world in tin reserves, holding approximately 24.26% of the total (Figure 1.13).

World Iron Reserves

According to 2024 USGS data, total global iron reserves in 2023 amounted to 190 billion metric tons. Indonesia ranks eighth globally in iron reserves, comprising 1.92% of the world’s total (Figure 1.14).

World Lead and Zinc Reserves

Based on 2024 USGS data, global lead reserves in 2023 reached 85 million metric tons. Indonesia ranks eighth globally, contributing 2% of the world’s lead reserves (Figure 1.15). Additionally, the total global zinc reserves in 2023 were 210 million metric tons, with Indonesia ranking ninth and holding 1% of the world's zinc reserves (Figure 1.16).

World Silica Production

According to 2024 USGS data, total global silica reserves in 2023 stood at 402.6 million metric tons. Indonesia ranks nineteenth globally in silica reserves, representing 0.8% of the world’s total (Figure 1.17).

Indonesia’s significant mineral reserves and production capacity emphasize its critical role in global mineral markets, particularly in nickel, tin, and bauxite production. The country’s vast mineral wealth continues to drive its position as a key player in the international mining sector.

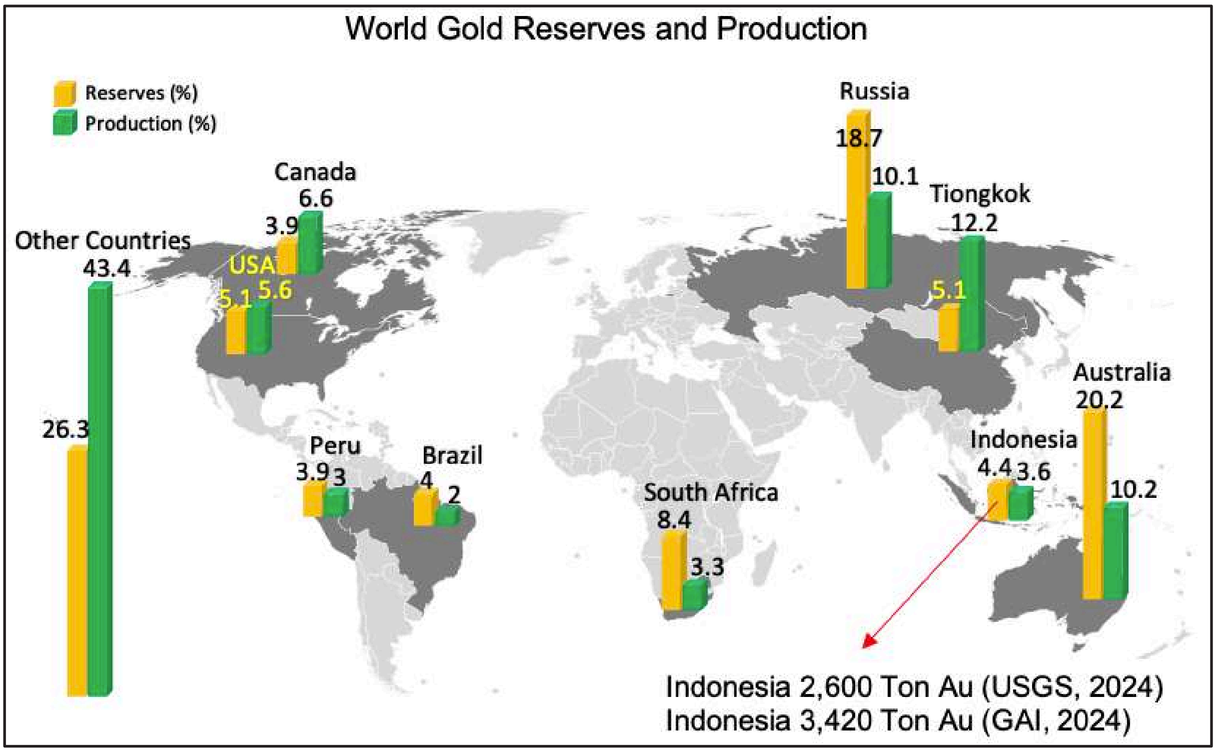


Figure 1.8 World Gold Reserves and Production
Modified from USGS, 2024 and Nursahan, et al., 2024

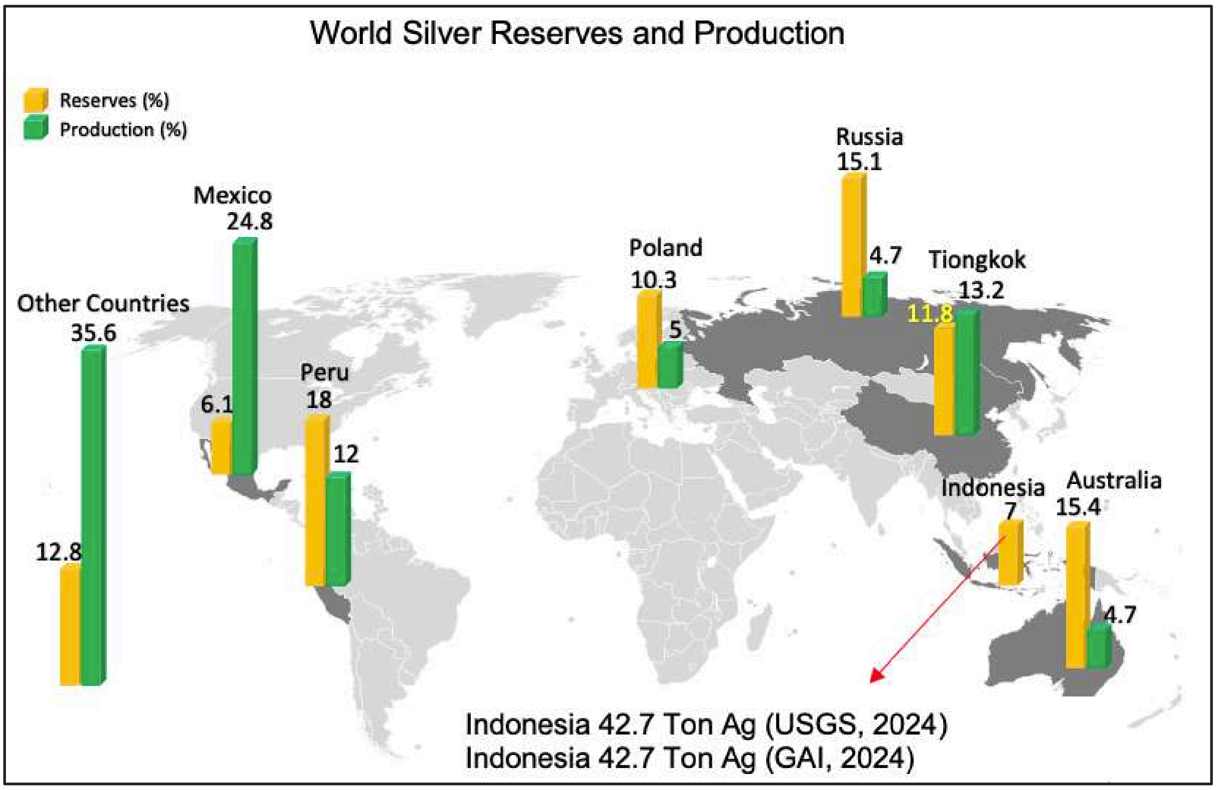


Figure 1.9 World Silver Reserves and Productions
Modified from USGS, 2024 and Nursahan, et al., 2024

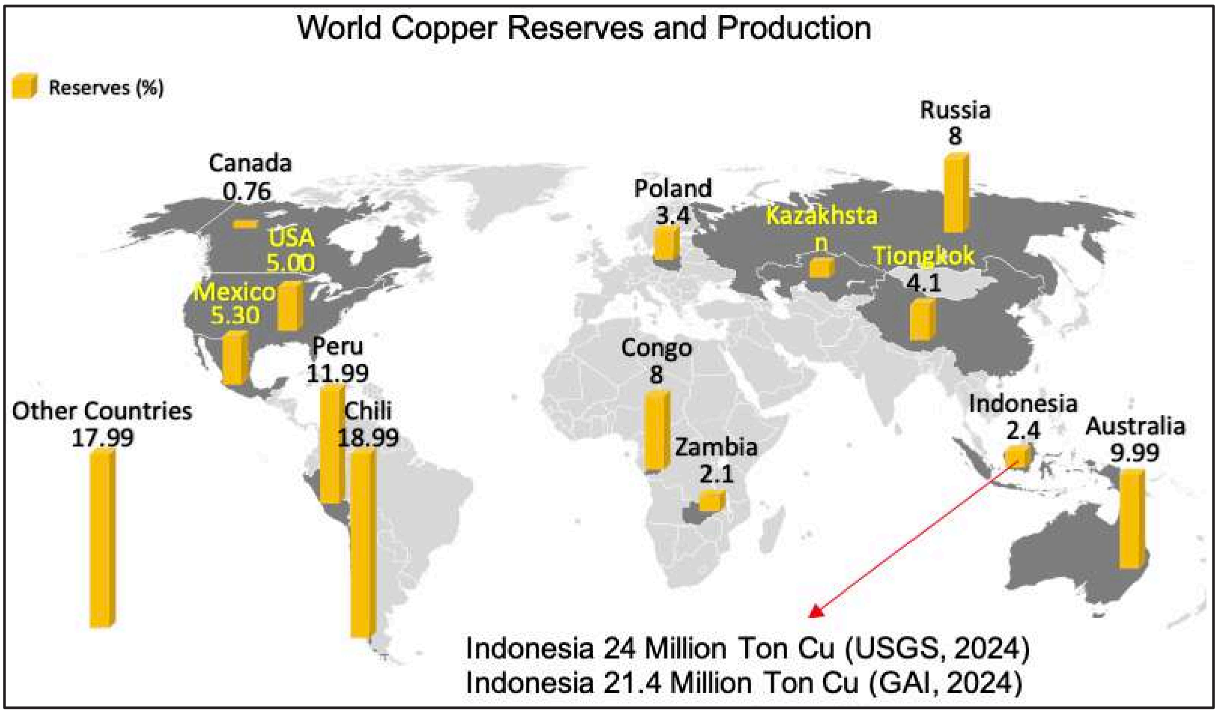


Figure 1.10 World Copper Reserves and Productions
Modified from USGS, 2024 and Nursahan, et al., 2024

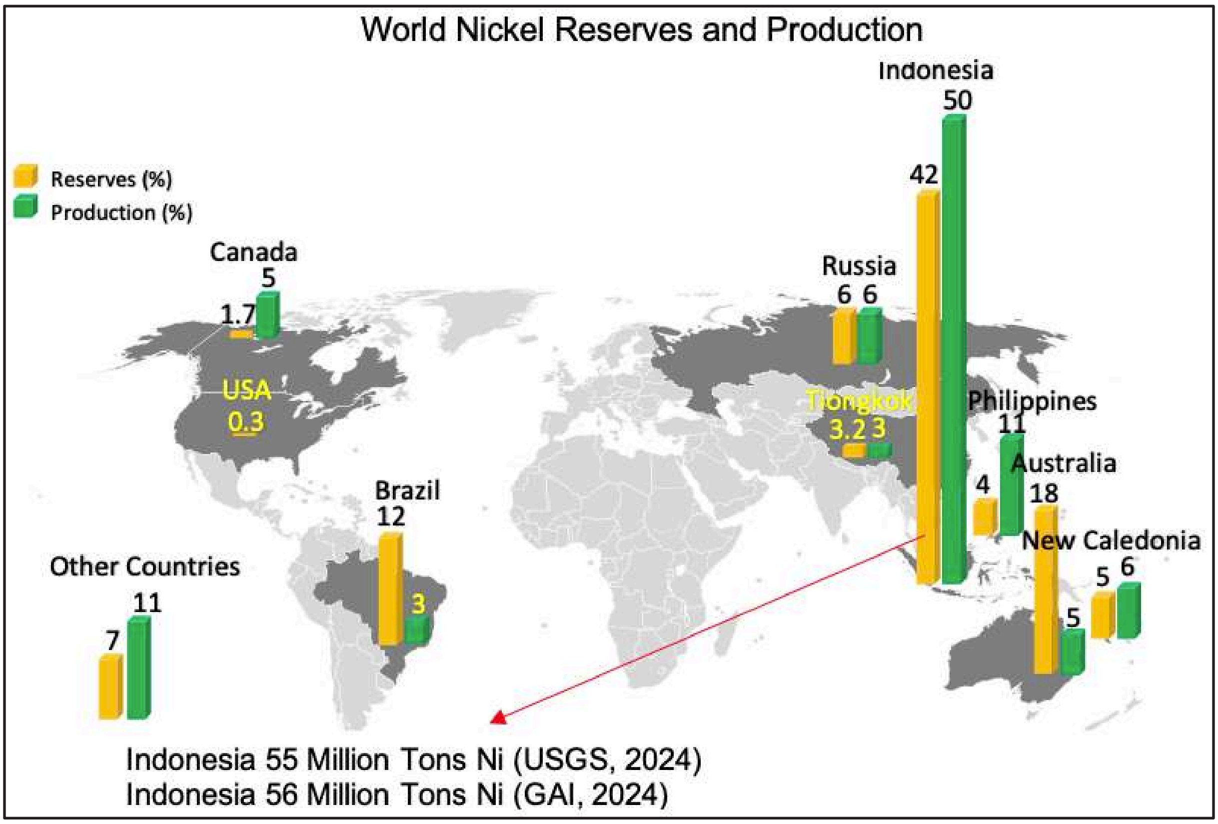


Figure 1.11 World Nickel Reserves and Production Map
Modified from USGS, 2024 and Nursahan, et al., 2024

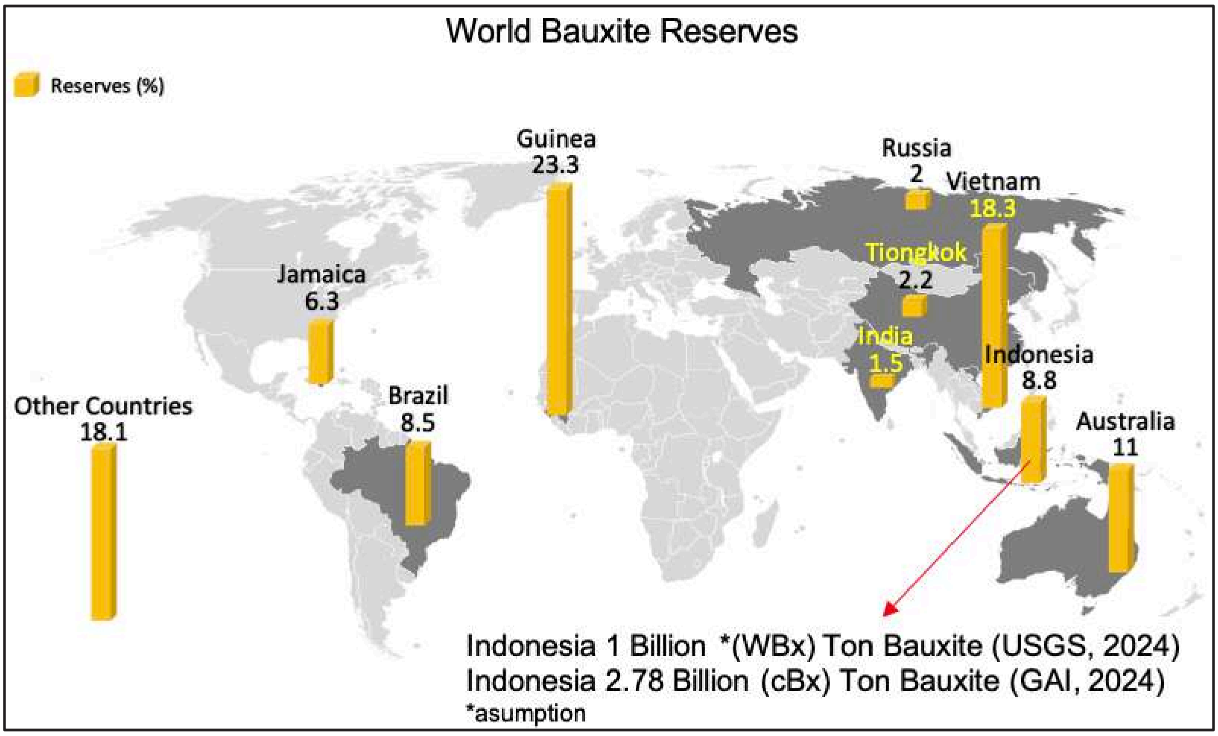


Figure 1.12 World Bauxite Reserves Map
Modified from USGS, 2024 and Nursahan, et al., 2024

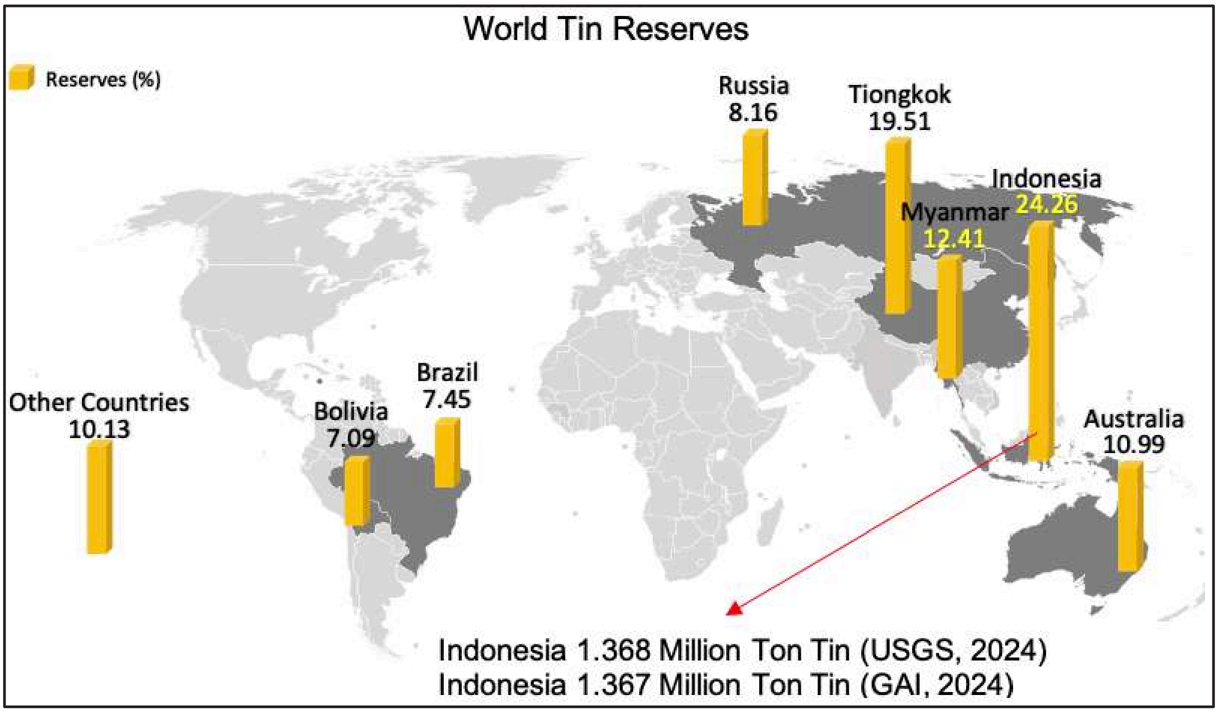


Figure 1.13 World Tin Reserves Map
Modified from USGS, 2024 and Nursahan, et al., 2024

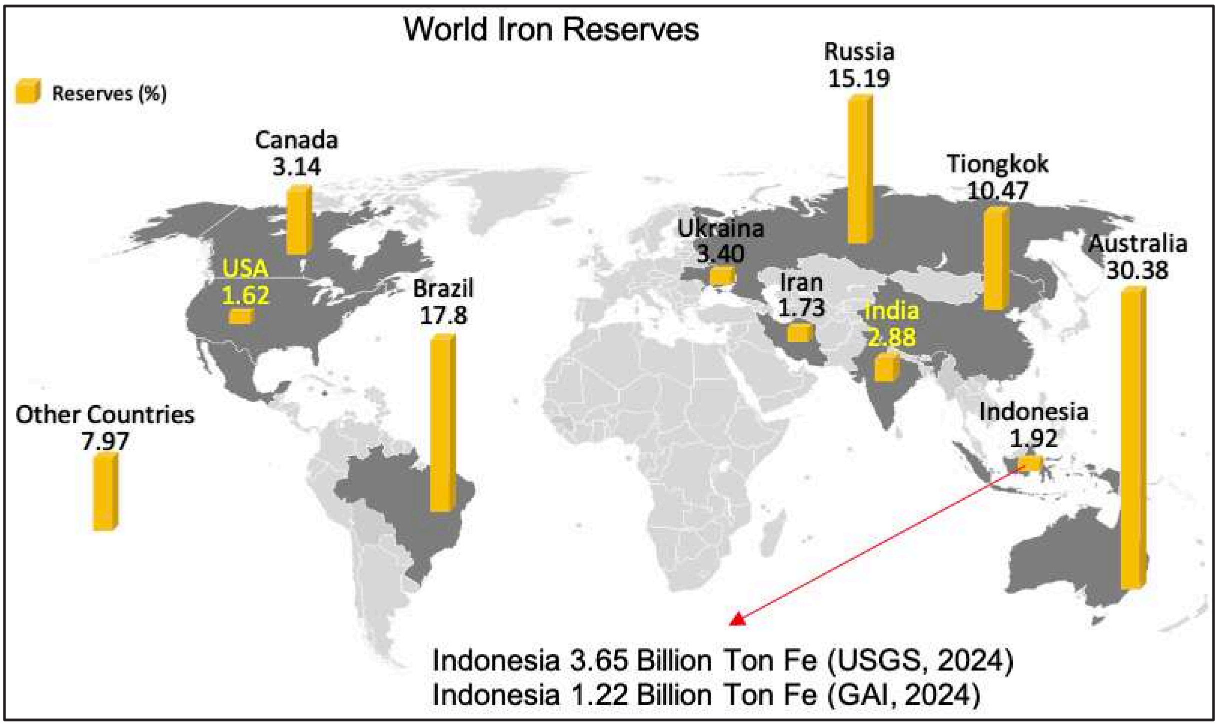


Figure 1.14 World Iron Reserves Map
Modified from USGS, 2024 and Nursahan, et al., 2024

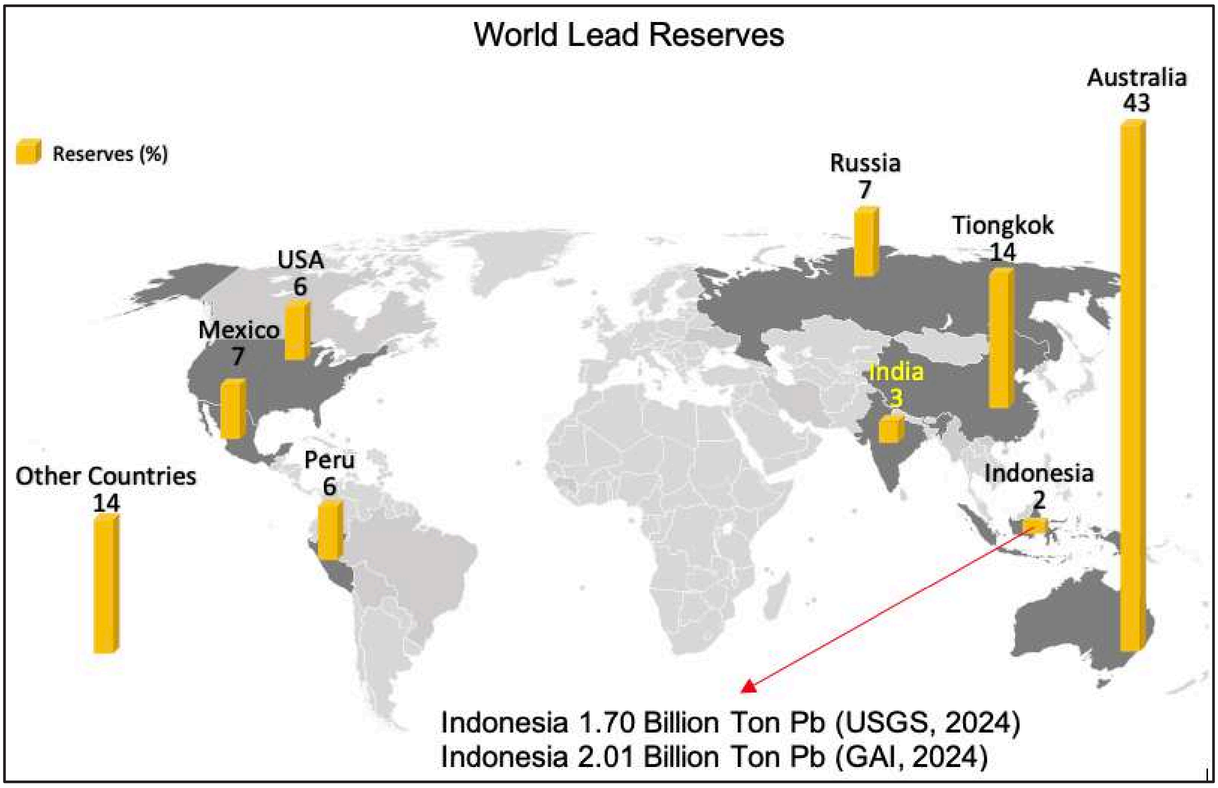


Figure 1.15 Global Lead Reserves Map
Modified from USGS, 2024 and Nursahan, et al., 2024

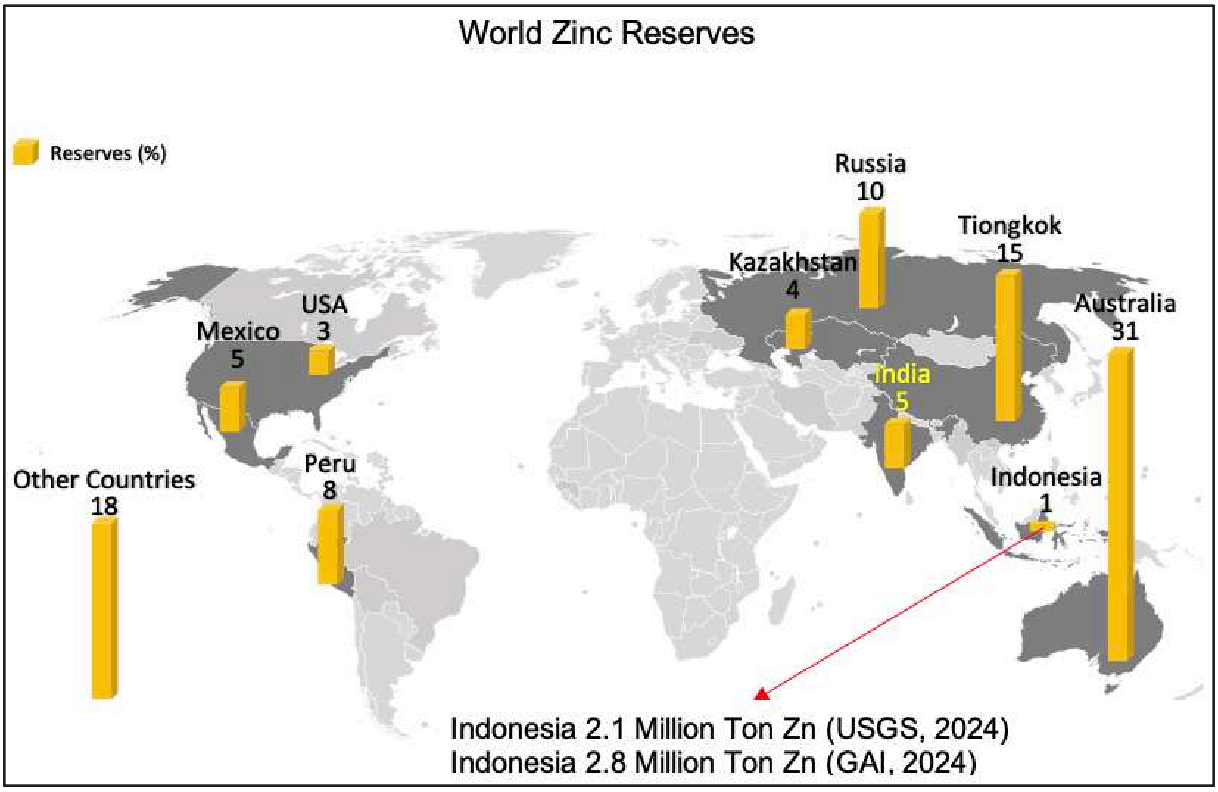


Figure 1.16 Global Zinc Reserves
Modified from USGS, 2024 and Nursahan, et al., 2024

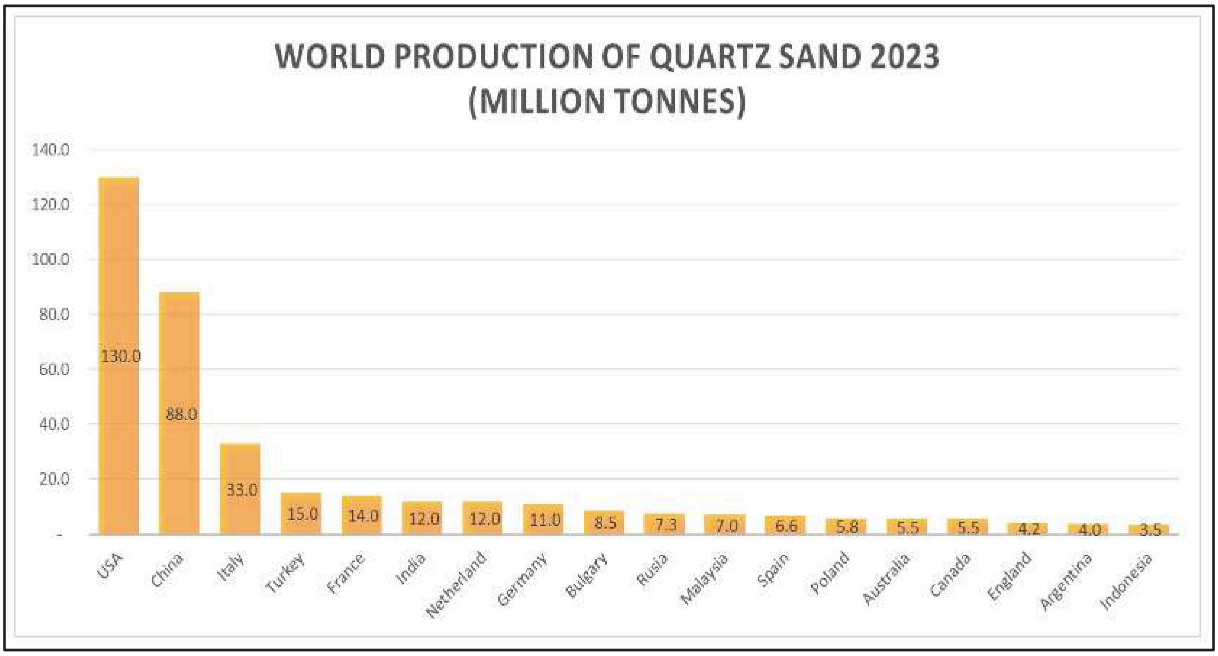


Figure 1.17. Quartz Sand Production in 2023
Modified from USGS, 2024 and Nursahan, et al., 2024

The Role of Minerals in Clean Energy Technologies

As the world transitions to cleaner energy solutions, the demand for essential minerals has surged. Electric vehicles (EVs) and renewable energy sources, such as wind and solar power, rely heavily on various minerals that play a crucial role in their performance and efficiency (Figure 1.18).

In the transport sector, electric cars require significantly more minerals than conventional vehicles. Battery components such as lithium, nickel, cobalt, and graphite are essential for energy storage, while copper plays a vital role in electric wiring. Compared to conventional cars, which primarily depend on copper, electric vehicles demand a much broader range of minerals to function efficiently.

The power generation sector also demonstrates significant mineral dependency. Offshore and onshore wind power require large amounts of copper, zinc, and rare earth elements for turbine production. Solar photovoltaic (PV) technology relies heavily on silicon, along with copper and other conductive materials. Meanwhile, nuclear energy depends on metals such as chromium, molybdenum, and nickel for reactor construction. In contrast, fossil fuel-based power generation, such as coal and natural gas, requires fewer minerals overall.

As nations push for decarbonization, securing a stable supply of these critical minerals has become a strategic priority. With the increasing demand for electric vehicles and renewable energy infrastructure, the mining and processing of these materials must be managed sustainably to avoid supply chain disruptions and environmental consequences. The shift to clean energy is not just about reducing emissions; it also involves addressing the complex challenges of mineral availability and responsible sourcing.

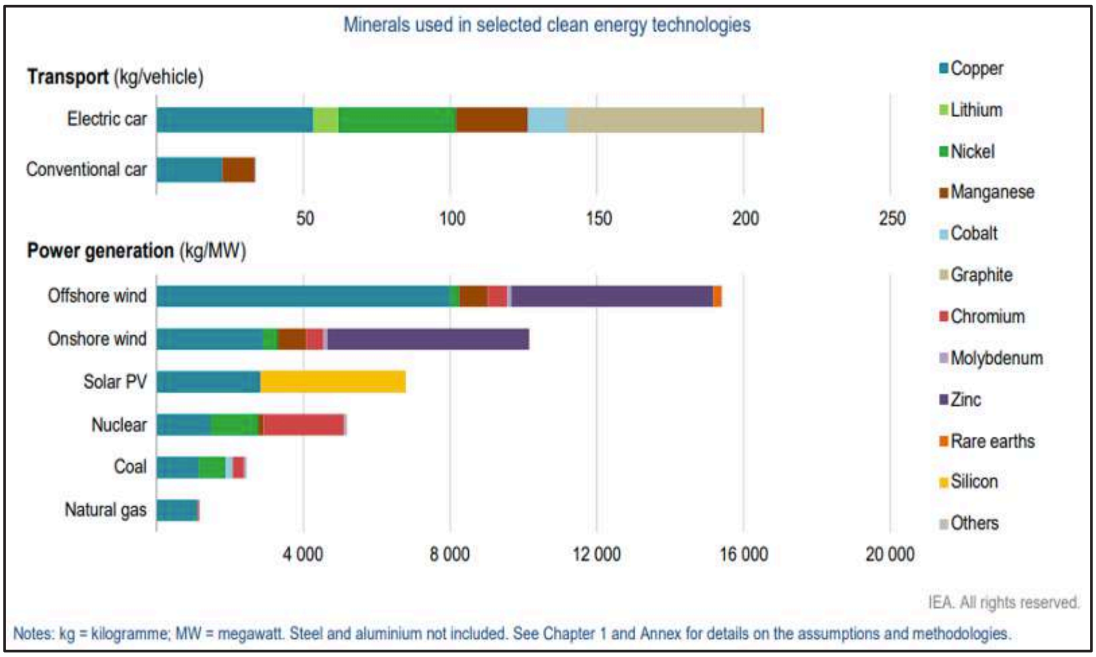


Figure 1.18. Mineral Used in selected clean energy technologies (IEA, 2021)

Projected Growth of Critical Minerals by 2040

The demand for critical minerals is set to skyrocket as the world accelerates the transition to sustainable energy technologies. According to projections, the need for lithium, graphite, cobalt, nickel, and rare earth elements will increase significantly by 2040 compared to 2020 levels (Figure 1.19).

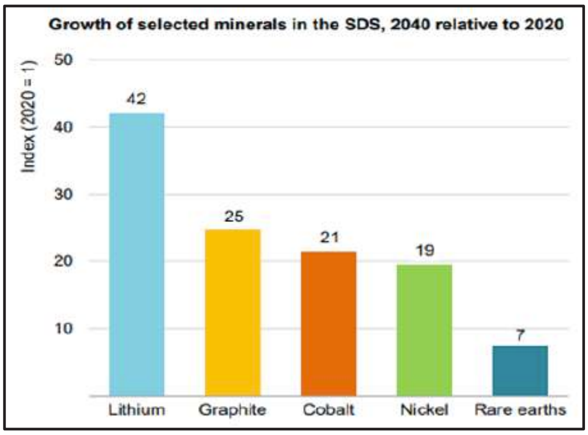


Figure 1.19. Growth of selected minerals in the SDS, 2040 relative to 2020 (IEA, 2021)

Lithium is expected to see the most dramatic surge, with demand rising 42 times its 2020 level. This sharp increase is primarily driven by its essential role in lithium-ion batteries, which power electric vehicles (EVs) and renewable energy storage systems. The growing electrification of transportation and grid storage solutions are pushing lithium to the forefront of global mineral demand.

Graphite demand is projected to increase 25 times, as it is a key component in battery anodes. With advancements in battery technology and increased EV adoption, the need for high-purity graphite is expected to remain strong.

Cobalt and nickel, both crucial for battery production and energy storage, are set to grow 21 and 19 times, respectively. These metals enhance battery performance and longevity, making them indispensable for the expanding EV market and renewable energy infrastructure.

Rare earth elements, while showing a relatively smaller increase (seven-fold), remain vital for manufacturing permanent magnets used in wind turbines and electric motors. Their continued demand highlights their importance in the clean energy supply chain.

As the shift to sustainable energy gains momentum, ensuring a stable and ethical supply of these critical minerals will be essential. The rising demand underscores the need for responsible mining, recycling innovations, and diversified supply chains to meet future energy goals sustainable.

The Energy Sector's Growing Dependence on Critical Minerals

As the world transitions towards clean energy, the energy sector is emerging as the dominant consumer of key minerals. The increasing demand for renewable energy technologies and electric vehicles is shifting mineral consumption patterns, making materials such as lithium, cobalt, nickel, copper, and rare earth elements more essential than ever.

The graphic illustrates the share of clean energy technologies in total demand for selected minerals over time. In 2010, the energy sector accounted for a relatively small portion of mineral consumption. However, by

2020, the demand had risen significantly, and projections for 2040 under different policy scenarios suggest a further increase (Figure 1.20).

Lithium: The Backbone of Battery Storage

Lithium stands out as one of the most crucial minerals for the energy transition, with its demand from the energy sector expected to exceed 80% by 2040. This surge is driven by the widespread adoption of lithium-ion batteries in electric vehicles and renewable energy storage.

Cobalt and Nickel: Key Elements in Battery Chemistry

Cobalt and nickel, essential for battery production, also show a sharp increase in their share of total demand from the energy sector. By 2040, the majority of cobalt and nickel consumption will be tied to clean energy technologies, primarily for battery applications.

Copper: Essential for Electrification

Copper, known for its excellent conductivity, plays a crucial role in power grids, wind turbines, and electric vehicle components. Its share in the energy sector is projected to continue growing, highlighting its importance in electrification and infrastructure expansion.

Rare Earth Elements: Powering Renewable Energy

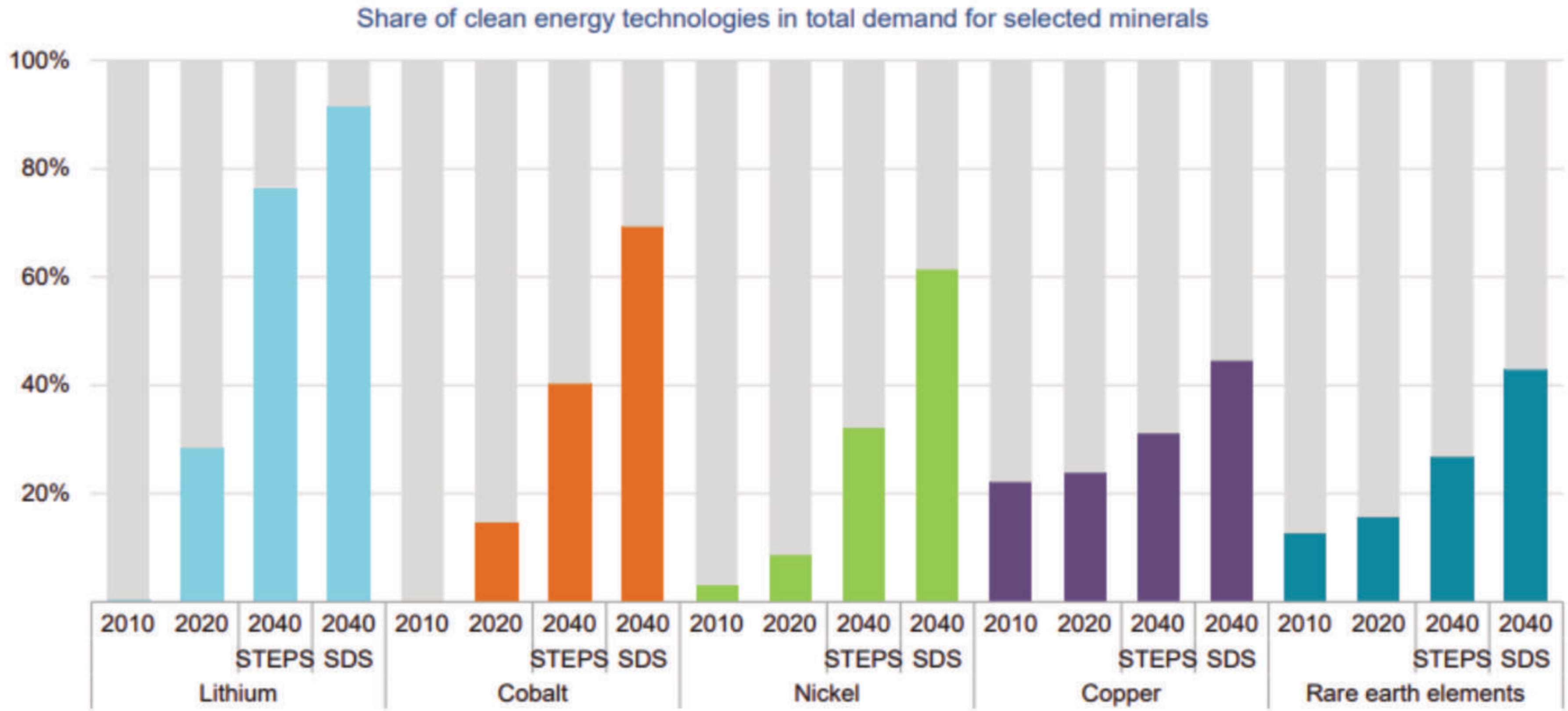
Rare earth elements, essential for producing permanent magnets used in wind turbines and electric motors, are also seeing increasing demand. Their role in advancing wind energy and electric mobility makes them indispensable in the clean energy transition.

The Future of Mineral Demand in the Energy Sector

The projections for 2040 under both the **Stated Policies Scenario (STEPS)** and the **Sustainable Development Scenario (SDS)** indicate that the energy sector will be the primary driver of mineral demand. The SDS, which aligns with global climate goals, shows an even higher reliance on these materials, emphasizing the need for sustainable and diversified supply chains.

The rapid growth in mineral demand underscores the necessity for responsible mining, recycling innovations, and strategic resource management to ensure a stable and ethical supply of these critical materials. As the world accelerates its transition to cleaner energy sources, securing these minerals will be pivotal in meeting future energy needs.

The energy sector becomes a leading consumer of minerals as energy transitions accelerate



Notes: Demand from other sectors was assessed using historical consumption, relevant activity drivers and the derived material intensity. Neodymium demand is used as indicative for rare earth elements. STEPS = Stated Policies Scenario, an indication of where the energy system is heading based on a sector-by-sector analysis of today's policies and policy announcements; SDS = Sustainable Development Scenario, indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

Figure 1.20. The Energy Sector Becomes a Leading Consumer of Minerals as Energy Transitions Accelerate (IEA, 2021)

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METALLOGENY MAP AND MINERAL DELINEATION MAP OF INDONESIA

The Indonesian government, under Law Number 3 of 2020, which amends Law Number 4 of 2009 on Mineral and Coal Mining, is mandated to conduct explorations and research to define Mineral and Coal Mining Business Areas. This includes managing geological data, mineral and coal resource potential, and mining-related information.

To boost investment, expand mineral and coal reserves, and secure raw material supply for downstream industries, the government issued Government Regulation Number 25 of 2023 on Mining Areas (WPs). This regulation grants the government authority to assign exploration and research tasks for the preparation of WPs, WIUPs (Mining Business License Areas) for Metal Minerals and Coal, and WIUPK (Special Mining Business License Areas) for coal utilization.

Under Article 3 of this regulation, areas eligible for designation as WPs must meet one or more of the following criteria:

1. Presence of rock formations known to contain minerals and/or coal.
2. Geological data indicating the potential presence of minerals and/or coal.
3. Confirmed mineral resources and reserves based on exploration data.

To further implement this, the Ministry of Energy and Mineral Resources (MEMR) issued Ministerial Regulation Number 14 of 2023, which provides guidelines for assigning exploration and research tasks. This regulation defines the minimum investigation and research standards for identifying and preparing Mining Areas and Mining Business License Areas.

Under Ministerial Regulation Number 9 of 2024, which governs the organization and work procedures of MEMR, geological explorations for WP preparation are the responsibility of the Geological Agency. These explorations provide essential data for establishing WPs and auctioning mining areas, and are carried out by the Center for Mineral, Coal, and Geothermal Resources (CMCGR) under the Geological Agency.

A key component of this process is the Delineation Map, prepared by the Geological Agency, which serves as the foundation for defining exploration and research areas. This map is an integral part of the Draft Ministerial Regulation issued by MEMR, which outlines guidelines for exploration and research assignments in the preparation of Mining Areas, Mining Business License Areas, and Special Mining Business License Areas. This regulation serves as an extension of Government Regulation Number 25 of 2023.

Currently, many Metallogeny Belts across Indonesia remain underexplored in terms of metallic mineral resource identification. To accelerate exploration and ensure the sustainable development of resources and reserves, the Geological Agency is tasked with updating the Metallogeny Map and developing a Metallic Mineral Potential Delineation Map. These initiatives aim to enhance exploration efforts, improve resource identification, and maximize Indonesia's mineral potential.

Metallogeny Belts and Magmatic Arcs in Indonesia

A metallogeny belt or metallogenic province is a linear or elongated region where metalliferous mineral deposits are concentrated. These regions are characterized by a distinct suite of mineral deposits, typically consisting of one or more types of characteristic mineralization. A single metallogeny belt may have undergone multiple episodes of mineralization over geological time, a phenomenon referred to as a metallogeny epoch.

Indonesia, an archipelagic nation comprising 17,504 islands, hosts approximately 128 active volcanoes. The formation of the Indonesian archipelago is attributed to the subduction of three major tectonic plates: the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. Convergent plate tectonic activity, including spreading, subduction, and magmatic intrusion, commenced in the Carboniferous period (~10 million years ago). These processes led to the formation of volcanic, pyroclastic, and sedimentary rock complexes, which in turn facilitated the development of volcano-magmatic arcs. The tectonic framework of Indonesia follows a predominantly convergent plate boundary model, where subduction zones are consistently associated with magmatic arcs (Hamilton, 1970; Katili, 1971).

Indonesia's Metallogeny Belts and Their Geological Evolution

Indonesia is part of two major metallogeny belts: a) The Asian Metallogeny Belt (Asian Tin Belt) and b) The New Guinea Metallogeny Belt (Porphyry Copper Belt)

Both belts, located within the Sundaland region, were formed during the Mesozoic era (250–65 million years ago) and the post-Mesozoic era, along the margins of the Eurasian continent. Additionally, the Bangka Tin Belt was established during the Triassic-Jurassic period (Mesozoic), while the Papua Cu-Au Belt developed more recently, during the Pliocene-Pleistocene period (5.5 million–55,000 years ago).

The evolution of these metallogeny belts is intrinsically linked to Indonesia's regional tectonic development, given its position at the convergence of the Eurasian, Pacific, and

Indo-Australian plates. The dynamic interplay between these plates has driven a series of tectonic and magmatic processes, including: Crustal spreading, Island arc and microplate development, Under thrusting of continental crust, Subduction of oceanic crust, Continental plate collisions, and Collisions between island arcs and continental masses.

Magmatic Arcs and Metallic Mineral Potential in Indonesia

Indonesia has identified 15 magmatic arcs formed between the Late Mesozoic and Cenozoic periods, covering a total land area of approximately 15,000 km (Figure 2.1). However, resource and reserve assessments, along with historical mining data, indicate that over 98% of Indonesia's potential metallic mineral resources are concentrated in just 7 magmatic arcs, all of which were formed during the Tertiary or later periods (Cenozoic).

Within volcanic-plutonic arc complexes, approximately 80% of Cenozoic-aged formations have been reported to contain metallic mineral deposits and metallogeny belts, primarily characterized by epithermal gold and porphyry copper mineralization (Charlie & Mitchell, 1994; Sillitoe, 1994).

The key magmatic arcs in Indonesia with significant metallic mineral deposits include:

1. Aceh Magmatic Arc
2. Sunda-Banda Magmatic Arc
3. Sumatra-Meratus Magmatic Arc
4. Central Kalimantan Magmatic Arc
5. East Sulawesi–Mindanao Magmatic Arc
6. Central Halmahera Magmatic Arc
7. Papua/Irian Jaya Magmatic Arc

These magmatic arcs serve as critical zones for mineral exploration and economic resource development, with strategic implications for Indonesia's mining policies and resource management strategies. The delineation of these metallogeny belts and magmatic arcs plays a vital role in ensuring sustainable mining practices, optimizing resource utilization, and strengthening Indonesia's position in the global minerals and mining sector.

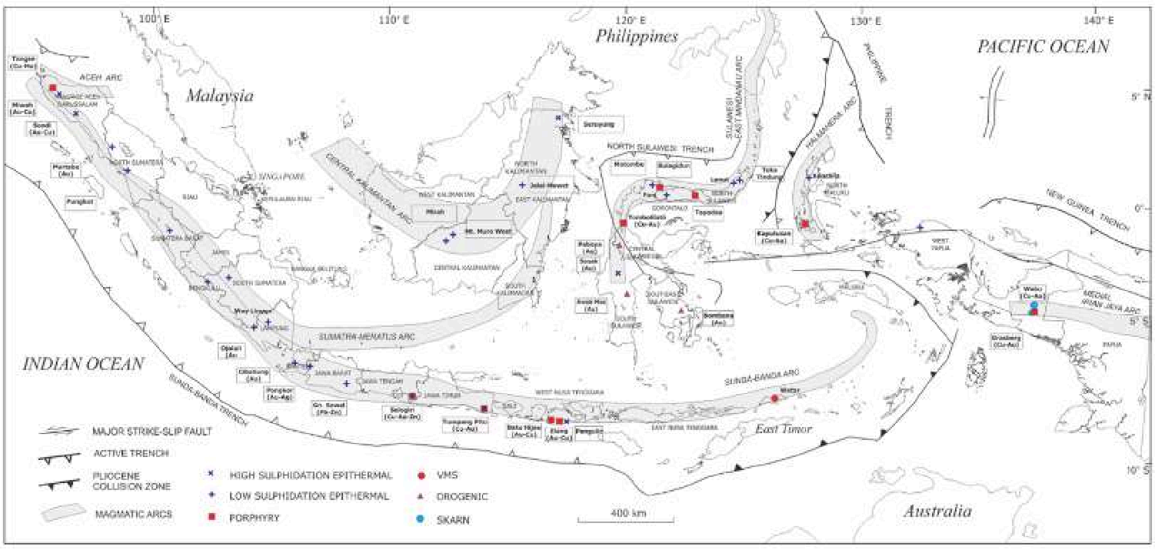

Figure 2.1 Magmatic Arc Distribution and Mineral Deposit Styles in Indonesia (Redrawn after Carlile & Mitchell, 1994; Setijadji & Maryono, 2012)

Indonesian Metallogeny Map: Development and Future Updates

In 2013, the Geological Agency published the Indonesian Metallogeny Map at a 1:5,000,000 scale (Figure 2.2), providing a comprehensive framework for understanding the country's metallogenic potential. This map is broadly categorized into five main magmatic units based on geological age: a) Neogene Magmatic Collision, b) Neogene Magmatic Arc, c) Neogene Back Arc Magma, d) Neogene Intraplate Magma, e) Pre-Tertiary Intrusive and Ophiolite.

Additionally, the map identifies six major magmatic arcs, which are:

1. Sunda-Banda Arc
2. Sumatra-Meratus Arc
3. Central Kalimantan Arc
4. Sulawesi-Mindanao-East Arc
5. Halmahera Arc
6. Papua/Irian Jaya Arc

Mineral Resource Data and Exploration Progress

According to the 2022 National Mineral Resources and Reserves Balance, 2,645 locations of 26 metal mineral commodities have been documented across Indonesia. Furthermore, the Geological Agency's mineral exploration database (2001–2022) has recorded numerous mineralized prospect areas, potential metallic mineral resources, and newly discovered types of metallic mineral deposits. These findings necessitate an update to the Indonesian Metallogeny Map, reflecting the latest advancements in exploration and geological understanding.

Despite significant progress in mineral exploration technology, the full extent of Indonesia's mineralization zones remains unexplored. Many prospective areas, particularly in remote and geologically complex regions, require further exploration. Therefore, an updated Indonesian Metallogeny Map (Figure 2.3) is essential to incorporate:

- Newly identified metallic mineral locations.
- Updated resource and reserve data.
- Enhanced geological and tectonic interpretations.
- Refined mineralization zones and belts based on tectonic age and mineral-hosting formations.
- Comprehensive classification of primary, lateritic, and placer deposits

Strategic Importance of the Indonesian Metallogeny Map

The Indonesian Metallogeny Map serves as a critical reference for mineral exploration, guiding efforts to identify new greenfield mineralization areas and optimize mineral resource management. By supporting national mineral resource development, this map plays a key role in enhancing Indonesia's mineral sector, ensuring sustainable mining practices, and strengthening economic and industrial growth.

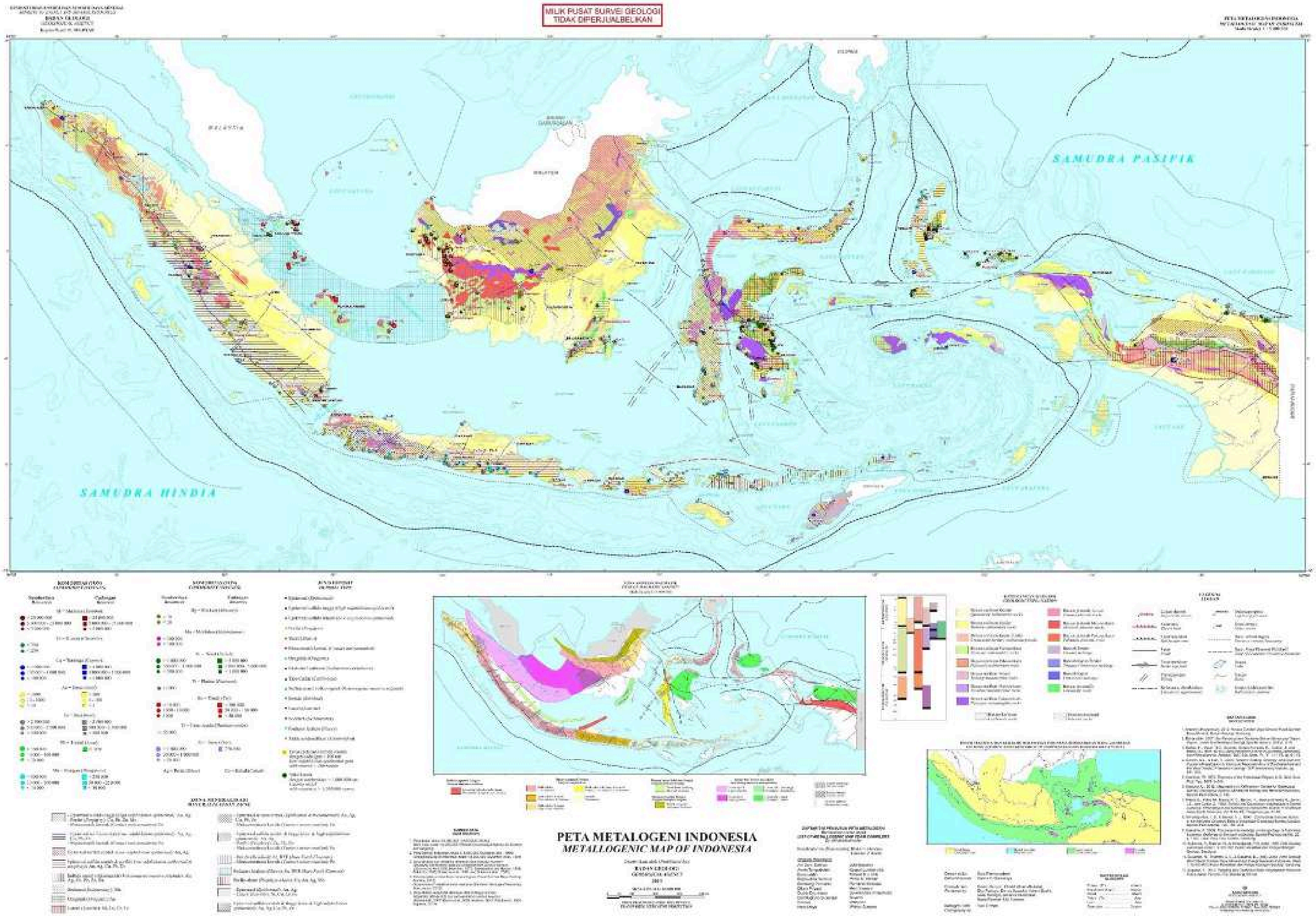

Figure 2.2 Metallogenic Map of Indonesia: Magmatic Arc Distribution and Mineral Deposits (GAI, 2013)

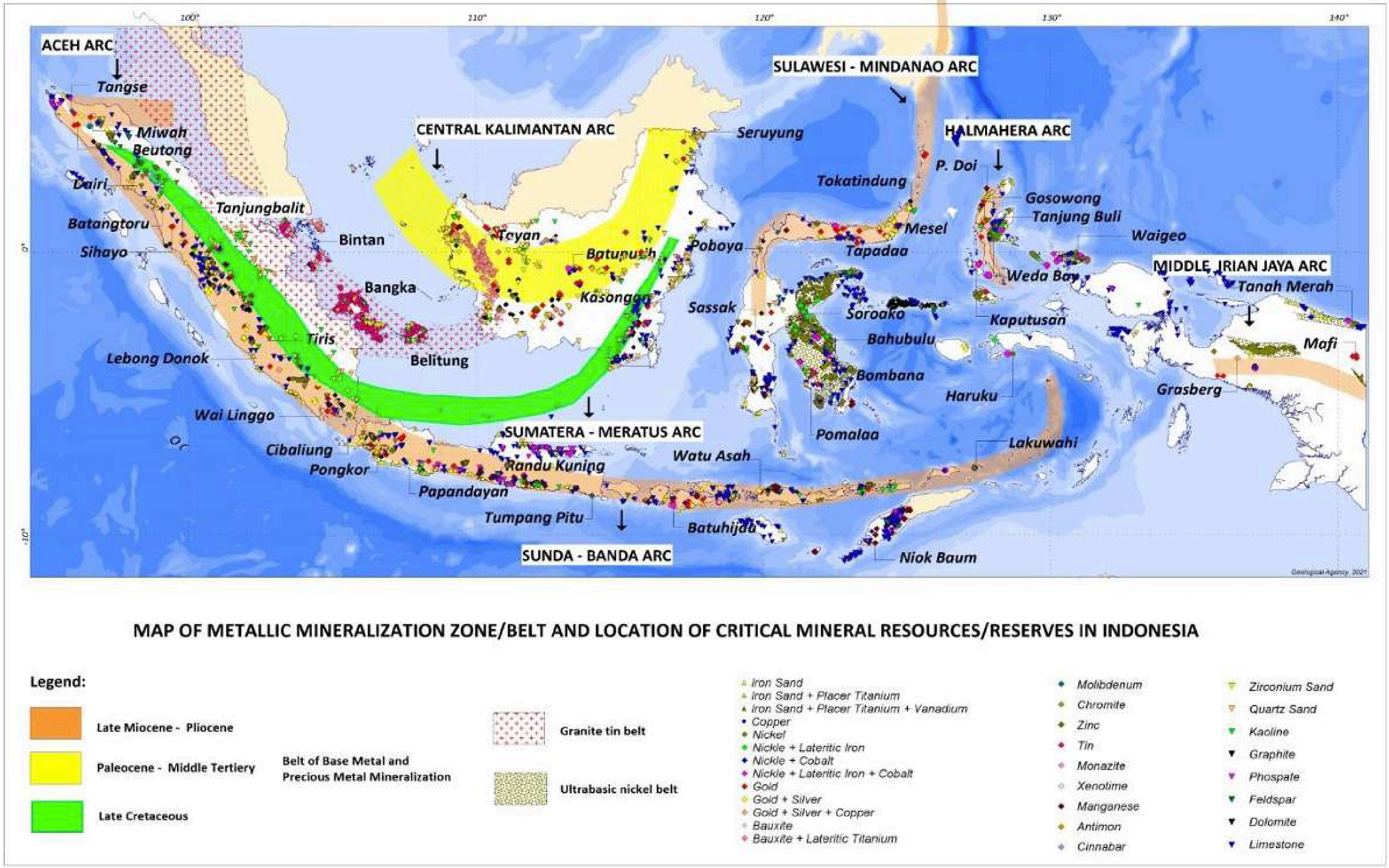

Figure 2.3 Map of Metallic Mineralization Zones and Critical Mineral Resources in Indonesia (GAI. 2022)

Conclusion

Updating the Indonesian Metallogeny Map is not merely a technical necessity but a strategic imperative for maximizing the potential of Indonesia's mineral resources. Through continuous refinement and integration of modern exploration data, the map will remain an invaluable tool for geoscientists, policymakers, and the mining industry, paving the way for future discoveries and responsible resource utilization.

Metallic Mineral Potential Delineation Map

A Metallic Mineral Potential Delineation Map is a specialized map that defines the boundary lines of potential metallic mineral occurrences, providing a spatial representation of areas with significant mineralization potential. The map is developed as an overlay integrating multiple geological datasets, including:

- Mineralized host formations
- Geochemical survey data
- 2022 Mineral Resources and Reserves Balance data
- Boundaries of IUP (Mining Business Permit), KK (Contract of Work), and KP (Mining Authorization) status as of December 2023

By incorporating these datasets, the delineation of potential mineral zones is conducted using GIS-based delineation methods combined with manual digitization techniques, ensuring high precision in identifying and mapping resource-rich areas.

Development of Metallic Mineral Potential Delineation Map

Currently, the CMCGR has compiled a series of Metallic Mineral Potential Delineation Map, each focusing on different mineral resources. These include:

1. Nickel and Other Critical Minerals Potential Delineation Map (Figure 2.4)
2. Bauxite and Other Critical Minerals Potential Delineation Map (Figure 2.5)
3. Tin and Other Critical Minerals Potential Delineation Map (Figure 2.6)
4. Gold, Copper, and Other Critical Minerals Potential Delineation Map (Figure 2.7)

These maps serve as essential tools for strategic mineral resource management, supporting exploration activities, investment planning, and policy development for critical mineral security in Indonesia. By integrating advanced geological mapping techniques, they contribute to sustainable resource utilization and enhance national mineral exploration efforts.

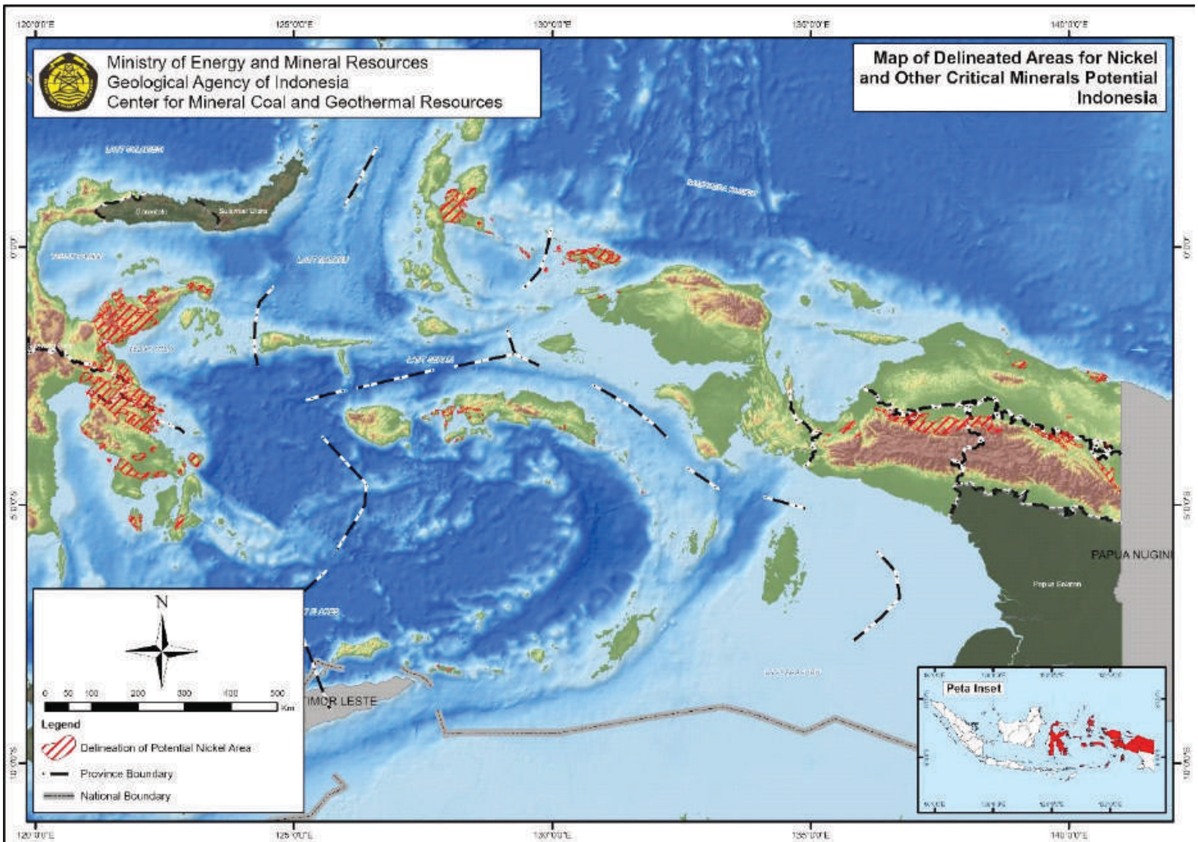

Figure 2.4 Map of Delineated Areas for Nickel and Other Critical Minerals Potential in Indonesia (GAI, 2024)

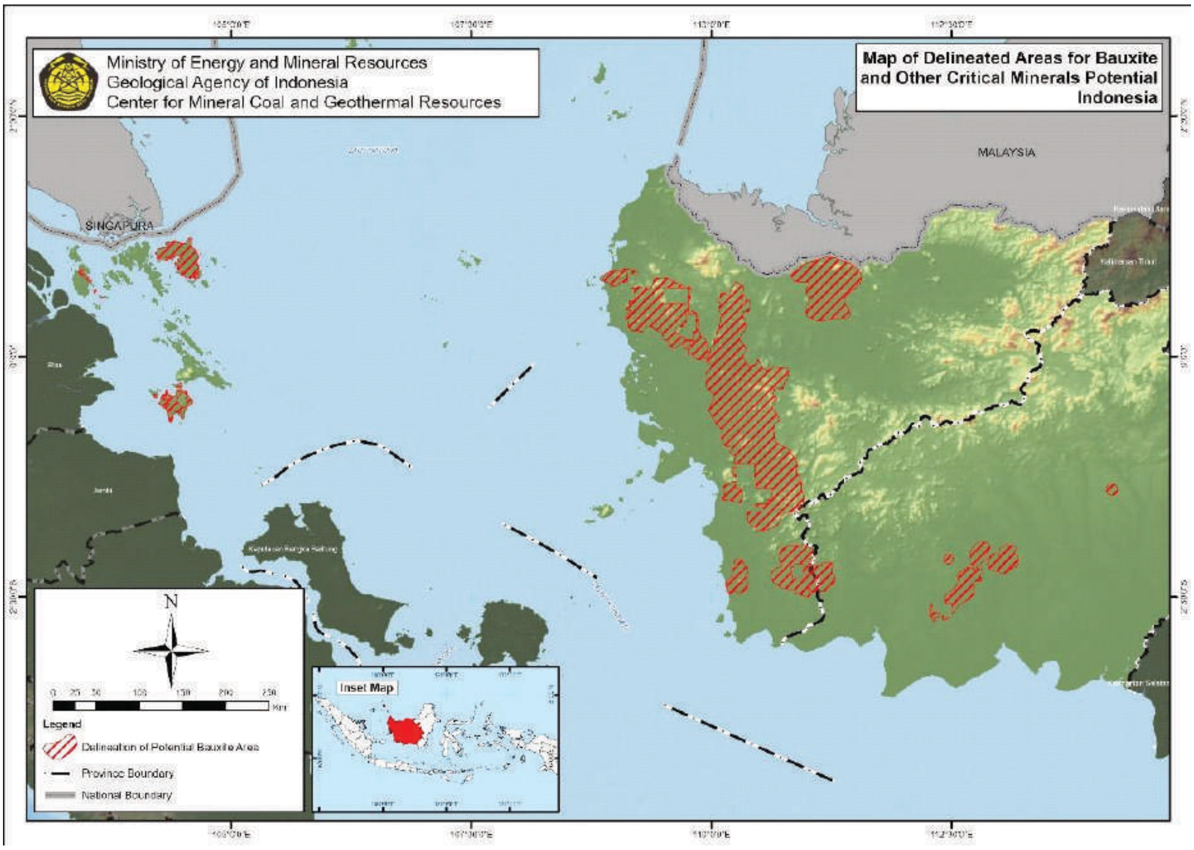

Figure 2.5. Maps of delineated Areas for Bauxite and Others Critical Minerals Potential in Indonesia (GAI, 2024)

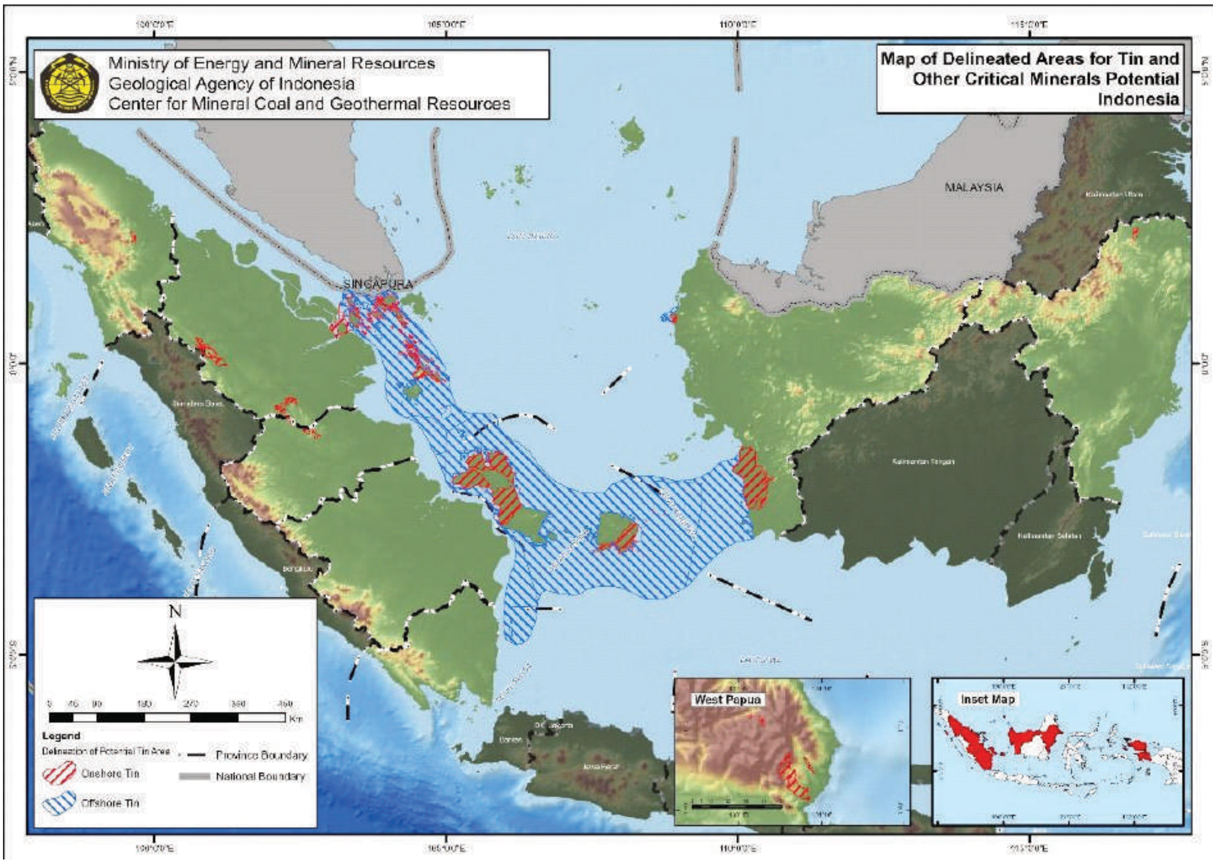

Figure 2.6. Maps of delineated Areas for Tin and Others Critical Minerals Potential Indonesia (GAI, 2024)

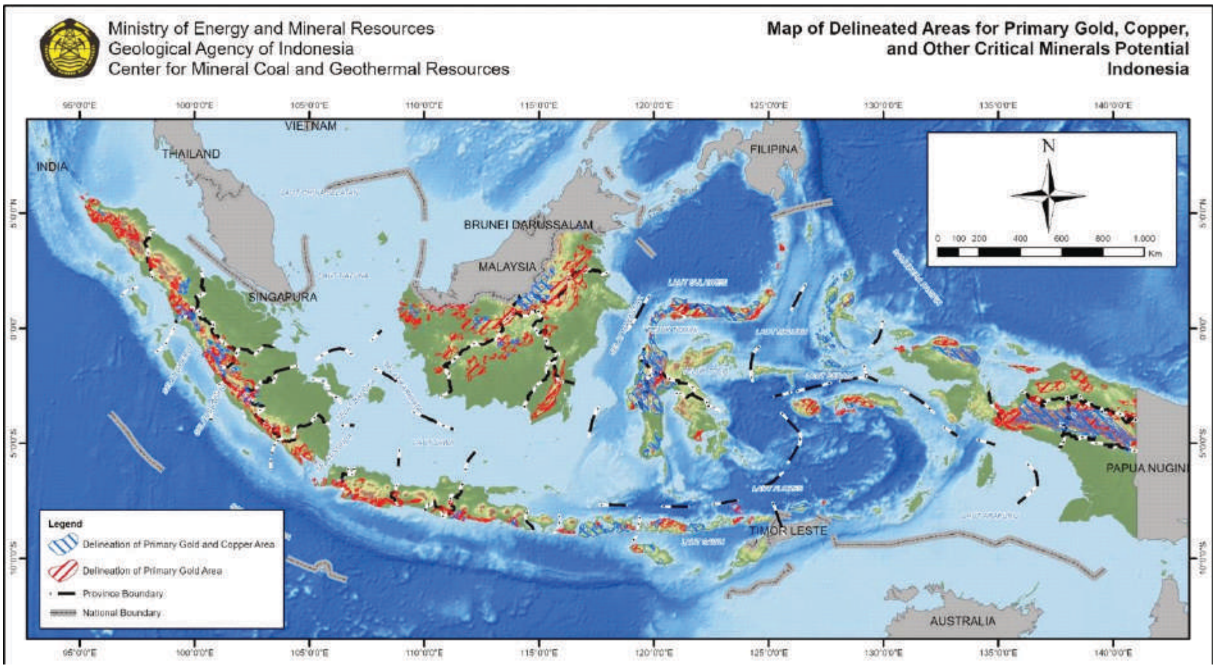

Figure 2.7. Maps of delineated Areas for Primary Gold, Cooper, and Other Critical Minerals Potential (GAI, 2024)

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3

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Copper

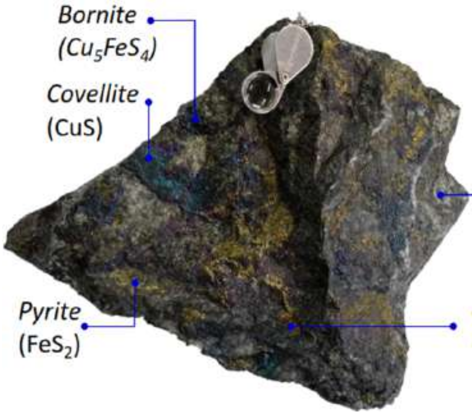

Image: Copper Ore, Grasberg, Papua
Courtesy of: CMCGR, 2023

Copper is a chemical element with the symbol Cu (derived from the Latin *cuprum*) and an atomic number of 29. It is a soft, malleable, and ductile metal with exceptionally high thermal and electrical conductivity, making it an essential material in various industrial applications. Copper is widely used in electrical wiring, plumbing, and cookware due to its excellent conductivity and resistance to corrosion. Additionally, brass (a copper-zinc alloy) and bronze (a copper-tin alloy) are two significant copper-based alloys used extensively in manufacturing and engineering (The Editors of Encyclopedia Britannica, 2024).

Copper Ore Types and Their Economic Significance

Copper occurs in nature primarily in sulfide ores and oxide ores. Sulfide ores generally contain higher copper concentrations than oxide ores, making them more economically viable for extraction. The copper in sulfide ores is also easier to separate from associated gangue minerals, making these deposits the preferred choice for large-scale copper mining operations. In contrast, oxide ores usually have lower copper content, but technological advancements such as hydrometallurgical leaching have made their extraction increasingly viable.

Major Copper Minerals

The most abundant copper-bearing mineral is chalcopyrite ($CuFeS_2$), which accounts for approximately 50% of global copper production. Other important sulfide minerals include chalcocite (Cu_2S), known for its high-grade copper content; covellite (CuS), which often forms from the alteration of other sulfides; and bornite (Cu_5FeS_4), also called "peacock ore" due to its iridescent colors.

Although sulfide ores dominate copper production, lower-grade oxide ores can still be economically mined. Important copper oxide minerals include chrysocolla ($(Cu, Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$), found in oxidized copper deposits; malachite ($Cu_2(OH)_2CO_3$), a vibrant green copper carbonate mineral; and azurite ($Cu_3(OH)_2(CO_3)_2$), a deep blue mineral often associated with malachite.

While sulfide ores remain the primary source of copper, continuous improvements in hydrometallurgical processing have expanded the use of oxide ores, ensuring the sustainable utilization of copper resources worldwide.

Copper Mineralization in Indonesia

Occurrence and Geological Setting

Copper mineralization in Indonesia is largely controlled by its position within the Pacific Ring of Fire, a geologically active region known for intense magmatic activity. The convergence of tectonic plates and associated volcanic processes have given rise to significant copper deposits, predominantly of the porphyry and skarn types, along with other hydrothermal mineralization styles such as epithermal and Volcanogenic Massive Sulfide (VMS) deposits. These deposits form through complex geological processes involving magmatic intrusion, hydrothermal fluid circulation, and metal precipitation.

Porphyry Copper Deposits: The Primary Source of Copper

Among these, porphyry copper deposits are the most economically significant due to their large ore reserves and long-term production potential. These deposits form in magmatic environments associated with intrusive igneous rocks, such as granite and diorite. The process begins when magma intrudes into the Earth’s crust and undergoes slow cooling beneath the surface. As the magma crystallizes, it releases hydrothermal fluids enriched with metallic elements, leading to the deposition of copper-bearing sulfide minerals, primarily chalcopyrite ($CuFeS_2$).

World-Class Copper Deposits in Indonesia

One of the most notable porphyry copper deposits in Indonesia is the Grasberg copper-gold deposit in Papua, considered a world-class deposit due to its high-grade ore and substantial copper and gold reserves. The Grasberg mining complex includes multiple porphyry copper deposits (Grasberg and Ertsberg Stockwork Zone) and skarn-type deposits (Kucing Liar, DOZ Block Cave, and Big Gossan).

Beyond Grasberg, several other regions in Indonesia host significant porphyry copper deposits (Hammarstrom et al., 2013), including:

Aceh – Tangse-Beutong
Central Java – Randu Kuning
East Java – Tumpang Pitu (Banyuwangi),

Tasikmadu-Trenggalek (Figure 3.1)
West Nusa Tenggara – Batu Hijau, Elang
East Nusa Tenggara – Ngada
Central Kalimantan – Baroi, Rina, Beruang Kanan, Beruang Tengah
South Sulawesi – Sasak
Gorontalo – Kayubulan, Sungai Mak, Cabang Kiri, Tapadaa, Tulabalo, Tambang Tua, Kelapa Dua
North Maluku – Kaputusan
Papua – Komopa

Figure 3.1 Copper oxide mineralization composed of malachite and azurite in the Tasikmadu area, Trenggalek Regency, East Java Province (Heditama, et al., 2022)

These deposits play a critical role in Indonesia's mining industry, contributing to both domestic demand and global copper supply. Given Indonesia's rich geological potential, ongoing exploration and technological advancements are expected to further enhance copper resource development in the country.

Skarn Copper Deposits

Skarn deposits are an important source of copper, comparable in significance to porphyry copper deposits. These deposits form at the contact zone between magmatic intrusive rocks and carbonate-rich sedimentary rocks. When magma intrudes into carbonate formations, it triggers contact metamorphism, leading to the formation of copper-bearing minerals such as chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4).

Notable skarn deposits in Indonesia include those in Papua, such as Kucing Liar, DOZ Block Cave, and Big Gossan, which are part of the world-class Grasberg mining complex. Skarn copper deposits are also present in Kalimantan and Sumatra, including the Batahan area in West Sumatra, which has been identified as a prospective mineralized zone.

Epithermal Copper Deposits

Unlike porphyry and skarn deposits, which have the potential for large-scale copper mineralization, epithermal copper deposits are generally smaller in scale. These deposits form at shallow depths under lower temperature conditions, typically associated with volcanic activity. Hydrothermal fluids originating from shallow magma chambers migrate through fractures in the Earth's crust, depositing copper along with other metals, such as gold and silver.

Epithermal copper deposits in Indonesia are commonly found in volcanic regions of Sumatra and Sulawesi. A significant example is the Dunu area in Monano District, North Gorontalo Regency, Gorontalo Province, which hosts epithermal copper mineralization with grades reaching up to 8.69% Cu (Nugraha, R., S., and Putra, E., 2023) (Figure 3.2).

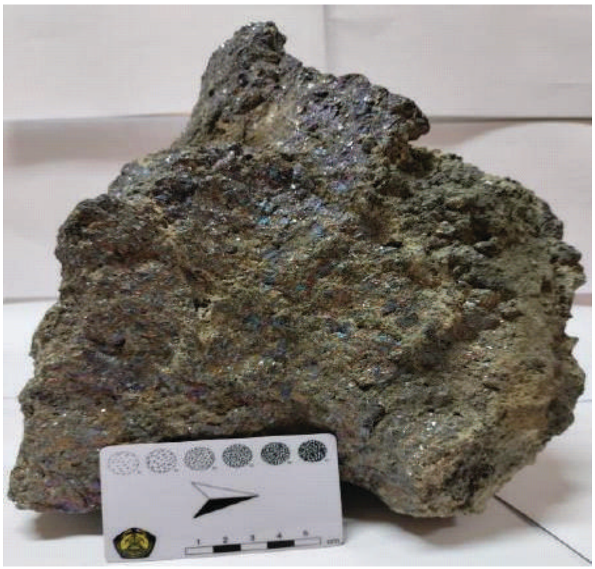

Figure 3.2 Copper mineralization; chalcopyrite, bornite, and azurite vein-type (epithermal) in the Dunu area, Monano District, North Gorontalo Regency, Gorontalo Province (Nugraha, et al., 2023)

Volcanogenic Massive Sulfide (VMS) Deposits

In addition to porphyry, skarn, and epithermal copper deposits, Indonesia also has Volcanogenic Massive Sulfide (VMS) deposits, which hold significant exploration potential, particularly in the Flores region of East Nusa Tenggara. These deposits typically form in submarine volcanic environments, where hydrothermal vents release copper- and sulfur-rich fluids that precipitate onto the seafloor, forming sulfide mineral deposits.

The formation of VMS deposits involves the interaction between copper-rich hydrothermal fluids and cold seawater, which causes rapid precipitation of copper sulfide minerals on the ocean floor. This process leads to the accumulation of stratiform sulfide layers rich in copper, zinc, and lead, often forming extensive mineralized zones.

Indonesia’s Copper Resource Distribution

According to the 2023 Mineral Resource and Reserve Inventory, 104 locations of copper resources and reserves have been identified across 20 provinces in Indonesia. These deposits, spread across Sumatra, Sulawesi, Papua, Kalimantan, and East Nusa Tenggara, represent a strategic national asset for copper production and exploration. As demand for copper continues to grow globally, further geological surveys and advanced exploration techniques will be crucial in unlocking Indonesia’s full mineral potential.

Global Copper Reserves and Indonesia’s Position

According to the 2024 USGS report, the top 10 countries with the largest copper reserves in the world in 2023 are presented in Figure 3.3. Indonesia ranks 10th globally, with copper reserves totaling 24 million tons, accounting for approximately 2.4% of the world’s total copper reserves.

Chile holds the largest copper reserves globally, with an estimated 190 million tons, representing 19% of total global reserves. This makes Chile the leading copper reserve holder in 2024, further reinforcing its position as a dominant player in the global copper market.

Figure 3.3. Top 10 Countries with the Largest Copper Reserves in the World (2023) (USGS, 2024)

Copper Resources, Reserves, and Production in Indonesia

Indonesia's total copper ore resources amount to 16.5 billion tons, distributed across different resource classifications: a) Inferred resources: 8.3 billion tons, b) Indicated resources: 5.5 billion tons, and c) Measured resources: 2.7 billion tons.

In addition, Indonesia's total copper ore reserves stand at 2.8 billion tons, categorized into: a) Probable reserves: 1.8 billion tons and b) Proven reserves: 1 billion tons

In terms of metal content, Indonesia's total copper metal resources amount to 70.6 million tons, while total copper metal reserves reach 21.4 million tons. A detailed breakdown of copper ore resources and reserves by province is presented in Figure 3.4.

Key Copper Deposits in Indonesia

Most Indonesia's copper resources and reserves are concentrated in West Nusa Tenggara and Papua provinces.

West Nusa Tenggara hosts significant copper deposits at the Batu Hijau and Elang mines, both of which are key contributors to Indonesia's copper production.

Papua is home to Indonesia's largest copper deposit, located at the Grasberg Mine, operated by PT Freeport Indonesia. Grasberg is recognized as one of the world's most productive copper and gold mining complexes.

A comprehensive chart detailing total copper ore and metal resources and reserves by province in 2023 is provided in Figure 3.4, while Figure 3.5 illustrates the distribution of locations with copper ore resources and reserves across Indonesia.

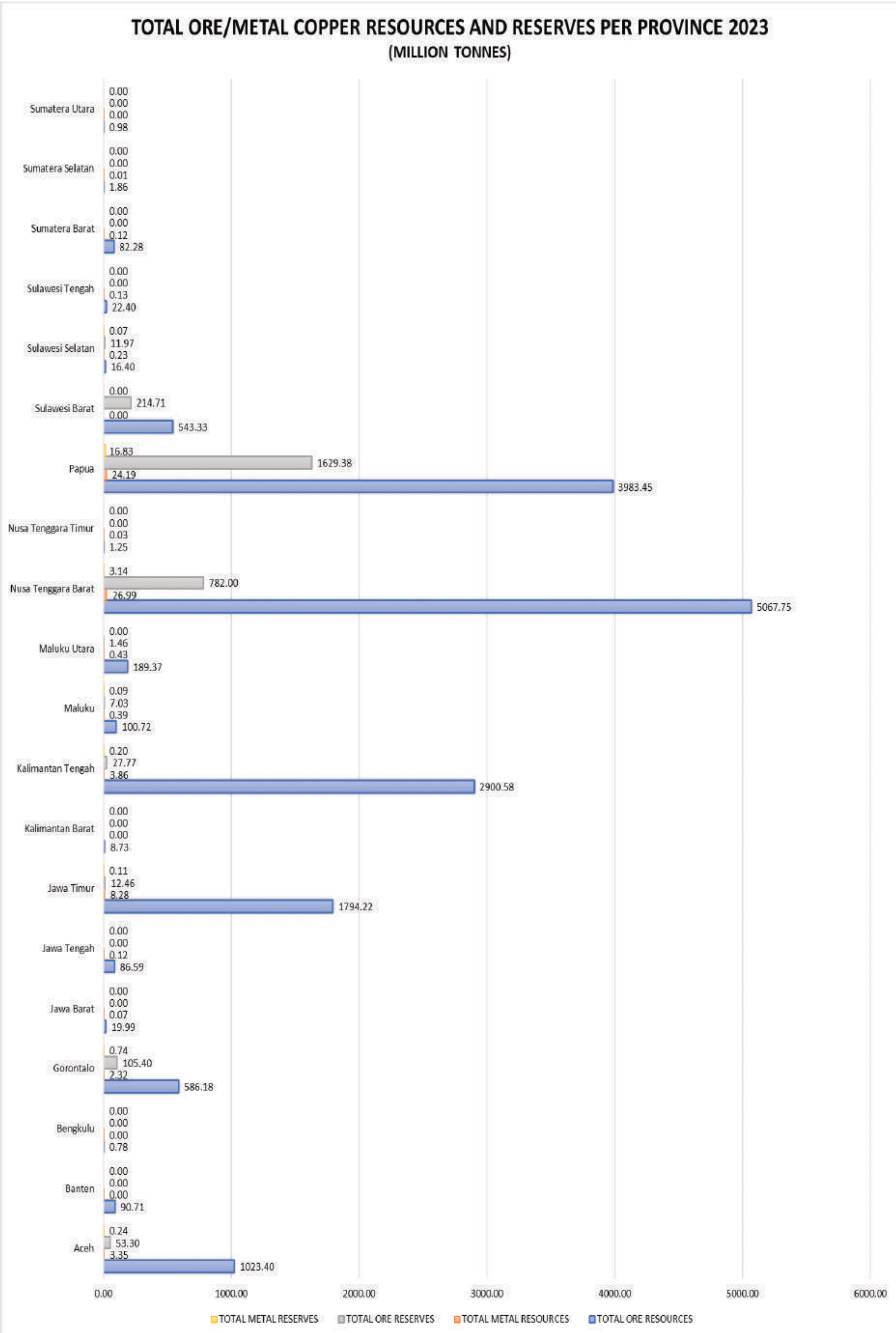

Figure 3.4 Total Copper Ore and Metal Resources and Reserves by Province in 2023 (Million Tonnes) (Nursahan, et al., 2024).

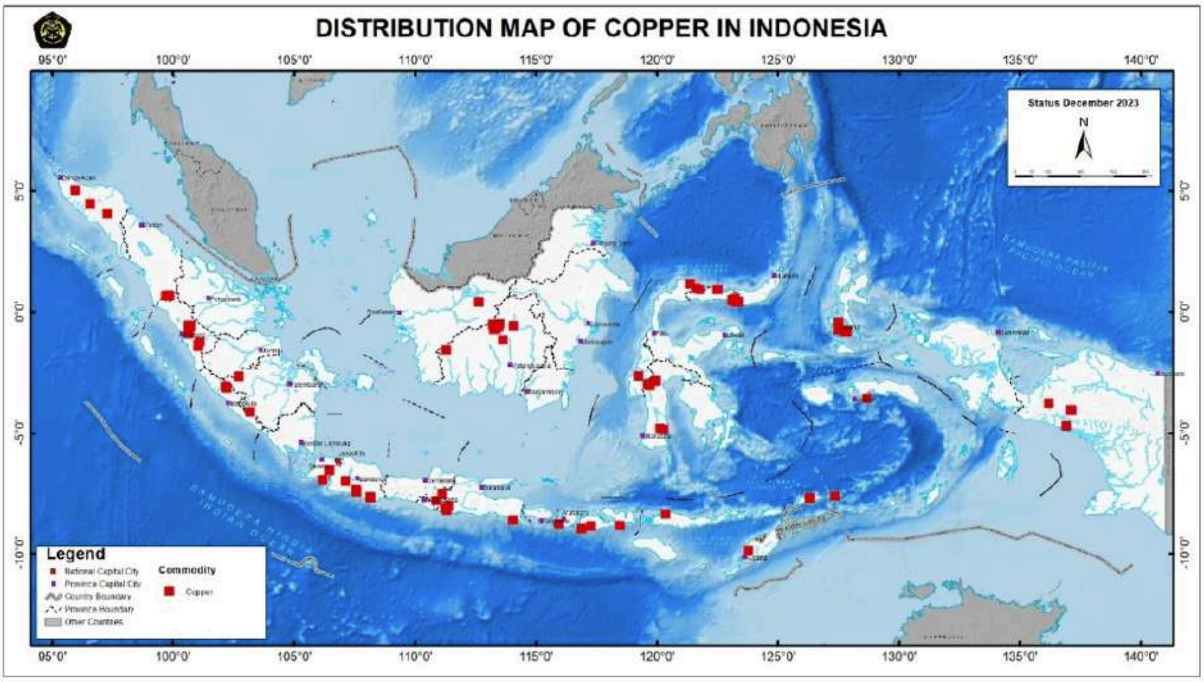

Figure 3.5 Distribution of copper ore resource locations in Indonesia (GAI, 2024)

Trends in Copper Ore Resources, Reserves, and Production in Indonesia

Resource and Reserve Development (2019–2023)

Over the past five years, from 2019 to 2023, the development of copper ore resources and reserves in Indonesia has exhibited a gradual upward trend, despite experiencing a decline in 2021. While total estimated reserves have shown a moderate decline, proven reserves have recorded a slight increase, indicating continued exploration and reserve classification adjustments.

In 2023, total copper ore resources increased by 719.5 million tons, whereas total copper ore reserves decreased by 191.2 million tons compared to 2022 (Figure 3.6 and Figure 3.7). This trend suggests ongoing resource exploration, reclassification of reserves, and possible depletion due to mining activities.

National Copper Ore Production and Reserve Sustainability

Indonesia's national copper ore production capacity in 2023 was recorded at 132 million tons per year, sourced from major mining companies, including: PT Amman Mineral Nusa Tenggara (AMNT), PT Freeport Indonesia (FI), PT Batutua Tembaga Raya (BTR), and PT Kalimantan Surya Kencana (KSK)

Assuming a constant production rate and considering Indonesia's total copper ore reserves of 2.8 billion tons, the estimated lifespan of copper reserves is projected to extend until 2044, or approximately 22 years (Figure 3.8).

This estimation is based on the 2020 RKAB Long-Term Plan from the Directorate General of Mineral and Coal, as well as data from the 2023 Mineral Resources and Reserves Balance Sheet from Geological Agency.

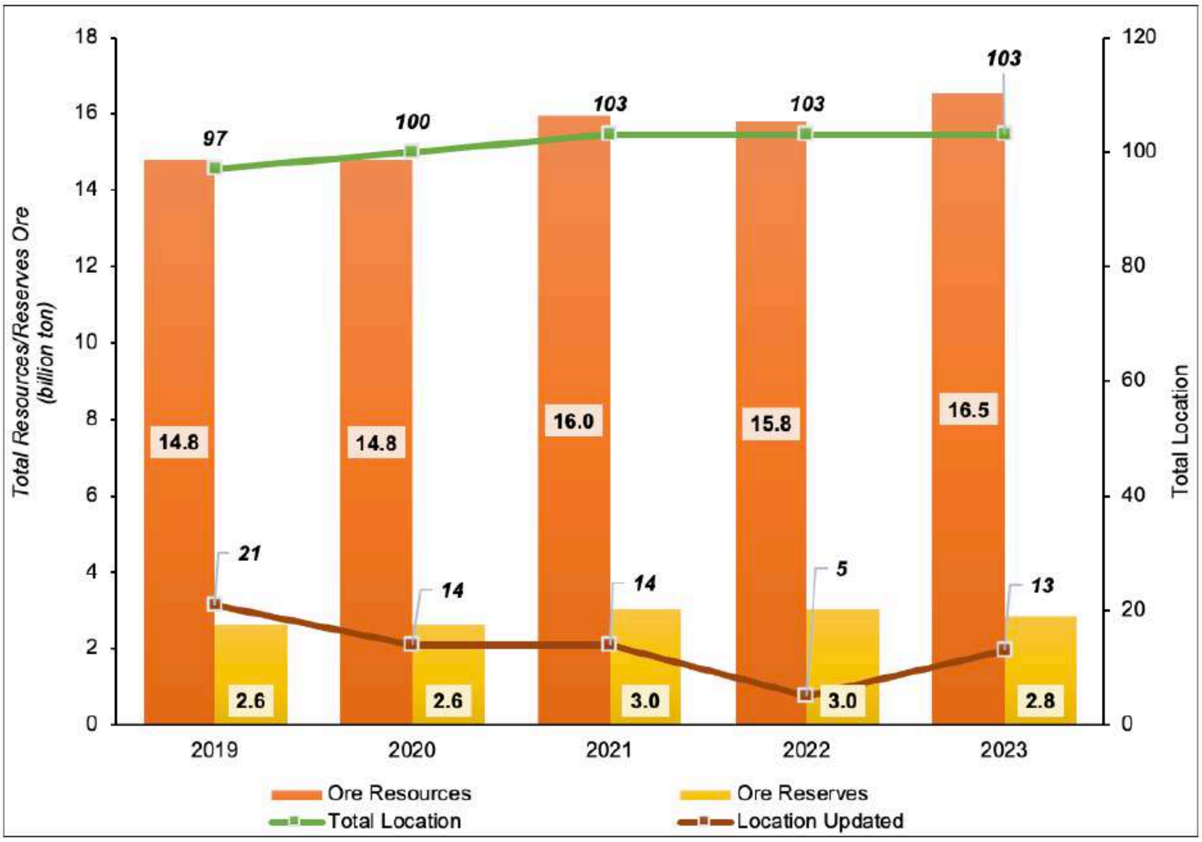

Figure 3.6 Trends in Copper Ore Resources and Reserves (Nursahan, et al., 2024)

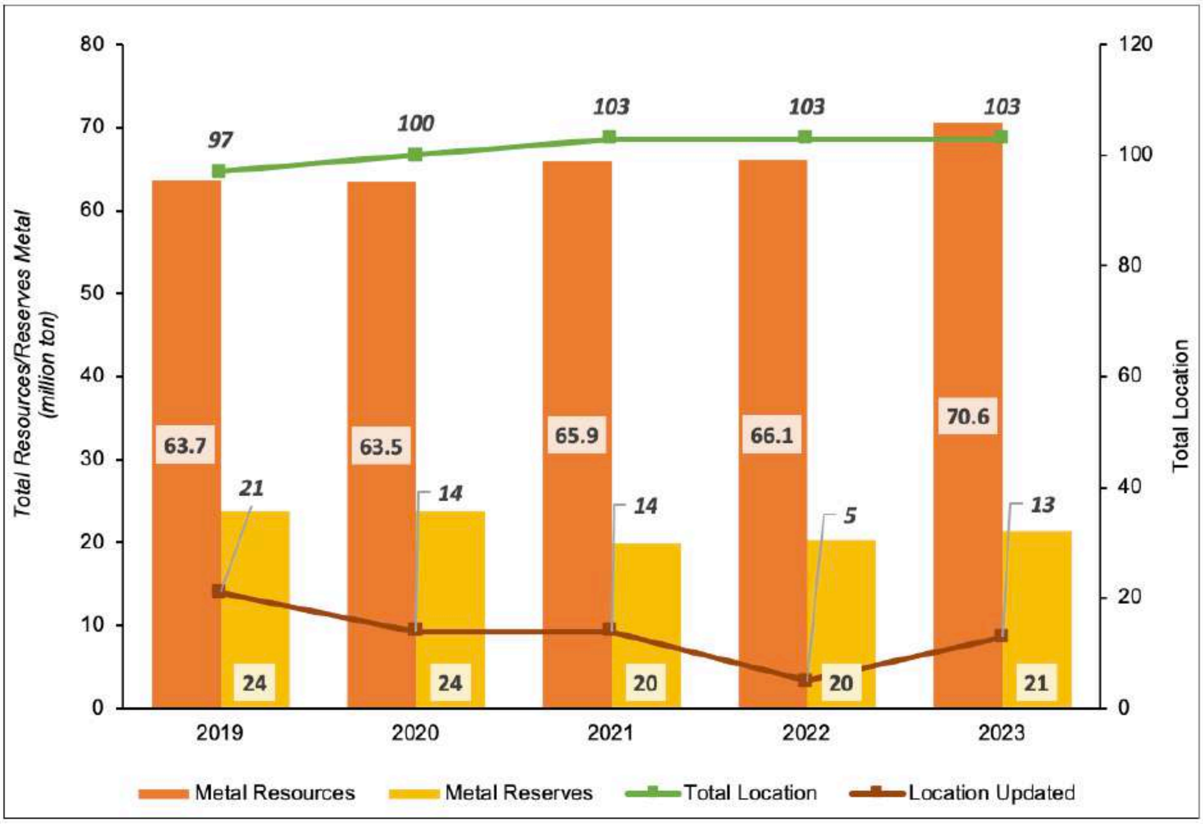

Figure 3.7 Trends in Copper Metal Resources and Reserves (Nursahan, et al., 2024)

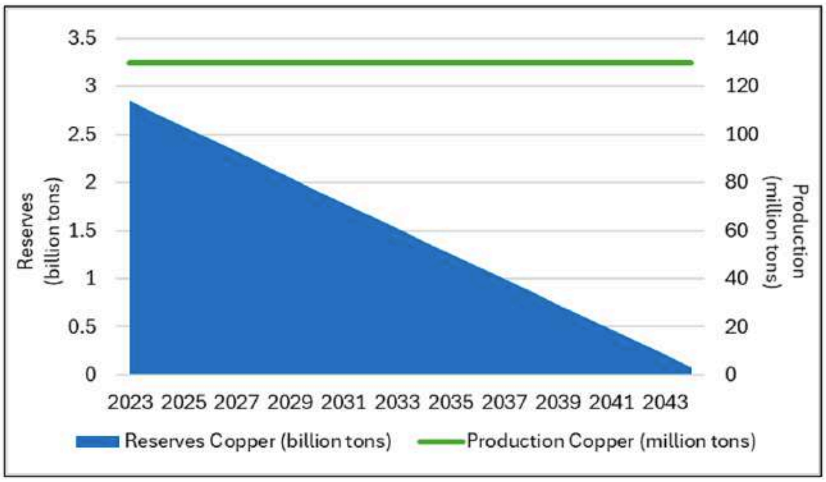

Figure 3.8 Projected Depletion of Copper Reserves and Production Trends (2023-2043) (Nursahan, et al., 2023)

Copper Concentrate Production (2019 - 2023)

According to data from the 2023 USGS Minerals Yearbook (January 2024 edition), Indonesia's copper concentrate production (in metric tons) from 2019 to 2023 was as follows:

- 2019: 334 thousand metric tons
- 2020: 269 thousand metric tons
- 2021: 290 thousand metric tons
- 2022: 310 thousand metric tons
- 2023: 200 thousand metric tons

This production output, illustrated in Figure 3.9, reflects fluctuations in mining operations, export regulations, and market demand. The primary sources of Indonesia's copper concentrate are two world-class mines: Grasberg in Papua, operated by PT Freeport Indonesia, and Batu Hijau in Sumbawa, owned by PT Medco Energi International.

Indonesia's copper industry plays a strategic role in the global supply chain, and continuous exploration, technological advancements, and sustainable resource management will be crucial in ensuring long-term copper production and economic growth.

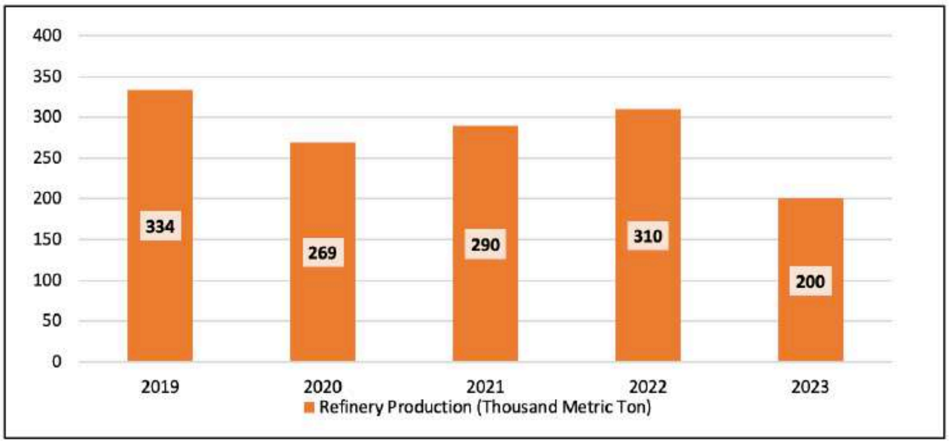

Figure 3.9 Trends in Copper Concentrate Production (2019-2023) (Nursahan, et al., 2024)

Trends and Challenges in Indonesia's Copper Industry

Global Copper Prices and Indonesia's Export Policy

As of October 2024, global copper concentrate prices have experienced a notable increase, impacting Indonesia's Export Reference Price (HPE) for copper. The Ministry of Trade applies this price adjustment to mining products subject to export duties, ensuring that export tariffs align with market trends. In addition to copper, other base metals such as zinc and lead concentrates have also seen price increases, whereas some commodities, like lateritic iron, have declined. These fluctuations are driven by changes in global demand and volatility in international markets (Prayudhia, M. C. G., 2024).

A key policy shaping Indonesia's mining industry is the requirement for domestic mineral processing before export, particularly for copper. This initiative aims to enhance the value of Indonesia's mineral exports, strengthen the domestic downstream industry, and potentially influence global copper prices (Prayudhia, M. C. G., 2024).

Projected Global Copper Demand (2026–2040)

Global copper consumption is expected to rise significantly by 2040, with an average annual growth rate of 1.7% from 2026 to 2040. By 2040, total global demand for copper is projected to reach 33 million tons, with China alone accounting for approximately 50% of this demand. The rapid expansion of green technologies, including electric vehicles (EVs), renewable energy infrastructure, and energy storage systems, is expected to drive a 40% increase in copper demand for clean energy applications (Wood Mackenzie, 2020, as cited in Mitchell, 2022) (Figure 3.10). According to the International Energy Agency (IEA, 2021), the projected total copper demand for clean energy technologies is illustrated in Figure 3.11.

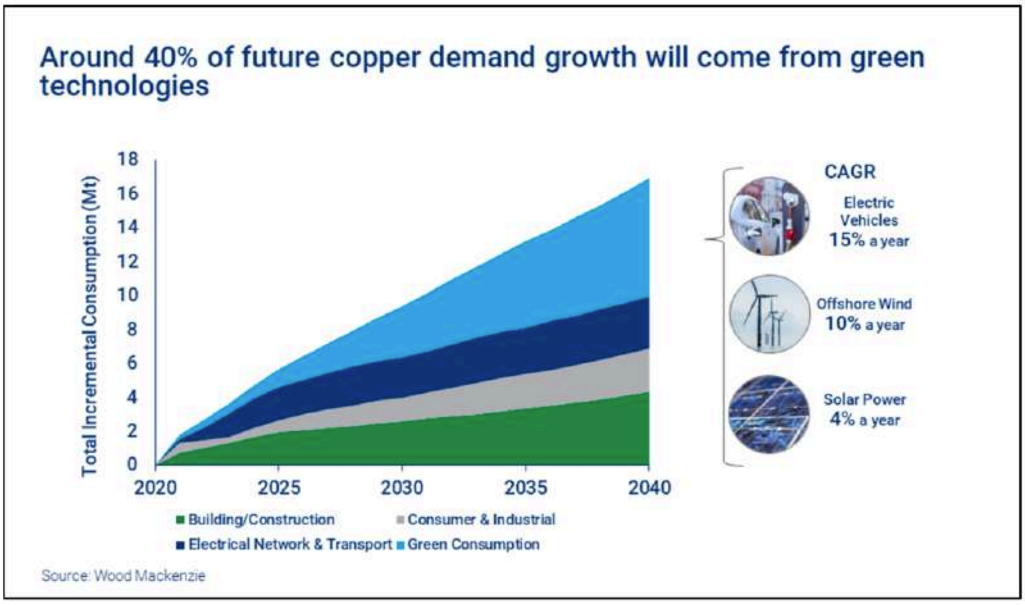

Figure 3.10 Projected Copper Demand Growth: 40% Attributed to Green Technologies (Wood Mackenzie, 2020, as cited in Mitchell, 2022)

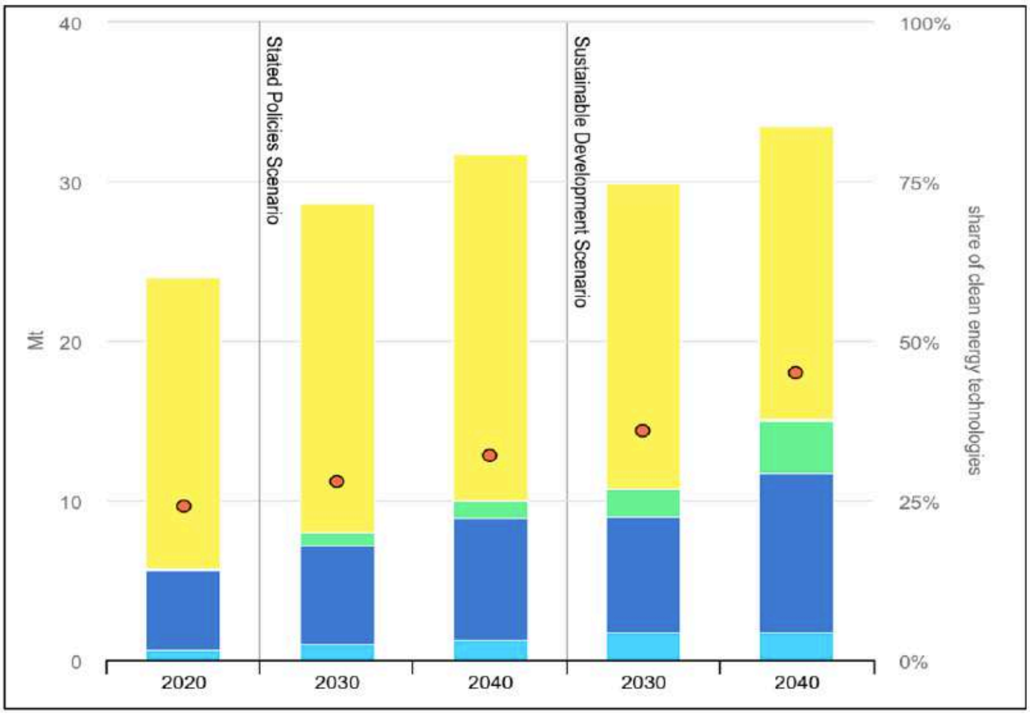

Figure 3.11 Scenario of copper demand for clean energy 2040 (IEA, 2021)

Sustainability of Indonesia's Copper Reserves and the Need for Exploration

Indonesia's copper ore reserves, currently estimated at 2.8 billion tons, are projected to be depleted within 22 years, reaching exhaustion by 2044 under current extraction rates. Given the projected global copper demand surge, securing new reserves is imperative to sustain Indonesia's role in the international copper market.

To address this challenge, Indonesia must intensify exploration efforts in both greenfield and brownfield areas:

Greenfield Exploration – Focused on identifying new, undiscovered copper deposits in unexplored regions.
Brownfield Exploration – Targeted at upgrading existing resources and reserves through advanced geological surveys and technological improvements.

By expanding exploration activities, Indonesia can ensure long-term resource sustainability, strengthen its mining industry, and continue contributing to global copper supply chains.

Trends in Copper Cathode Production and Consumption

An analysis of copper cathode production and consumption trends over the past five years (Figure 3.12) reveals several key insights:

Rising Domestic Demand (2022): There was a notable increase in domestic demand for copper cathodes in 2022, driven primarily by copper wire manufacturers, including PT Karya Sumiden Indonesia, PT Tembaga Mulia Semanan, and PT Kabel Metal Indonesia.

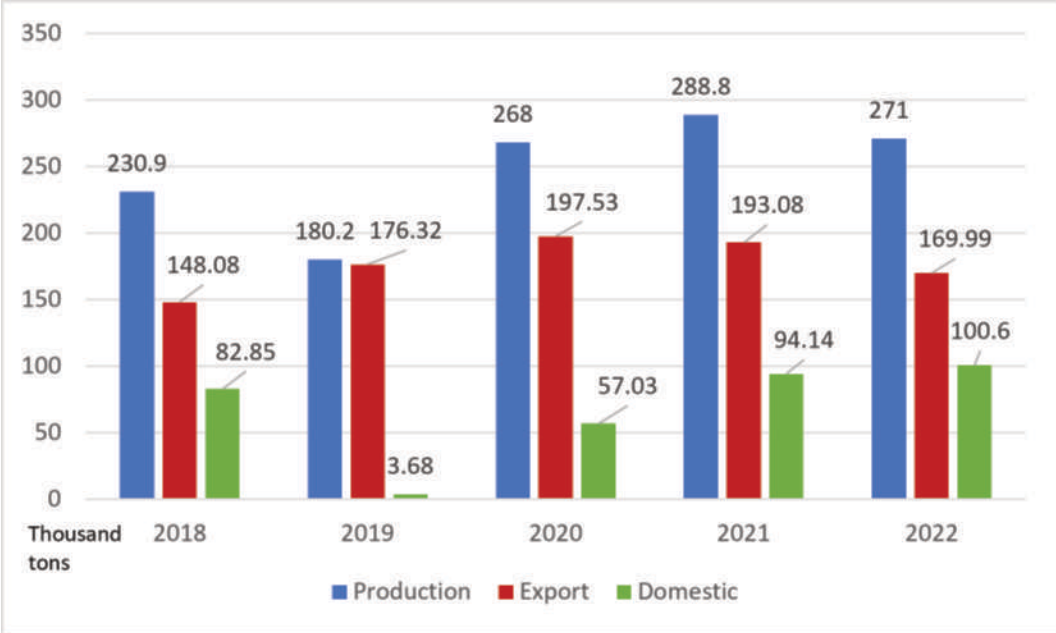

Figure 3.12 Copper Cathode Production, Export, and Domestic Consumption Trends (2018-2022) (GAI, 2023)

Limited Absorption by Downstream Industries: Despite growing domestic demand, Indonesia's downstream industries have not yet fully absorbed locally produced copper cathodes, leading to a continued reliance on exports.

Key Export Destinations: The largest export markets for Indonesian copper cathodes include Thailand, Malaysia, and Vietnam, highlighting the region's dependence on Indonesian copper supply.

The Future of Indonesia's Copper Production and Global Supply Chain Influence

Starting in 2024 and for the foreseeable future, Indonesia's role in the global copper market will become increasingly significant, particularly due to the expansion of domestic smelting capacity. Indonesia is set to operate some of the largest cumulative copper cathode production facilities globally, led by three world-class smelter companies: PT Smelting, PT Freeport Indonesia, and PT Amman Mineral Industri.

With the commencement of full-scale operations at these smelters, Indonesia will emerge as a major global supplier of refined copper products, significantly impacting international copper prices. The projected copper cathode production capacity is estimated to reach one million tons per year, positioning Indonesia as the world's largest copper cathode producer (Alfan, S.I., 2023).

As Indonesia strengthens its position in the copper value chain, the country's downstream processing policies and industrial expansion will not only enhance its economic growth but also reshape the global copper supply landscape, influencing commodity pricing and trade dynamics.

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4

Lead - Zinc

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Image: Lead - Zinc Ore
Courtesy of: https://ausenco-www-staging.s3.amazonaws.com/upload/user/image/dairi-lead-zinc-project_Image120170922185620687.jpg

Lead (Pb): Properties and Occurrence

Lead (Pb) is a heavy metal with an atomic number of 82 and is relatively abundant in the Earth's crust. It is soft, highly malleable, and has a greyish metallic luster at room temperature. Despite its industrial significance, lead is also known for its toxicity and environmental hazards (Smith et al., 2023).

Lead occurs in nature primarily as lead ore minerals, with galena (PbS) being the most abundant, containing approximately 86.6% Pb. Other important lead ores include cerussite ($PbCO_3$), which consists of 77.6% Pb, and anglesite ($PbSO_4$), which contains 68.2% Pb. The standard method for extracting lead involves roasting the ore to produce lead oxide, reducing the oxide with carbon, and distilling the metal (Jones et al., 2023).

Zinc (Zn): Properties and Occurrence

Zinc (Zn) is a transition metal with an atomic number of 30 and ranks as the 24th most abundant element in the Earth's crust. It is brittle at room temperature but becomes malleable when heated, with a lustrous greyish appearance. Zinc plays a crucial role in medicine, industry, and agriculture due to its ability to form various compounds with essential applications (Smith et al., 2023).

Zinc is found in multiple ore minerals, with sphalerite (ZnS) being the most economically significant, containing 38–67% Zn. Other important zinc ores include smithsonite ($ZnCO_3$) at 52% Zn, hemimorphite

($Zn_4Si_2O_7(OH)_2 \cdot H_2O$) at 54% Zn, willemite ($Zn_2SiO_4$) at 58.5% Zn, and franklinite ($(Zn, Mn, Fe)_2O_4$), which contains 27.2% Zn. The extraction process involves roasting the ore to form zinc oxide, reducing it using carbon or coal, and then distilling the metal (Jones et al., 2023). The minimum economic grade for lead and zinc ores typically falls between 6% and 10%, depending on market conditions and extraction costs.

Industrial Applications of Lead and Zinc

Lead is extensively used in its metallic form, with nearly 50% of global production dedicated to lead-acid battery manufacturing, particularly for automobiles, renewable energy storage, and backup power systems. It is also essential for radiation shielding in medical imaging and nuclear facilities, as well as alloy manufacturing in solders, bearings, and ammunition. The remaining 50% of lead production is utilized in compounds for applications in paint, ceramics, and chemicals, although its use has been significantly restricted due to health and environmental concerns.

Similarly, zinc is primarily used in its metallic form, with about 75% of global zinc production allocated for galvanization, which protects iron and steel from corrosion. Zinc is also widely used as an alloying element in brass, bronze, and zinc-based alloys, as well as in structural applications such as zinc roofing and cladding. The remaining 25% of zinc production is utilized in chemical, rubber, paint, and agricultural industries, particularly as zinc oxide in coatings and fertilizers.

With the increasing demand for lead and zinc, particularly in battery technology, construction, and industrial coatings, sustainable mining and resource management are critical to ensuring long-term supply stability and minimizing environmental impact.

Formation of Lead (Pb) and Zinc (Zn) Deposits

The formation of lead (Pb) and zinc (Zn) deposits is closely linked to magmatic-hydrothermal processes, which play a crucial role in concentrating these metals into economically viable ore bodies. In Indonesia, lead and zinc deposits are found in various geological settings, each associated with distinct mineralization processes (Figure 4.1).

Sedimentary - Exhalative (SEDEX) Deposits

SEDEX (Sedimentary-Exhalative) deposits, also known as syngenetic hydrothermal deposits, form on shallow seabed where hydrothermal fluids exude from the seafloor and precipitate sulfide minerals rich in lead and zinc within sedimentary basins. These deposits typically occur in fine-grained sedimentary rocks, such as shales and carbonates, and are often characterized by stratiform mineralization. One of Indonesia's most significant SEDEX deposits is in Dairi, North Sumatra, which hosts high-grade lead-zinc sulfide mineralization.

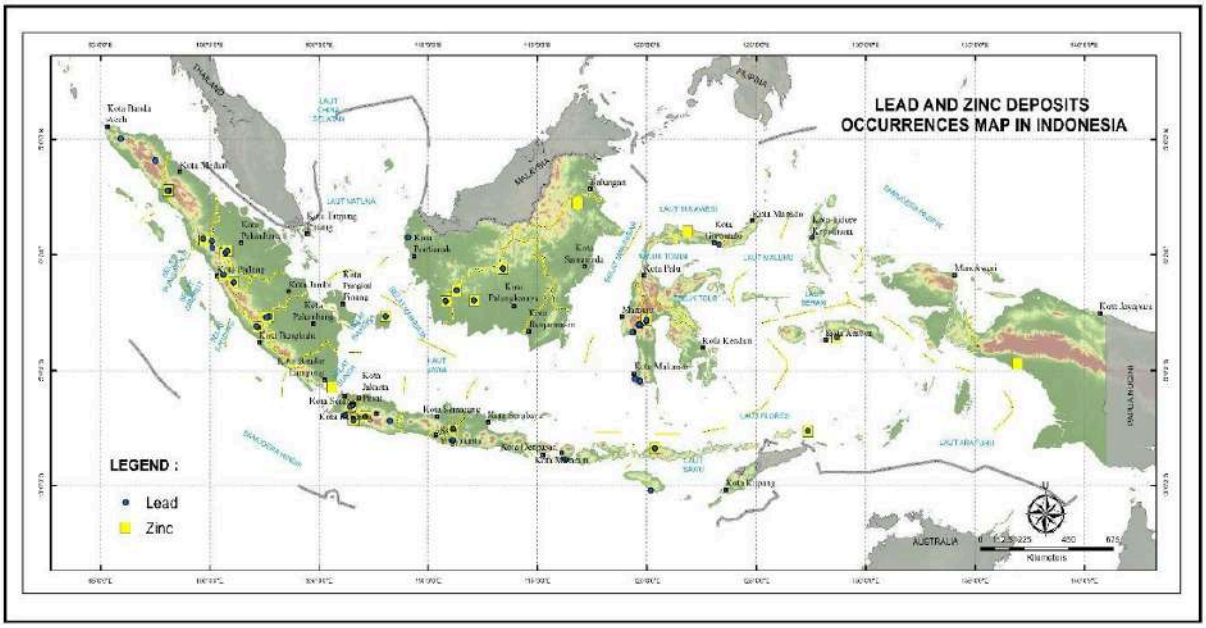

Figure 4.1 Distribution map of lead and zinc resources and reserves in Indonesia (Dana et al., 2022; van Leuween, 2018)

Volcanogenic Massive Sulfide (VMS) Deposits

Volcanogenic Massive Sulfide (VMS) deposits are polymetallic sulfide-rich ore bodies that form on the ocean floor in association with submarine volcanic activity. These deposits result from hydrothermal vents, also known as "black smokers," which release metal-rich fluids that precipitate upon contact with cold seawater. Over time, this leads to the accumulation of zinc, lead, copper, and other metals in layered sulfide deposits. In Indonesia, a significant example of this type of deposit is found on Wetar Island, where VMS mineralization is actively explored.

Skarn Deposits

Skarn deposits form through hydrothermal-magmatic interactions between carbonate-rich sedimentary rocks and intruding igneous bodies. As hydrothermal fluids permeate carbonate formations, metasomatic reactions lead to the development of lead-zinc sulfide minerals alongside other metallic ores such as copper and iron. Notable skarn deposits in Indonesia include Takengon, Cihaur, and Batu Hijau. Recent geological investigations indicate that lead and zinc ore exploration is ongoing in Ruwai, Central Kalimantan, which is emerging as a promising mineralized zone (Dana et al., 2022; van Leuween, 2018).

Vein-Type Deposits

Vein-type deposits form through hydrothermal alteration, where mineral-rich fluids migrate through rock fractures and deposit lead-zinc sulfides along fault zones, shear zones, or fracture networks. These deposits are commonly associated with magma intrusions and are often enriched in silver, gold, and copper as well. In Indonesia, Grasberg (Papua) and Gorontalo (Sulawesi) are key locations exhibiting vein-hosted lead-zinc mineralization, often occurring alongside gold and copper mineralization in epithermal and porphyry systems.

Conclusion

The diverse geological environments across Indonesia provide a rich potential for lead and zinc mineralization, spanning sedimentary, volcanic, and intrusive rock settings. Each deposit type presents unique exploration and extraction challenges, but advancements in geological surveys, remote sensing, and geochemical analysis continue to enhance the identification of new reserves. As global demand for lead and zinc grows, understanding these formation processes will be critical for ensuring sustainable mining and resource development in Indonesia.

Resources, Reserves, and Production of Lead (Pb) and Zinc (Zn) in Indonesia

Lead Resources and Reserves

Indonesia's lead resources and reserves are distributed across 48 locations, with a total inferred resource of 2.55 billion tons. This includes 1.49 billion tons of inferred ore resources, 2.36 billion tons of indicated ore resources, and 144.35 million tons of measured ore resources. The proven and probable ore reserves are estimated at 75.53 million tons, consisting of 38.11 million tons of probable reserves and 37.42 million tons of proven reserves (Figure 4.2).

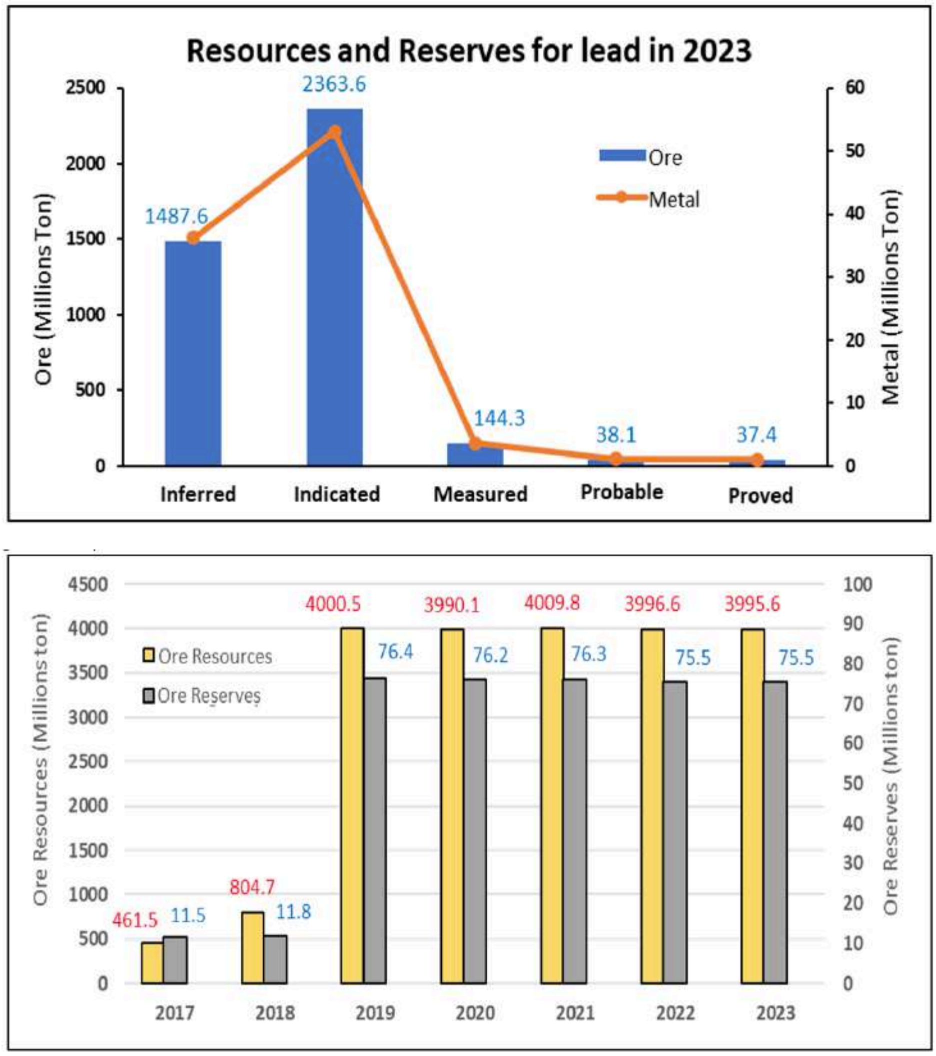

Figure 4.2 Lead (Pb) Resources, Reserves, and Trends in Indonesia (2017–2023) (Nursahan, et al., 2024)

Aceh Province holds a significant portion of Indonesia's lead reserves, with key deposits in Penuntungan, Subussalam City. A detailed breakdown of lead resources and reserves by province is presented in Figure 4.3.

Zinc Resources and Reserves

Indonesia's zinc resources and reserves are distributed across 32 locations, with a total inferred resource of 3.76 billion tons.

This includes 1.38 billion tons of inferred ore resources, 2.32 billion tons of indicated ore resources, and 53.1 million tons of measured ore resources. The proven and probable ore reserves are estimated at 67.9 million tons, consisting of 33.47 million tons of probable reserves and 34.53 million tons of proven reserves (Figure 4.4).

Aceh Province also plays a significant role in Indonesia's zinc reserves, with major deposits in Subussalam City, Aceh. A detailed provincial distribution of zinc resources and reserves is illustrated in Figure 4.5.

Lead and Zinc Production and Consumption Trends

Indonesia plays a crucial role in the global mining sector, particularly in the extraction and processing of lead (Pb) and zinc (Zn). Over the past six years, the country has maintained stable production levels, balancing domestic demand and export potential (Figure 4.6).

Lead mining in Indonesia has remained steady, with consistent ore extraction and metal production. Refined lead output has generally exceeded domestic consumption, indicating a surplus available for export. While metal consumption has shown a gradual increase, it remains lower than production levels, suggesting that industrial demand is growing but not yet matching supply.

Like lead, zinc ore extraction has followed a stable pattern. Metal production has remained within a predictable range, meeting both local and international market demands. However, domestic zinc consumption showed a slight decline in 2022, possibly due to shifting industrial needs or external economic factors. Despite this, Indonesia continues to be self-sufficient in zinc production, with reserves supporting long-term sustainability.

Indonesia's lead and zinc industries have demonstrated resilience and efficiency, maintaining a steady supply despite fluctuations in demand. The country's surplus production positions it as a key player in the global market, with potential for increased exports. Future trends will depend on industrial growth, government policies, and global demand, shaping Indonesia's role in the mining sector in the years ahead.

Trends, Challenges, and Future Prospects

Indonesia has emerged as a significant player in the global mining industry, particularly in the production of lead (Pb) and zinc (Zn). These metals are essential in various industries, including renewable energy, battery manufacturing, and construction. Over the past seven years

(2017–2023), Indonesia has seen substantial growth in its lead and zinc resources and reserves.

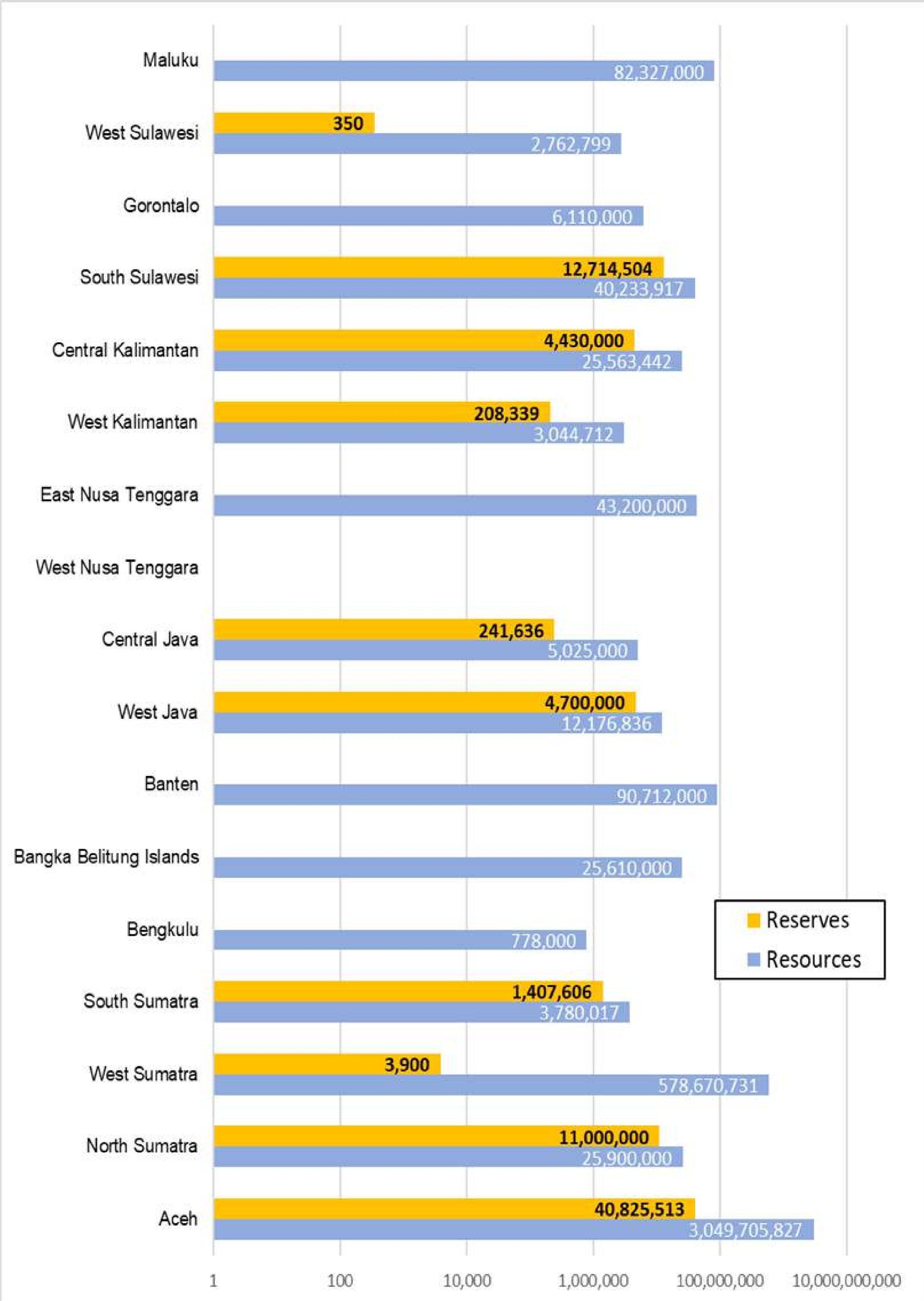

Figure 4.3 Total Lead Ore Resources and Reserves by Province (Nursahan, et al., 2024)

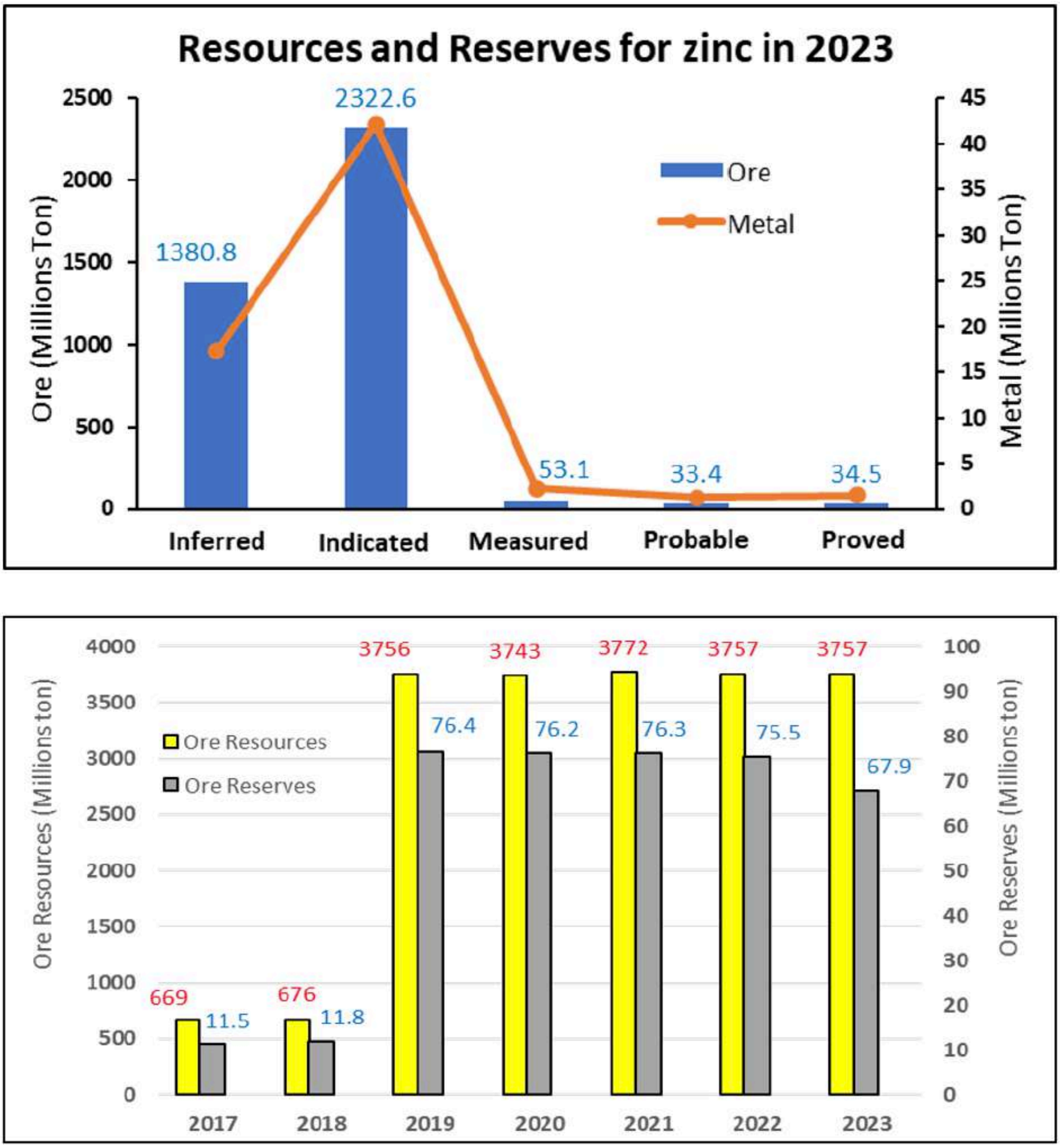

Figure 4.4 Zinc (Zn) Resources, Reserves, and Trends in Indonesia (Nursahan, et al., 2024)

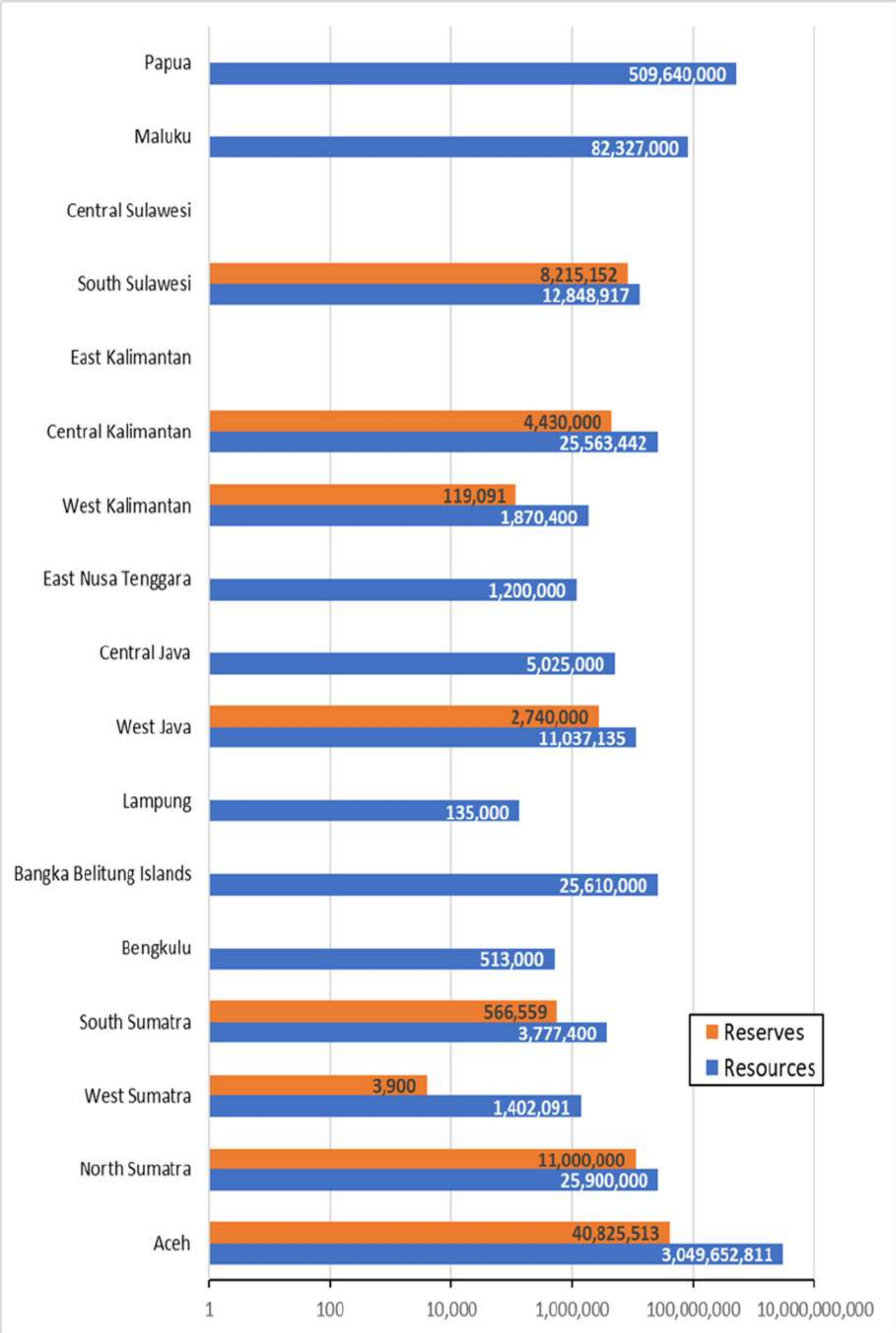

Figure 4.5 Total of Zinc Ore Resources and Reserves by Province in Indonesia (Nursahan, et al., 2024)

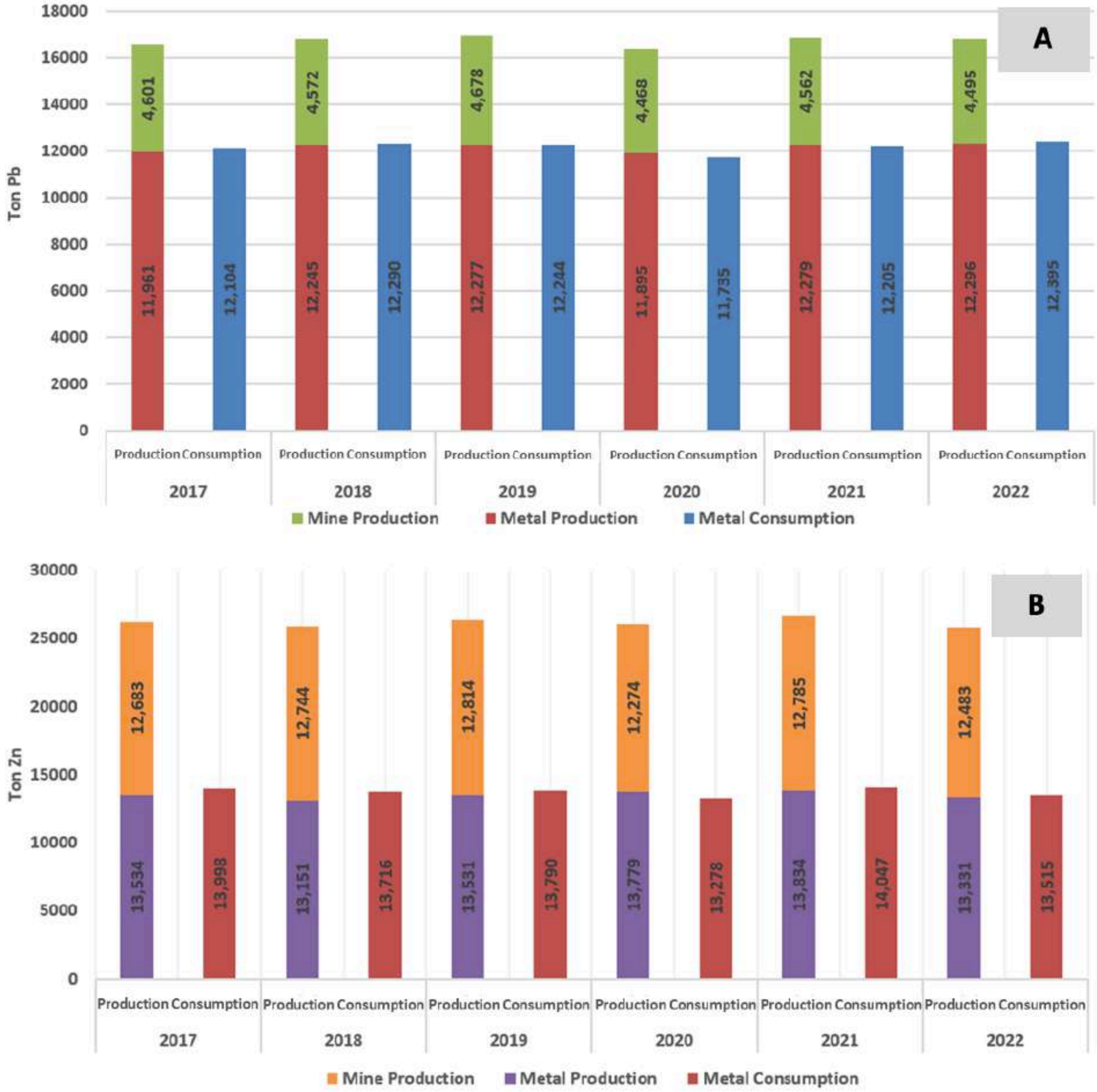

Figure 4.6 Trends in Lead **(A)** and Zinc **(B)** Ore and Metal Production and Consumption in Indonesia (2017-2022) (Nursahan, et al., 2024)

Trends in Lead and Zinc Resources and Reserves

According to recent data (Figure 4.7), Indonesia's lead and zinc ore resources and reserves have expanded significantly due to increased exploration and mining activities. Metal resources surged from 11.3 million tons in 2017 to approximately 91–92 million tons between 2019 and 2023, while metal reserves grew steadily, reaching 2.0–2.9 million tons. Ore resources experienced a dramatic increase from 461.5 million tons in 2017 to around 4000 million tons in 2019, maintaining stability through 2023. Ore reserves followed a similar trend, rising from 11.5 million tons in 2018 to approximately 75.5–76.4 million tons. These figures highlight Indonesia's success in expanding its resource base through investments in exploration and improved resource classification.

Figure 4.7 (A) Lead (Pb) and **(B)** zinc (Zn) ore resources and reserves in Indonesia over the last seven years (2017-2023) (Nursahan, et al., 2024)

Market Dynamics and Pricing Trends

By the end of 2024, global demand for lead and zinc has led to notable price increases. The Ministry of Trade reported a 0.72% rise in lead prices, reaching approximately USD 826.18 per wet metric ton (WMT), while zinc prices surged by 10.82% to around USD 760.10 per WMT in October 2024. These increases were driven by tight supply and growing demand in the construction and manufacturing sectors, particularly in renewable energy and battery production (Prayudhia, 2024; Fajri, 2024).

Growing Demand for Green Energy and Industrial Applications

The role of lead and zinc in renewable energy technologies is becoming increasingly vital. Zinc is crucial for steel galvanization and solar and wind power infrastructure. As renewable energy expands, zinc demand for solar panels and energy storage systems is expected to rise by 360 thousand tons annually by 2030, compared to 110 thousand tons in 2020. Lead remains essential for electric vehicle (EV) batteries and stationary energy storage, with global demand growing by 1.9% annually. However, strict environmental regulations continue to impact lead production, creating supply challenges (Cleary, 2021).

Indonesia's Competitive Advantage in the Global Market

Indonesia's geological conditions provide a strategic advantage for lead and zinc mining. To strengthen its global competitiveness, the country is focusing on exploring new deposits, expanding domestic refining capabilities, and developing infrastructure to process raw materials before export. The construction of smelters is playing a crucial role in boosting Indonesia's refining capacity.

The PT Kapuas Prima Coal (KPC) and PT Kobar Lamandau Mineral (KLM) smelters are among Indonesia's first lead and zinc refining facilities. As of 2024, the lead smelter has been completed, while the zinc smelter is 93% complete, with an annual production capacity of 30,000 tons of zinc ingot (Sigit Dzakwan, 2022). Additionally, copper smelters operated by PT Freeport Indonesia (FI) in Gresik and PT Amman Mineral Industri (AMIN) in Sumbawa are expected to produce lead as a by-product, with annual outputs of 2,200 tons and 460 tons, respectively.

Conclusion

Indonesia's lead and zinc mining industry has experienced rapid growth, positioning the country as a key global supplier. With increasing demand in renewable energy, electric vehicles, and infrastructure development, Indonesia's investments in exploration and refining will ensure long-term economic benefits. By focusing on sustainable mining and value-added processing, Indonesia is set to strengthen its role in the international market while supporting the global transition to green energy.

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5

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Gold - Silver

Image: Nugget Gold, Tana Toraja, South Sulawesi
Courtesy of: CMCGR, 2023

Gold is a rare, dense, and highly valuable metal with unique physical and chemical properties. In its pure form, it is soft, ductile, and malleable, exhibiting a distinctive yellow luster. Gold is exceptionally resistant to chemical attack and corrosion, making it one of the most durable metals. Additionally, it possesses excellent electrical conductivity. Represented by the chemical symbol Au, gold derives its name from the Latin word aurum, meaning "shining dawn." As a transition metal, it has an atomic number of 79 and an atomic mass of 196.96657 u, belonging to Group 11 of the periodic table. Notably, gold is highly resistant to corrosion, yielding only to powerful acid mixtures such as aqua regia (a combination of nitric and hydrochloric acid).

Silver, known chemically as Ag (from the Latin argentum), is a soft, lustrous white transition metal renowned for its exceptional thermal and electrical conductivity, as well as its remarkable reflectivity. Highly ductile and malleable, silver can be polished and shaped into intricate forms. It occurs naturally in its native state or as an alloy with gold and other metals in minerals such as argentite, chlorargyrite, and electrum. Often extracted as a by-product of copper, gold, lead, and zinc mining, silver shares similarities with gold as a noble metal, being highly resistant to corrosion and oxidation. Silver is widely used in jewelry, either in its pure form or alloyed for added durability, and has extensive applications in various industrial, technological, and medicinal fields.

Occurrences

Gold and silver are often found in association with copper and other metals within sulfide mineral deposits. The prevailing understanding of gold and silver formation and their distribution on Earth is largely based on the long-established paradigm that hydrogen sulfide and chloride ligands play a crucial role in mobilizing and precipitating gold-bearing fluids throughout the lithosphere.

The formation of gold deposits involves hydrothermal fluids that transport and concentrate gold-bearing components derived from magmatic sources. As these fluids migrate through fractures and porous rock formations, they become trapped and precipitate, leading to the accumulation of gold in economically viable concentrations. Consequently, most primary gold deposits are linked to subduction zones and collisional tectonic settings, where geological processes facilitate ore deposition.

Gold-Silver Deposits in Indonesia

Indonesia hosts a diverse range of gold-silver deposit types, broadly classified into primary deposits - formed through hydrothermal processes - and secondary placer deposits, which result from the weathering and transportation of primary ores. The primary deposit types found in Indonesia include: a) Epithermal, b) Porphyry, c) Skarn, d) Orogenic gold, e) Volcanogenic massive sulfide (VMS), f) Sedimentary exhalative (SEDEX), and g) Carlin-type. Among these, epithermal gold deposits are the most widespread in Indonesia, followed by porphyry-type gold deposits. These deposits are distributed across approximately 15 distinct mineralization belts spanning the Indonesian archipelago (Figure 5.1).

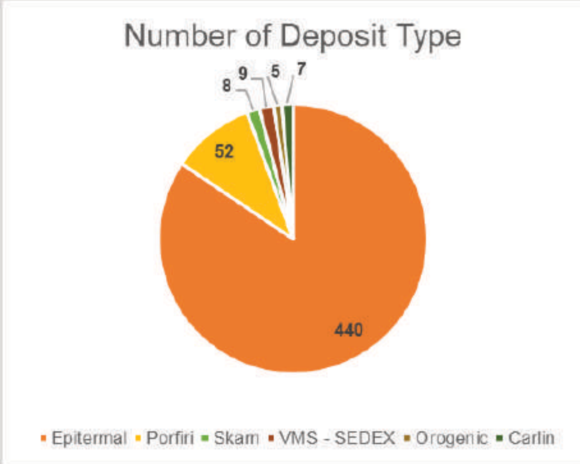

Figure 5.1. Gold deposit types in Indonesia

One of the latest promising discoveries, made by the Geological Agency in 2022, is the porphyry Cu-Au (copper-gold) mineralization in the Tasik Madu area of Trenggalek Regency, East Java. This porphyry Cu-Au system is characterized by stockwork veinlets—notably M-type, A-type, and B-type veins—hosted within dioritic rock. These stockwork veinlets are closely associated with chalcopyrite-bearing veins, which have undergone oxidation, leading to the formation of malachite (Figure 5.2).

Resources and Reserves of Gold

According to Indonesia's Minerals Resources and Reserves Report (2023), the majority of the country's gold ore and metal resources are classified as inferred. The total gold ore resources are estimated at 15.5 billion tons, while total metal resources amount to 120.5 thousand tons. In terms of reserves, Indonesia holds 3.5 billion tons of gold ore and 34.1 thousand tons of recoverable metal reserves. To upgrade inferred resources to indicated and measured categories, detailed exploration activities are essential (Figure 5.3).

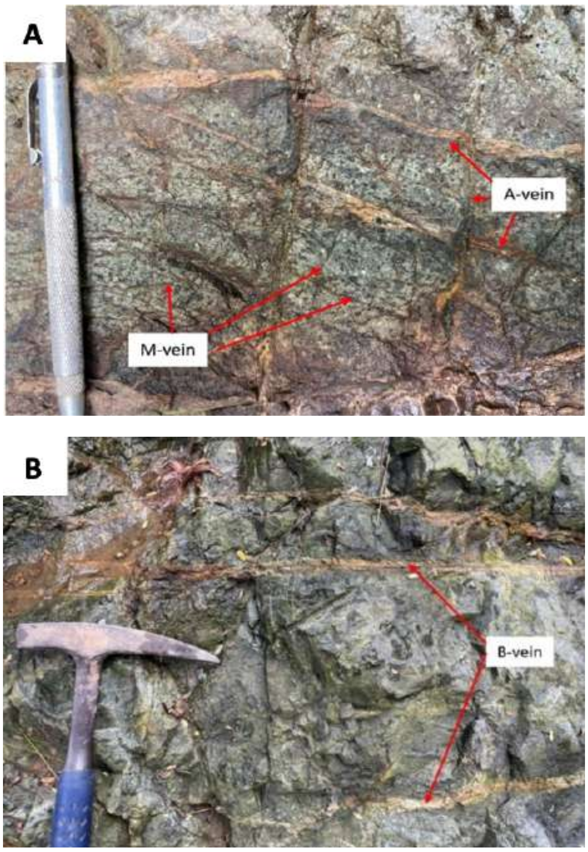

Figure 5.2. (A) M-vein and A-vein in magnetite-K feldspar (Potassic) alteration rock; **(B)** B vein in magnetite-K feldspar (Potassic) alteration **(**Heditama, et al., 2022)

While epithermal deposits are the most abundant gold deposit type in Indonesia, porphyry deposits contain the largest volume of ore resources and reserves. However, epithermal deposits exhibit the highest metal resources and reserves, highlighting their economic significance (Figure 5.4).

Major Gold-Bearing Metallogeny Belts in Indonesia

Indonesia's gold resources are primarily concentrated along the Sunda–Banda Metallogeny Belt, which extends from Sumatra and Java to the Nusa Tenggara islands. This belt hosts numerous significant epithermal gold deposits, such as: Pongkor in Java, Lebong Tandai and Martabe in Sumatra

Additionally, it contains major porphyry gold deposits, including: Batu Hijau and Hu'u in Sumbawa

As a result, the Sunda–Banda Metallogeny Belt holds the largest ore resources and reserves in Indonesia.

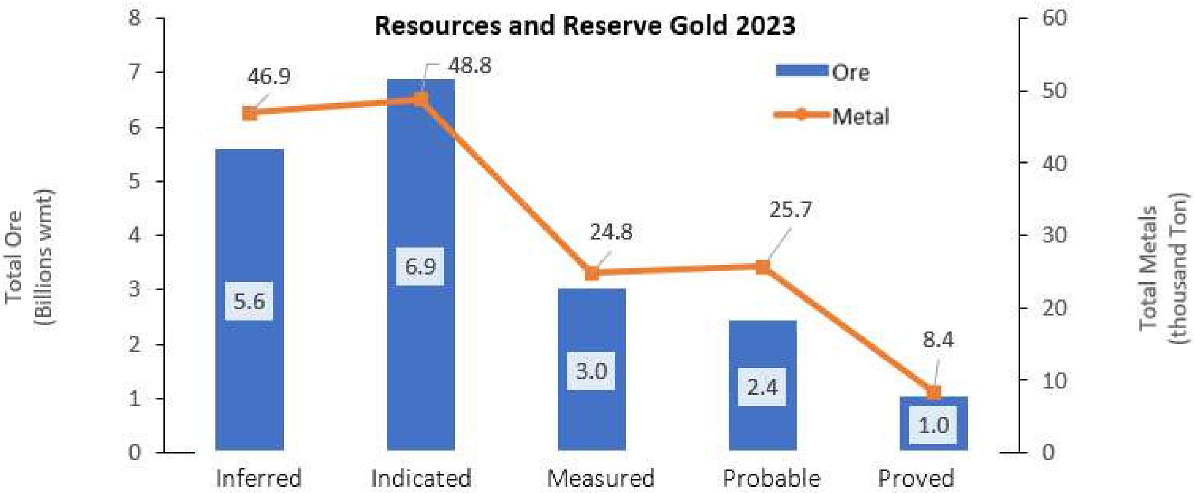

Figure 5.3 Gold Ore Resources and Reserves 2023 (Nursahan, et al., 2024)

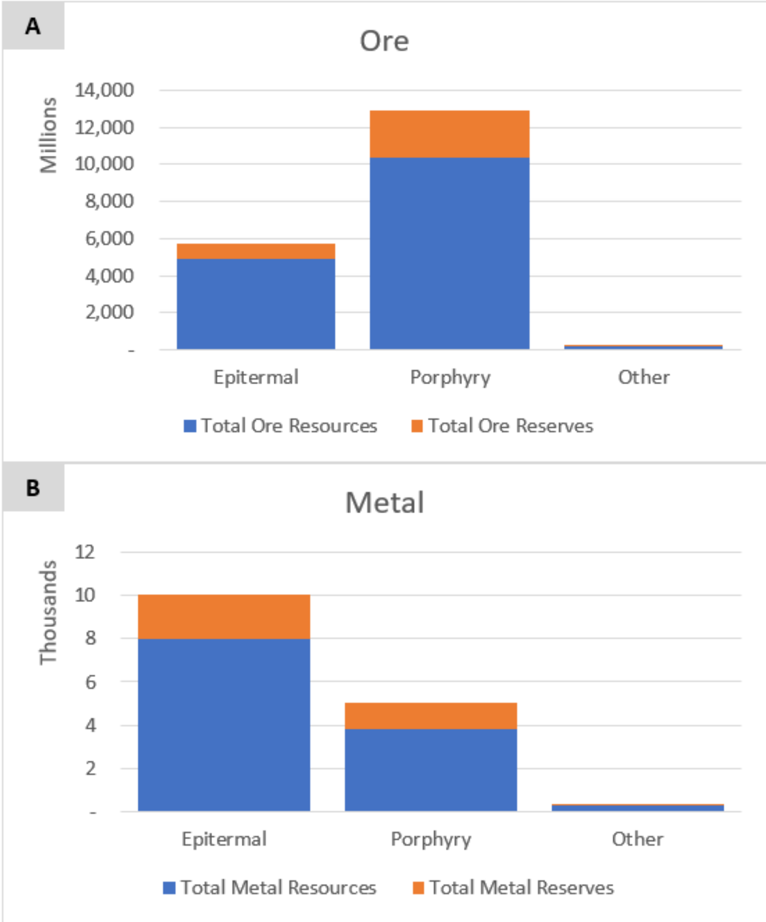

Figure 5.4 Gold resources and reserves in Indonesia based on deposit types for **(A)** ore and **(B)** metal (Nursahan, et al., 2024)

However, the Papua Metallogeny Belt contains the country's largest metal resources and reserves, primarily sourced from the world-class Grasberg Mine, operated by PT Freeport Indonesia.

Other significant gold deposit types and their key locations include:

- **Skarn-type deposits** – Grasberg Mine, Papua
- **Volcanogenic massive sulfide (VMS) deposits** – Maluku
- **Carlin-type deposits** – Sulawesi
- **Orogenic gold deposits** – Bombana (Southeast Sulawesi) and Buru (Maluku)

Figures 5.5 and 5.6 illustrate this distribution.

Trends in Gold Resources and Reserves

The distribution of primary gold ore resources and reserves across Indonesia's provinces is presented in Figure 5.7. Over the past five years, gold ore and metal resources have generally increased. However, a slight decline was recorded in 2023 compared to 2022, reflecting fluctuations in exploration and extraction activities (Figure 5.8).

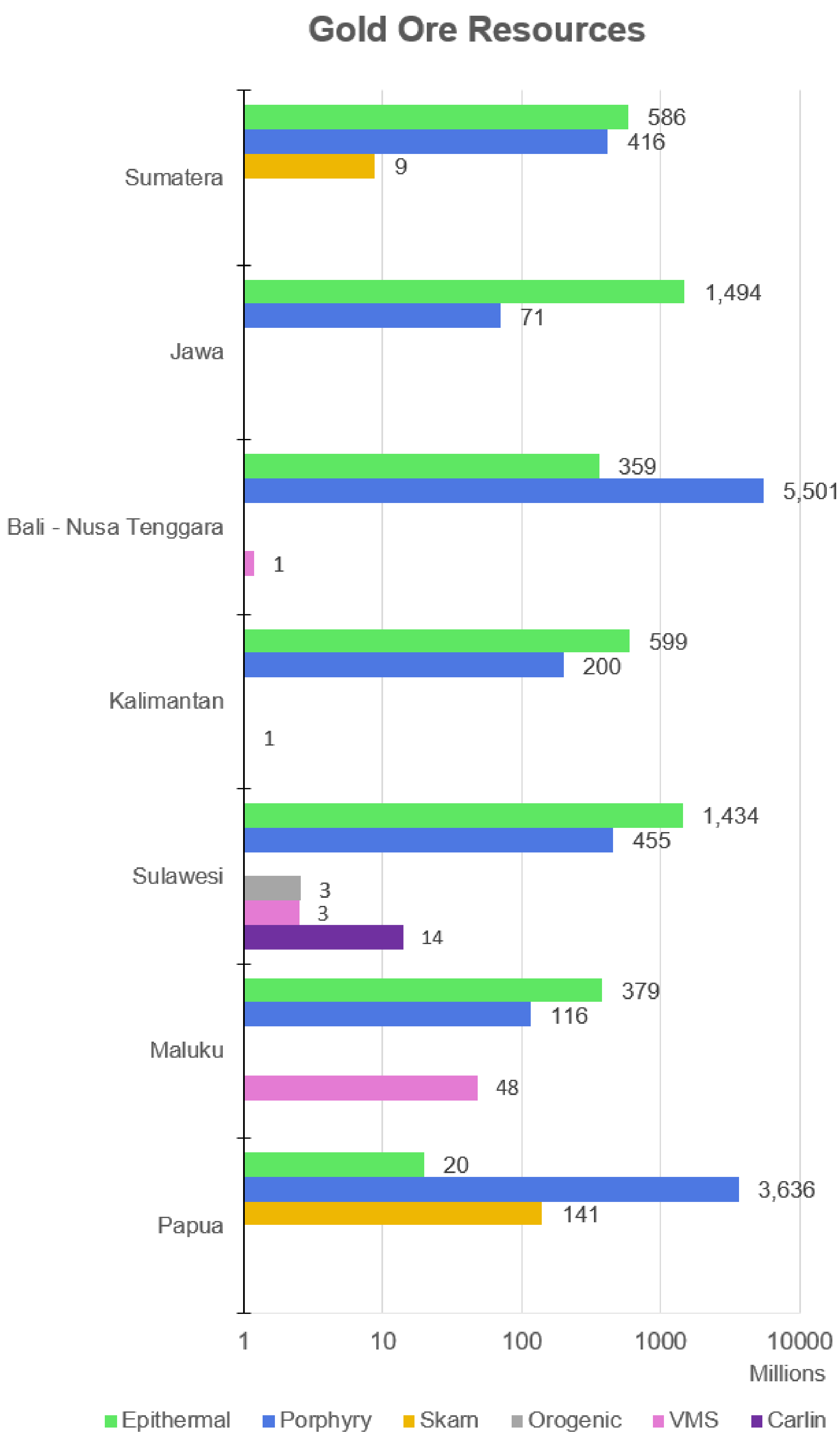

Figure 5.5. Gold ore resources and deposit type in each island (Nursahan, et al., 2024)

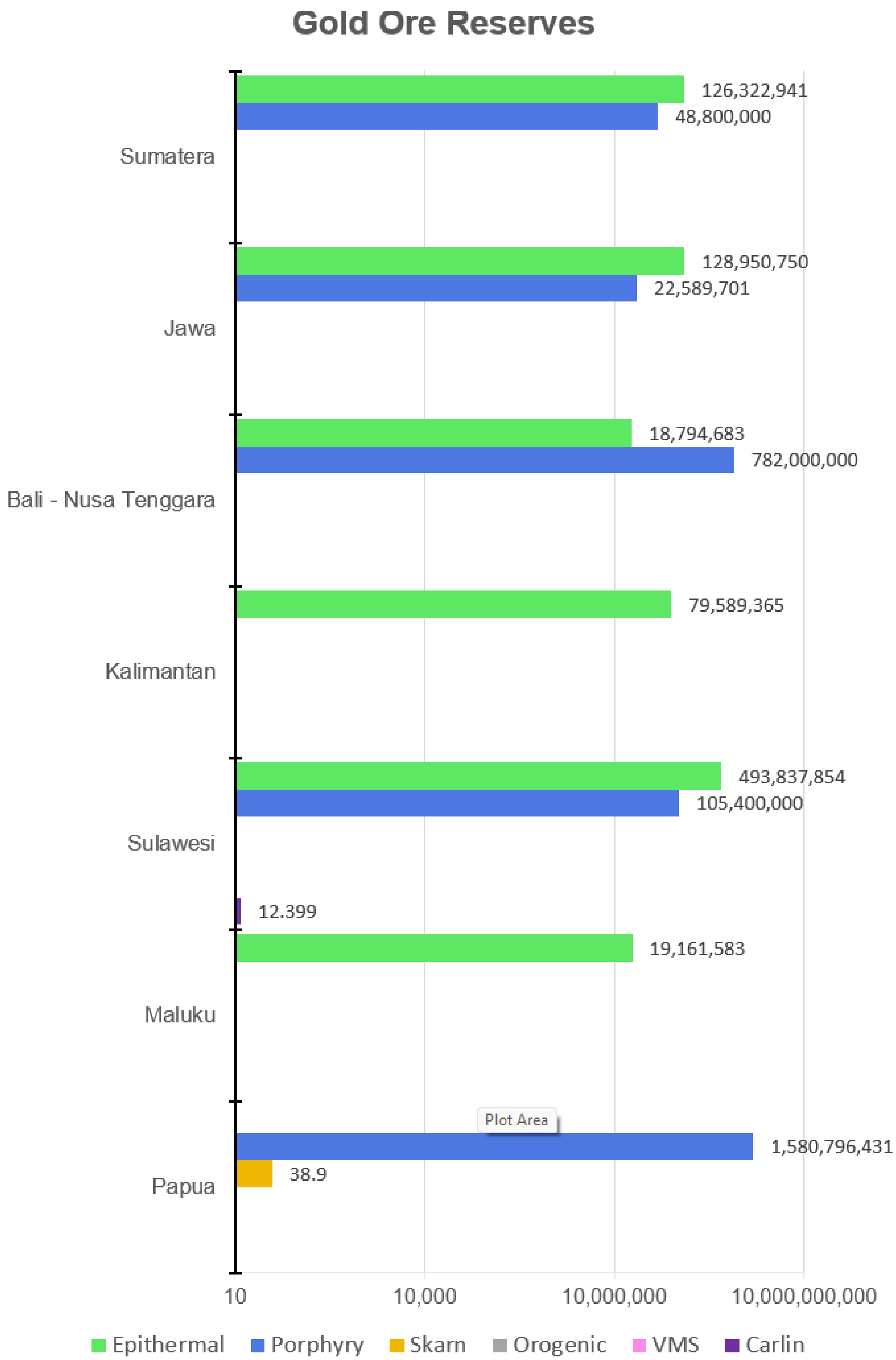

Figure 5.6. Gold ore reserves and deposit type in each island (Nursahan, et al., 2024)

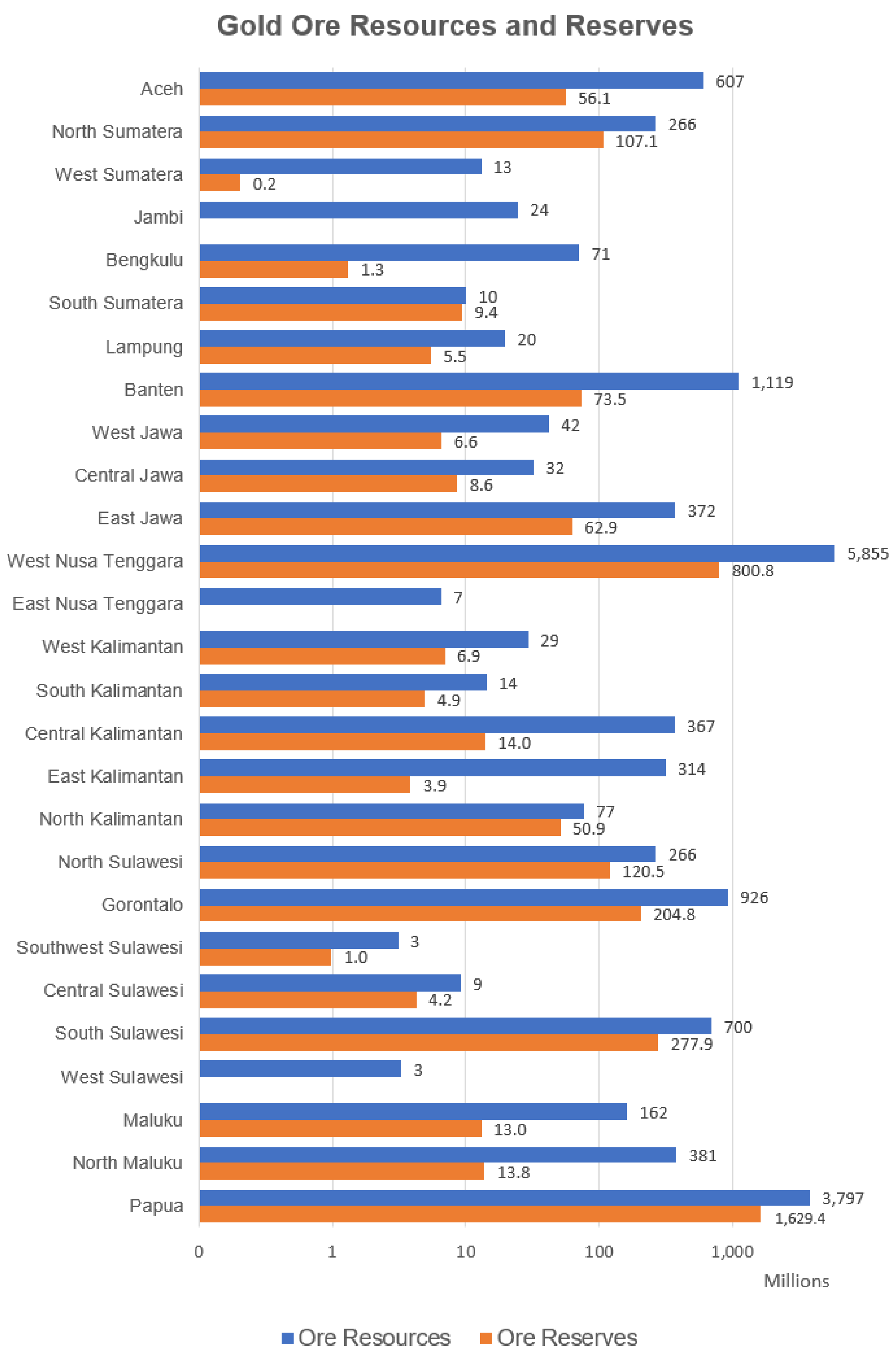

Figure 5.7 Gold ore resources and reserves in each province (Nursahan, et al., 2024)

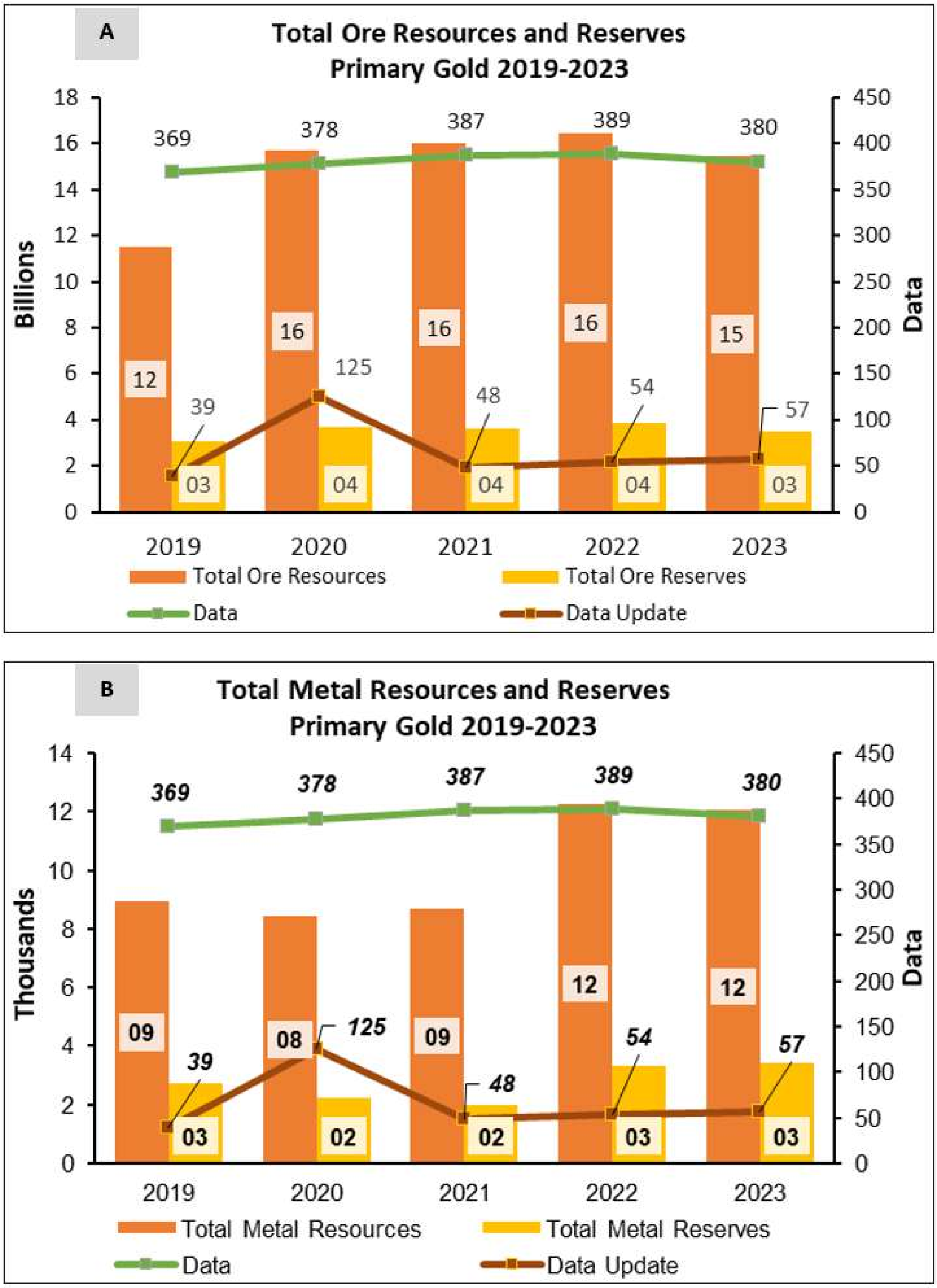

Figure 5.8 (A) Ore and **(B)** metals resources and reserves for primary gold commodity from 2019 to 2023 (Nursahan, et al., 2024)

Resources and Reserves of Silver

According to the Indonesia's Minerals Resources and Reserves Report (Nursahan et al., 2023), the majority of the country's silver ore and metal resources are classified under the inferred and indicated resource categories (Figure 5.9). The total silver ore resources are estimated at 11.4 million tons, while the total silver metal resources reach 166.3 tons. In terms of reserves, Indonesia possesses 3.2 million tons of silver ore and 42.6 tons of contained metal.

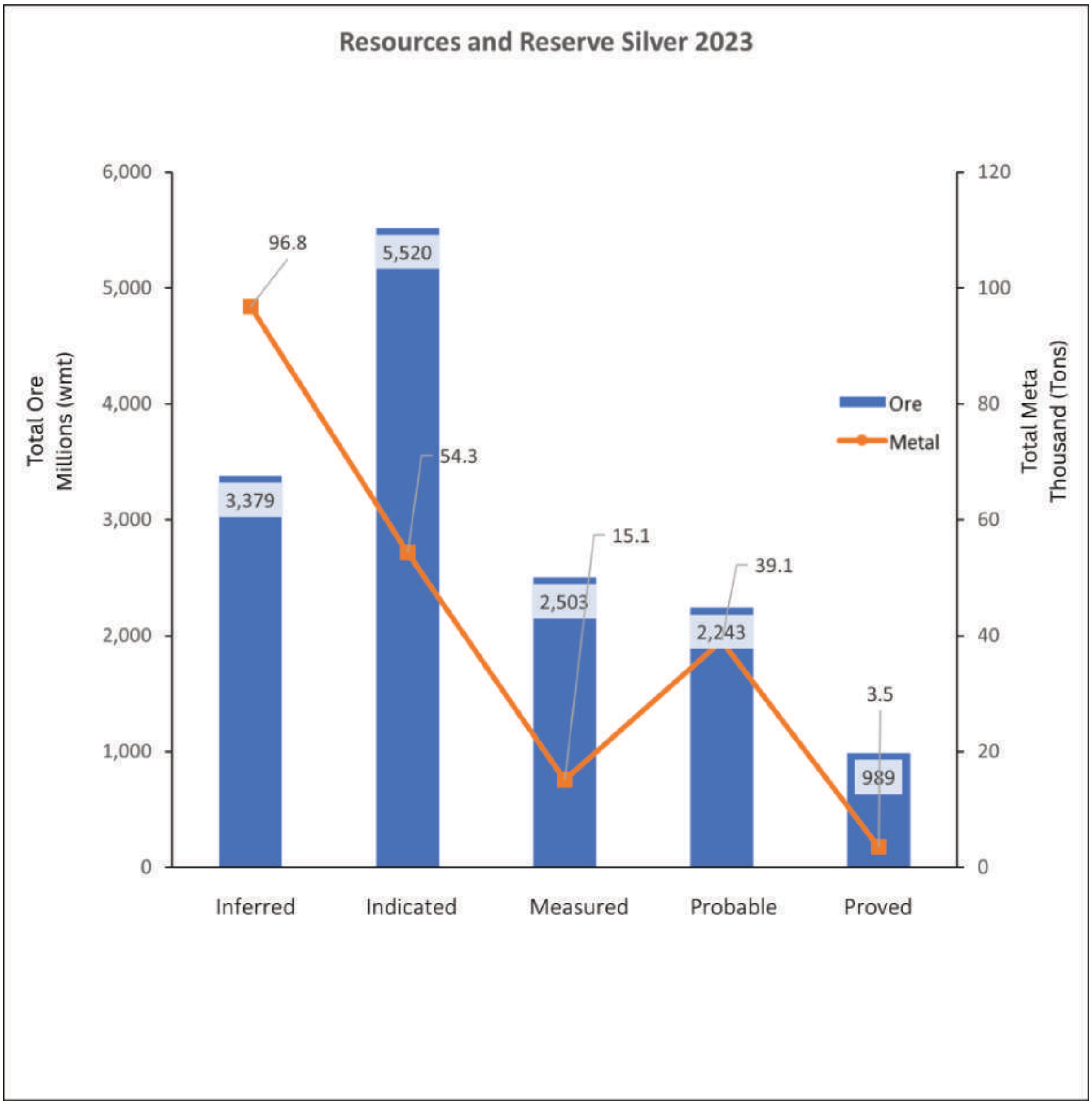

Figure 5.9. Silver Resources and Reserves in 2023 (Nursahan, et al., 2024)

Alluvial Gold

Secondary gold deposits—such as lateritic, colluvial, alluvial, and coastal placer deposits—are formed through the natural processes of erosion, transportation, and sedimentation that act upon primary gold sources. Among these, alluvial gold deposits are particularly significant and are commonly found in residual soils, forming as colluvial deposits or alluvial fans, and are frequently associated with fluvial systems.

These deposits typically occur in Quaternary-age basins, located within river valleys that shape the surrounding landscape. The gold-bearing layers may appear as single or multiple horizons, extending vertically or laterally, often lying beneath gently sloping terrain. These layers can reach several meters in thickness, and gold particles are typically irregularly distributed within the sediments.

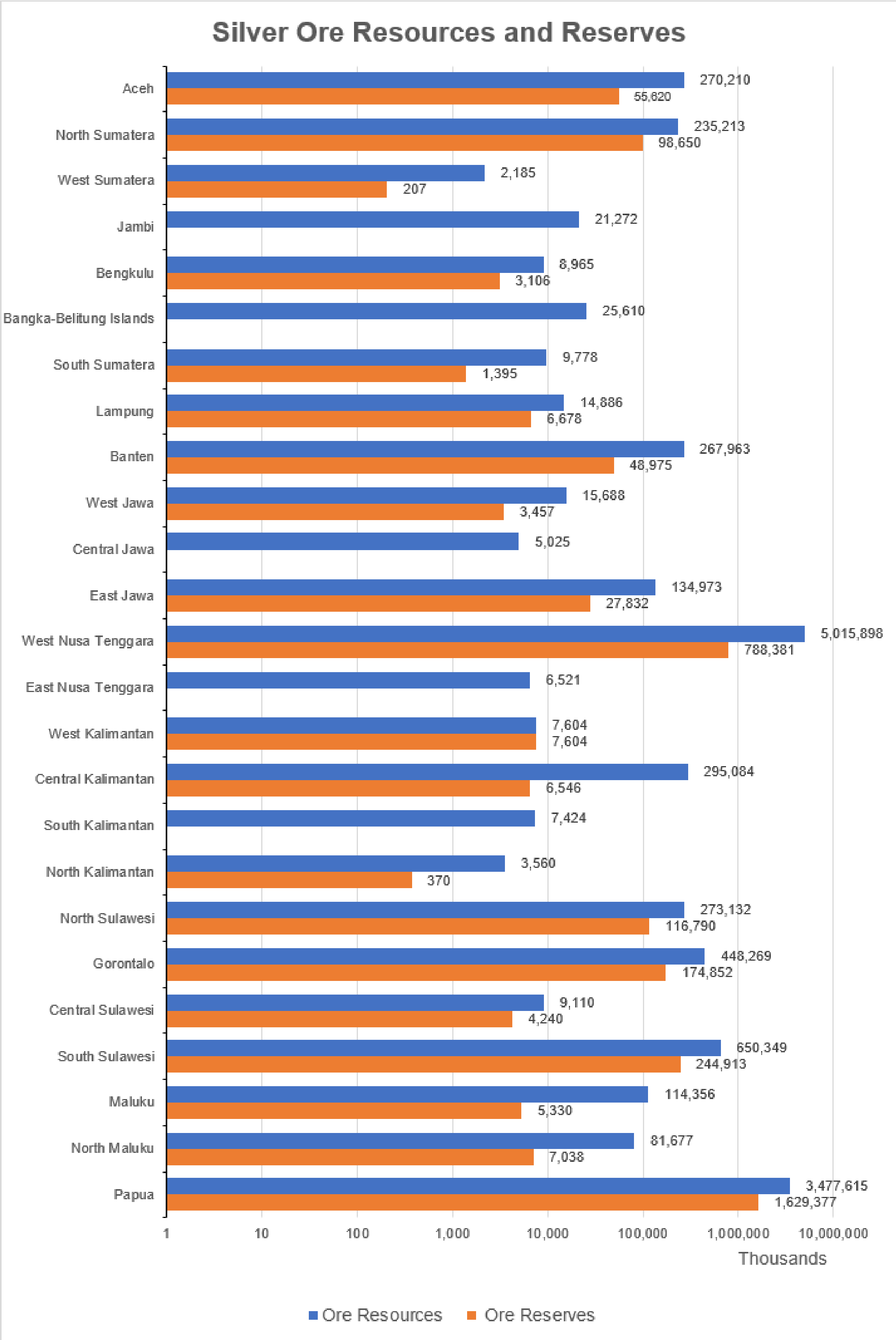

Figure 5.10. Silver ore resources and reserves in each province (Nursahan, et al., 2024)

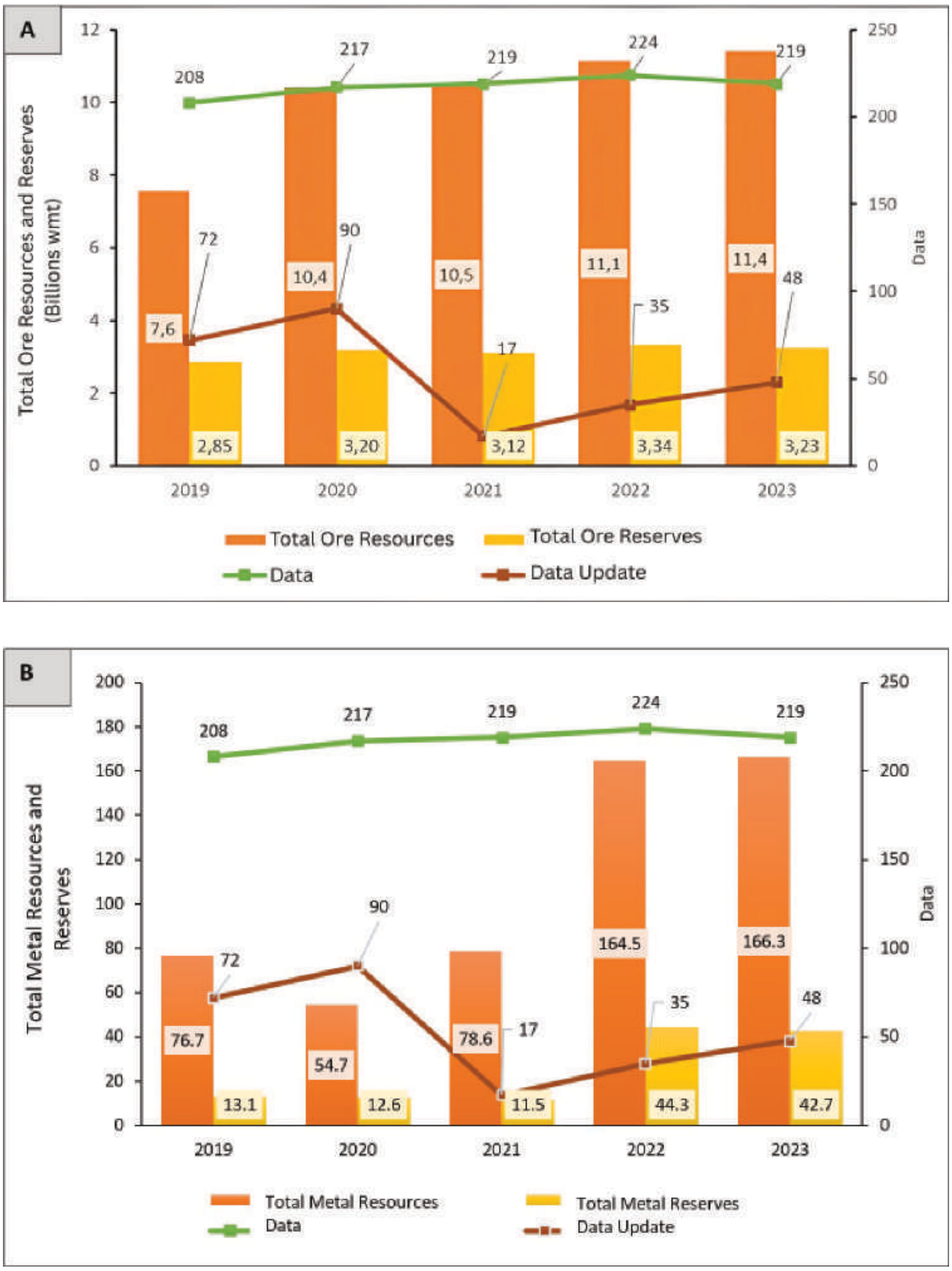

Figure 5.11. **(A)** Ore and **(B)** metals resources and reserves for silver commodity from 2019 to 2023 (Nursahan, et al., 2024)

Alluvial gold potential is widespread across Indonesia, with notable concentrations in Kalimantan, Sumatra, Sulawesi, and Papua. However, many of these deposits have been extensively mined, leaving behind residual and scattered resources.

Significant exploration activities targeting alluvial gold were carried out by small- to medium-scale mining companies during the 1980s to early 1990s, primarily in Kalimantan and Sumatra. These efforts often focused on areas with a known history of gold mining—whether by Chinese and Dutch colonial operations or local traditional miners. Targeted locations typically featured recent to Quaternary-age gravels, sourced from active river systems, buried paleochannels, or ancient drainage systems.

Resources, Reserves, and Production of Alluvial Gold

In comparison to primary gold deposits, Indonesia's alluvial gold resources and reserves are relatively modest. As of the latest data, total gold resources from alluvial deposits amount to approximately 2.04 billion tons, with reserves totaling 429 tons.

These resources and reserves are geographically distributed across various provinces (Figure 5.12), including Aceh, North Sumatra, Riau, Jambi, and Lampung in Sumatra; Banten and East Java in Java; East Kalimantan, Central Kalimantan, and West Kalimantan in Kalimantan; North Sulawesi, Gorontalo, and Southeast Sulawesi in Sulawesi; and in Eastern Indonesia, covering North Maluku, West Papua, and Papua, particularly from tailings and residuals associated with PT Freeport Indonesia.

Trends in Indonesia's Gold Production, Export, and Domestic Consumption (2015–2020)

Indonesia has long been recognized as one of the world's leading producers of gold, with a mining industry that plays a pivotal role in the nation's economy. From 2015 to 2020, gold production and trade data reveal key patterns in resource output, export priorities, and domestic demand, offering insights into the country's strategic mineral utilization (Figure 5.13).

Sustained Production with 2018 Peak

Throughout the six-year period, Indonesia maintained a robust gold production rate, consistently outpacing both export and domestic consumption levels. Production remained relatively stable from 2015 to 2017, fluctuating between approximately 95 to 110 tons annually. The year 2018 marked a notable peak, with gold output surging to nearly 140 tons, the highest level recorded during this time-frame. This surge likely reflects increased mining activity, improved recovery rates, or the expansion of existing operations.

Export-Oriented Market Dynamics

Indonesia's gold market remains largely export-oriented. Across all years from 2015 to 2020, exports consistently exceeded domestic consumption, underscoring the strategic importance of gold as a foreign exchange earner. Between 2015 and 2018, export levels hovered around 75 to 85 tons, accounting for the majority share of annual production.

However, beginning in 2019, a shift began to emerge. Gold exports declined to around 70 tons, and in 2020, the number dropped further to below 50 tons. This downward trend in exports may be attributed to global market disruptions, changes in trade policies, or supply chain constraints during the COVID-19 pandemic.

Rising Domestic Consumption

In contrast to the relatively steady export figures, domestic consumption of gold in Indonesia demonstrated more dynamic behavior. From 2015 to 2017, local demand remained modest, ranging from 20 to 35 tons. A dramatic rise occurred in 2018, where domestic consumption surged to over 60 tons, nearly doubling from the previous year.

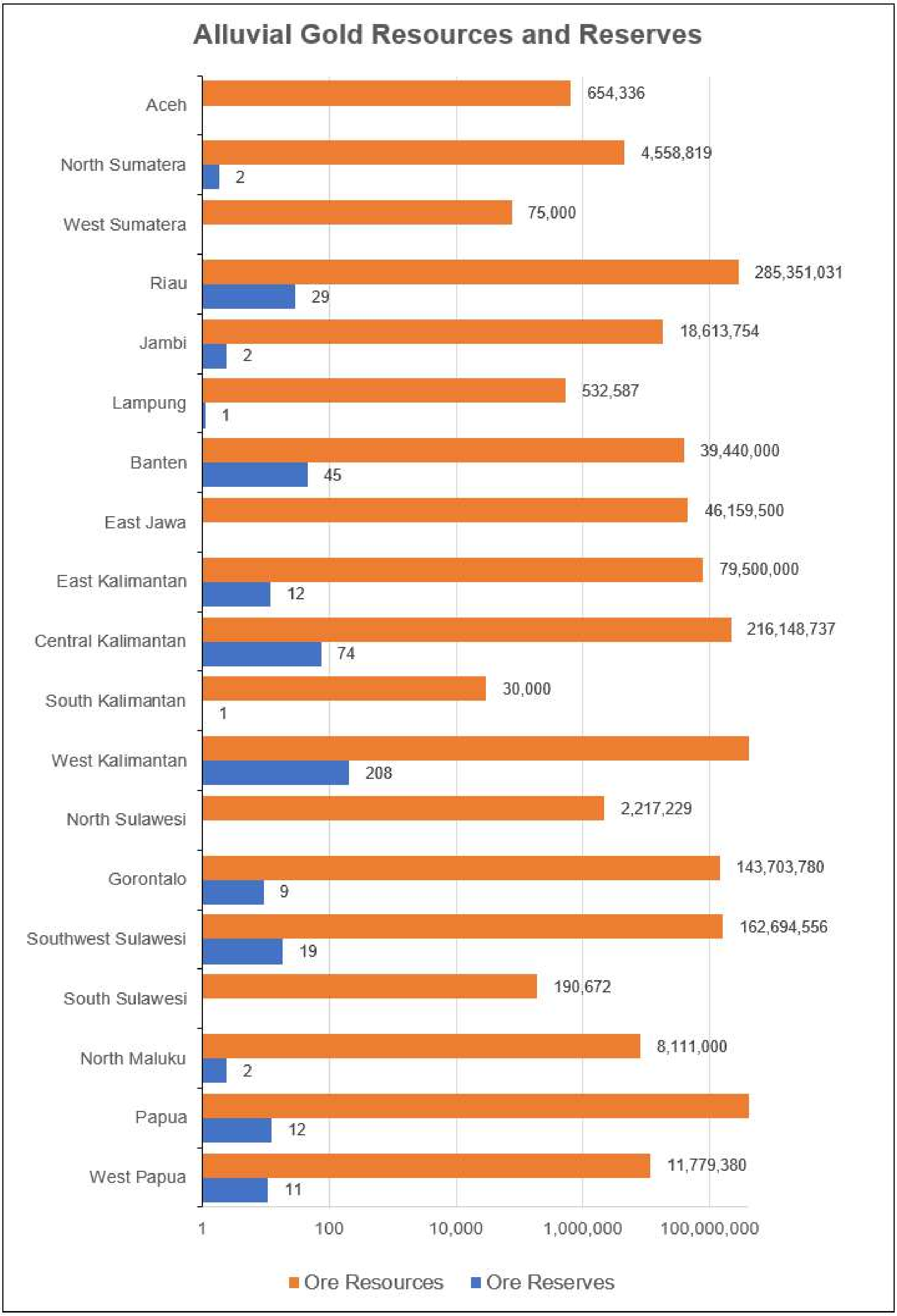

Figure 5.12 Alluvial gold ore resources and reserves in each province (Nursahan, et al., 2024)

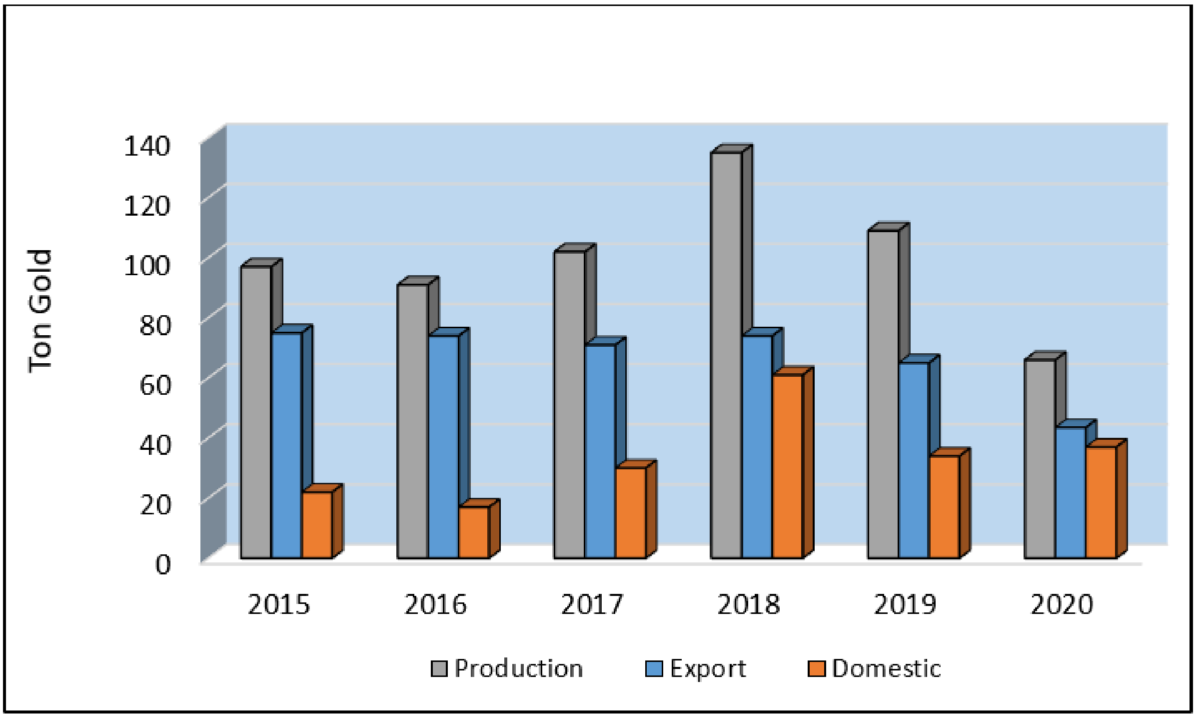

Figure 5.13. Production, domestic consumption and exports of gold from 2015 to 2020 (MEMR, 2022)

This spike may reflect increased demand in jewelry, investment, or industrial applications, possibly fueled by rising incomes and greater investor interest in gold as a hedge.

Interestingly, 2020 saw domestic consumption nearly matching export levels, each at about 40 tons. This rare convergence suggests a significant shift in Indonesia's internal gold utilization, perhaps driven by a combination of lower export capacity and a growing domestic appetite for gold amid uncertain economic conditions.

Conclusion

From 2015 to 2020, Indonesia's gold sector demonstrated a consistent production capacity with a strong emphasis on exports. However, emerging trends such as declining exports and rising domestic demand—particularly evident in 2020—signal a potential re-balancing of the country's gold economy. As Indonesia continues to develop its downstream industries and seeks to capture greater value domestically, these patterns may further evolve, reshaping the strategic landscape of gold in the national resource framework.

Gold Reserves Resilience

Indonesia holds an estimated 3.6 billion tons of gold ore reserves, a volume that provides substantial long-term resource security. As illustrated in Figure 5.14, if the current annual production rate of 13.2 million tons is sustained, these reserves are projected to last approximately 268 years, extending resource availability well into the 23rd century.

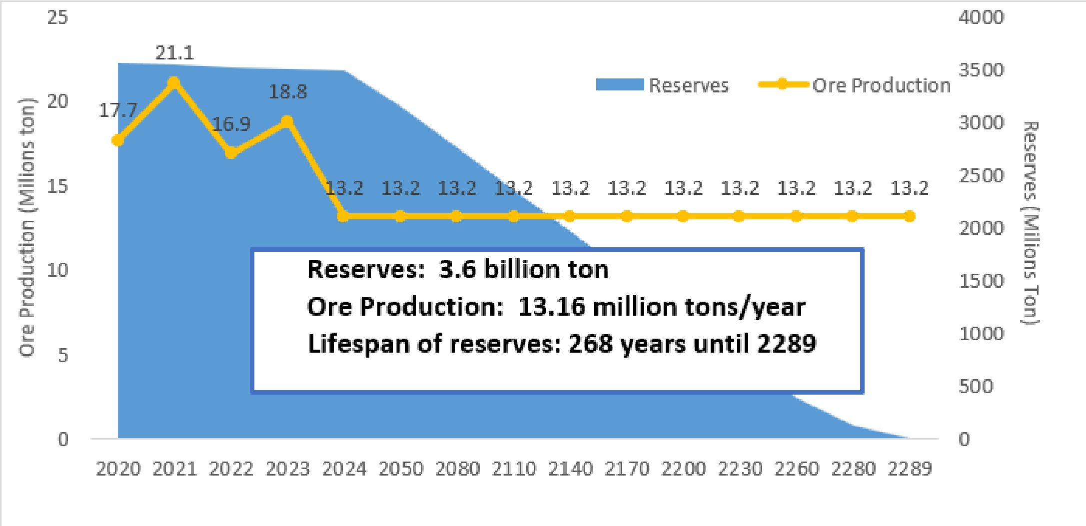

Figure 5.14 Projection of Gold Ore Production and Reserve Depletion in Indonesia (2020–2289) (MEMR, 2021)

The graph depicts historical and projected gold ore production alongside reserve depletion over time. From 2020 to 2023, production levels fluctuated between 16.9 and 21.1 million tons, before stabilizing at 13.2 million tons per year from 2024 onward. Meanwhile, reserves remain relatively steady until around 2050, after which a gradual decline begins—highlighting the long-term consumption impact under a constant production scenario.

While these projections underscore Indonesia's robust mineral endowment, they also signal a critical need for proactive measures. Rising global and domestic demand for gold, driven by industrial, technological, and economic factors, may accelerate production rates and shorten the lifespan of current reserves. Therefore, continuous mineral exploration, resource upgrading, and the development of advanced refining technologies are essential to ensure future supply, maximize resource efficiency, and maintain strategic resilience.

Trend and Issues in Strategic Gold and Silver Utilization

In April 2024, the Indonesian government officially updated the Strategic Mineral List through Ministerial Decree No. 69.K/MB.01/MEM.B/2024, recognizing gold as a strategic mineral. This pivotal decision is aimed at reinforcing regulatory support to accelerate exploration and mining activities. By doing so, the government intends to boost foreign exchange earnings, strengthen national economic resilience, and enhance Indonesia's competitiveness in the global mineral market.

Despite Indonesia's long history in gold mining, numerous greenfield areas with high exploration potential remain untapped. The Sunda-Banda metallogeny belt stands out as a promising region for gold and copper discoveries. Recent explorations have highlighted several prospective sites in southern East Java Province, including Tasikmadu in Trenggalek (Heditama et al., 2022), Pethuk Krebet in Tulungagung (Tim Evaluasi Mineral, 2018), Kaliuling in

Lumajang (Widodo, 2010), and Ngeni in Blitar (Widodo et al., 2002). Likewise, the Papua metallogeny belt, especially within its central mountain range, holds significant potential for future discoveries beyond the world-class Grasberg mine.

Gold Price Trends 2020–2024: A Reflection of Global Uncertainty and Strategic Value

Between January 2020 and December 2024, global gold prices experienced significant volatility and long-term growth, underscoring the metal's enduring status as a safe-haven asset and a strategic financial commodity. Starting at around USD 1,500 per ounce in early 2020, prices surged, stabilized, and then climbed sharply to reach over USD 2,700 by the end of 2024 — a near 80% increase over five years (Figure 5.15).

Pandemic-Induced Surge and Market Realignment (2020–2021)

The onset of the COVID-19 pandemic in early 2020 triggered a sharp rise in gold prices, driven by heightened investor anxiety, financial market instability, and the search for secure assets amid global lockdowns and economic contractions. By mid-2020, gold crossed the symbolic USD 2,000 mark for the first time, highlighting its role as a global hedge against crisis.

In 2021, the gold market began to recalibrate. As vaccines were distributed and economies gradually reopened, prices dipped slightly but remained robust, fluctuating between USD 1,700 and USD 1,900 per ounce. This period reflected cautious optimism and investor repositioning across global markets.

Temporary Decline and Renewed Momentum (2022–2023)

The price of gold saw further fluctuation in 2022, briefly dropping to levels near USD 1,600. However, this short-term weakness gave way to a renewed uptrend in early 2023, fueled by concerns over inflation, monetary tightening by major central banks, and geopolitical tensions.

Investors once again turned to gold as a stabilizing force in portfolios, driving demand upward. The market began to respond not only to macroeconomic stress but also to structural shifts in global energy, trade, and financial systems.

Figure 5.15 Gold Prices During Global Economic Uncertainty (2020–2024) (World Gold Council, 2024)

Strong Bullish Breakout (2023–2024)

From mid-2023 through late 2024, gold prices experienced a sustained rally, reaching historic highs above USD 2,700 per ounce. This phase reflects multiple converging factors: persistent inflation, a weakening U.S. dollar, global conflict risks, and surging demand from central banks and emerging markets.

Moreover, gold's role in the transition to a green economy — including its use in solar cells and hydrogen fuel technologies — began to elevate its value beyond traditional financial metrics. This intersection of industrial utility and monetary safety net further bolstered investor confidence.

Outlook and Strategic Importance

Despite a modest correction at the close of 2024, gold remains in a structurally strong position. Its price levels are significantly above the pre-pandemic average, confirming its importance in an increasingly uncertain world. The trends over this five-year span reinforce gold's dual role: a barometer of global confidence and a critical resource in future-oriented industries.

As economies continue to evolve amidst geopolitical shifts, energy transitions, and digital transformation, gold is expected to retain — and possibly expand — its relevance. For nations like Indonesia, where gold has recently been classified as a strategic mineral, this trend offers an opportunity to leverage domestic reserves for long-term economic resilience and global competitiveness.

In parallel, silver's role in the clean energy transition is becoming increasingly vital. As shown in the graph on silver demand in the automotive sector (Figure 5.16), silver usage is projected to triple by 2040, fueled by the rapid growth of electric vehicles (EVs), hybrid electric vehicles (HEVs), and internal combustion engine (ICE) vehicles utilizing more advanced electronics. The shift toward cleaner technologies is creating robust demand for silver due to its unparalleled electrical and thermal conductivity.

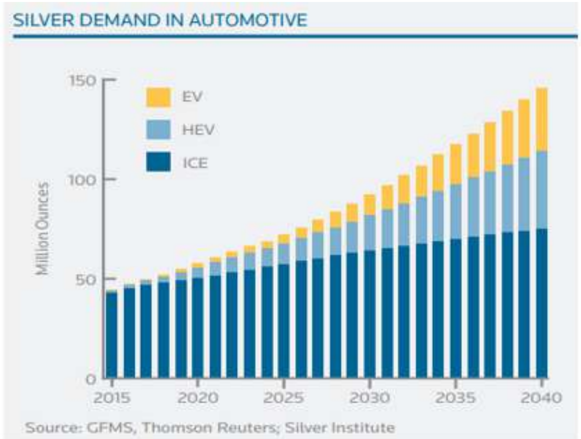

Figure 5.16 Silver Demand by Vehicle Type in the Automotive Industry (2015–2040): ICE, HEV, and EV Contributions (Silver Institute, 2017)

Beyond their monetary and ornamental value, gold and silver are indispensable to the green energy industry, particularly in renewable energy systems and electronics. These metals play critical roles in the development of cleaner energy technologies:

Gold, with excellent conductivity and resistance to corrosion, is used in solar panels to enhance energy conversion efficiency. It also serves as a catalyst in converting carbon dioxide into usable fuels and boosts hydrogen fuel cell performance through its nanoparticle form.

Silver is widely used in solar photovoltaics. Approximately 10% of global silver production is consumed by the solar industry, where it is a key component of conductive silver paste essential for capturing and converting sunlight into electricity.

The combined increase in demand for both gold and silver, driven by technological advancement and climate goals, underscores the urgency for sustained exploration efforts, resource development, and strategic policy support to ensure Indonesia's leadership in the future of green energy.

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6

Tin

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Image: Tin Ore
Courtesy of: https://mineraldressing.com/wp-content/uploads/rock-tin-ore.jpg

Tin is a chemical element listed on the periodic table with the symbol Sn, derived from the Latin word stannum, and has an atomic number of 50. It is a silvery-white, malleable post-transition metal known for its resistance to corrosion. Tin is widely used in alloys and as a protective coating for other metals to prevent rust. Its most significant ore is cassiterite (SnO_2), although smaller quantities can also be found in sulfide minerals such as stannite (Cu_2FeSnS_4).

Occurrences

Tin deposits occur in two main forms: primary and secondary. Primary deposits are formed through the intrusion of igneous rocks—typically pegmatites or aplites—within magma bodies beneath the Earth's surface, a process known as syngenesis. These deposits can also result from hydrothermal activity, where mineral-rich fluids circulate through the Earth's crust and deposit tin along fractures.

Secondary deposits, on the other hand, are created by the natural weathering and erosion of primary tin sources. Over time, cassiterite from these rocks accumulates as residual concentrations or is transported downslope by gravity, forming colluvial deposits. Once it enters the drainage system, cassiterite may be carried by rivers and deposited in valleys or coastal areas, forming alluvial and marine placer deposits.

This understanding of tin formation is supported by reports from the Global Tin Resources & Reserves Report (2016) and the Geological Agency – Tekmira (2021) (Figure 6.1).

Figure 6.1 Alluvial Tin Mining Landscape in Indonesia: Evidence of Secondary Tin Deposition (Top), Structural Mapping of Hydrothermal Veins in Primary Tin Deposit (Bottom) (GAI, 2021)

History

Tin mining in Indonesia began in the mid-19th century under the Palembang Sultanate. On Bangka Island, it was first exploited by a Dutch state-owned enterprise known as *Banka Tin Winning Bedrijf*. Meanwhile, on Belitung and Singkep Islands, private Dutch companies—*Gemeenschappelijke Mijnbouw Maatschappij Biliton* and *NV. Singkep Tin Exploitatie Maatschappij*—took charge of operations.

Following Indonesia's independence, from 1953 to 1958, these companies were nationalized into state-owned enterprises. In 1961, they were placed under the General Management Board of the State Tin Mining Company (*BPU PN Tambang Timah*), and by 1968, they were merged into a single national company. Since then, Indonesia has remained a major global tin producer, historically ranking as the second-largest worldwide.

The heart of Indonesia's tin industry is Bangka Island, where the mineral was first discovered in the Olin River, Toboali District, during the 18th century by explorers from Siantan and Johor, now part of modern-day Malaysia.

Resources, Reserves, and Production

Indonesia's tin deposits span across four provinces and are identified at 285 locations. The country classifies its tin resources into four categories based on the level of geological confidence: hypothetical, inferred, indicated, and measured. Its reserves are divided into two main groups: probable and proven. These classifications are consistent with international standards and are documented in the Global Tin Resources & Reserves Report (2016) published by the International Tin Association.

Strategic and Critical Mineral Status

Tin holds dual status in Indonesia's national mineral classification system. It is officially designated as a critical mineral under the Minister of Energy and Mineral Resources Decree No. 296.K/MB.01/MEM.B/2023, issued on September 14, 2023.

Furthermore, tin is also recognized as a strategic mineral under Decree No. 69.K/MB.01/MEM.B/2024, dated April 1, 2024. These classifications underscore tin's importance to Indonesia's economy, industrial development, and national interests.

Fluctuating Tin Ore Reserves Amid Stable Resources: A Five-Year Overview (2019–2023)

Indonesia's tin mining sector has long played a significant role in global supply, and an analysis of data from 2019 to 2023 offers valuable insight into the health of the industry (Figure 6.2). While the country continues to demonstrate a substantial base of tin ore resources, its reserves—the portion that is economically extractable—remain volatile and comparatively low. This divergence raises important questions about the progress from exploration to viable production.

Stable Resource Base with Sudden Drop in 2022

For the first three years (2019–2021), Indonesia maintained a stable volume of total ore resources at around 10 to 11 billion tons. These figures suggest consistent identification of tin-bearing ore bodies and point to strong exploration efforts. However, in 2022, there was a marked decline to 7 billion tons, followed by a partial rebound to 8 billion tons in 2023. The drop could reflect re-evaluation of previously identified deposits or a temporary slowdown in exploration activities.

Reserves Remain Critically Low

Despite a robust resource base, ore reserves—which indicate the amount of tin that is economically feasible to extract—have consistently trailed far behind. From 2 billion tons in 2019, reserves rose slightly to 7 billion tons in 2020, only to plummet to 3 billion tons in 2021. The figures stabilized somewhat in 2022 and 2023, hovering at around 6 billion tons, but this is still significantly lower than the total resources, suggesting a lag in turning potential deposits into mine-ready projects.

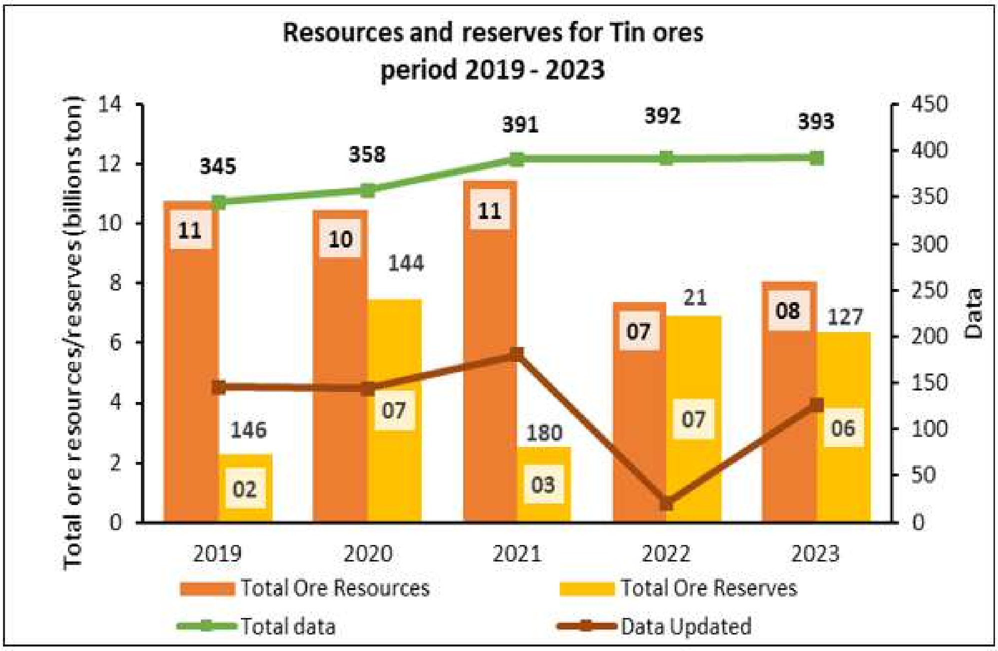

Figure 6.2 Tin Ore Potential and Reserves with Data Updates (2019–2023) (Nursahan, et al., 2024)

This discrepancy may be attributed to a range of factors, including technical constraints, environmental or regulatory hurdles, or economic considerations like market price or extraction cost.

Data Collection Remains Strong, Updates Fluctuate

The number of data entries collected over the period shows a consistent rise—from 345 records in 2019 to 393 in 2023. This upward trend reflects the government's ongoing commitment to mapping and monitoring tin resources. However, the number of data updates, which reflects efforts to verify, revise, or improve previously collected information, paints a more erratic picture.

In 2021, the highest number of updates was recorded at 180, but the figure fell sharply to 21 in 2022. It then improved to 127 in 2023. These fluctuations could be influenced by changes in funding, workforce availability, or shifting priorities within the geological survey programs.

Implications for the Industry

The trends seen over this five-year period highlight a key concern: Indonesia's abundant tin ore resources are not translating efficiently into proven reserves. Without steady investment in feasibility studies, reserve estimation, and project development, the country risks underutilizing its mineral wealth.

At the same time, consistent growth in data collection indicates a strong foundation for future development. The challenge lies in translating that data into actionable insights and viable mining projects.

Conclusion

Indonesia's tin sector remains rich in geological potential, as evidenced by its large ore resource base. However, the limited and fluctuating reserve levels underscore the need for more robust reserve classification and mining project maturation. With proper alignment between exploration, data management, and development strategy, the country can better leverage its tin resources for long-term economic benefit.

Indonesia's Tin Metal Landscape: Rising Resources, Shrinking Reserves (2019–2023)

Indonesia, one of the world's key tin producers, has seen significant shifts in its tin metal resources and reserves between 2019 and 2023. Based on recent data, the country has made considerable progress in identifying new tin resources, yet faces challenges in maintaining and increasing its confirmed reserves. Two complementary graphs provide a clear picture of this evolving trend (Figure 6.3 and Figure 6.4).

Uptrend in Resources, Downtrend in Reserves

The first chart (Figure 6.3), Comparison of Tin Metal Resources and Reserves (2019–2023), categorizes the nation's tin inventory into five key classifications: Inferred, Indicated, Measured, Probable, and Proved. These categories provide insights into the level of confidence in the geological data and the economic feasibility of extraction.

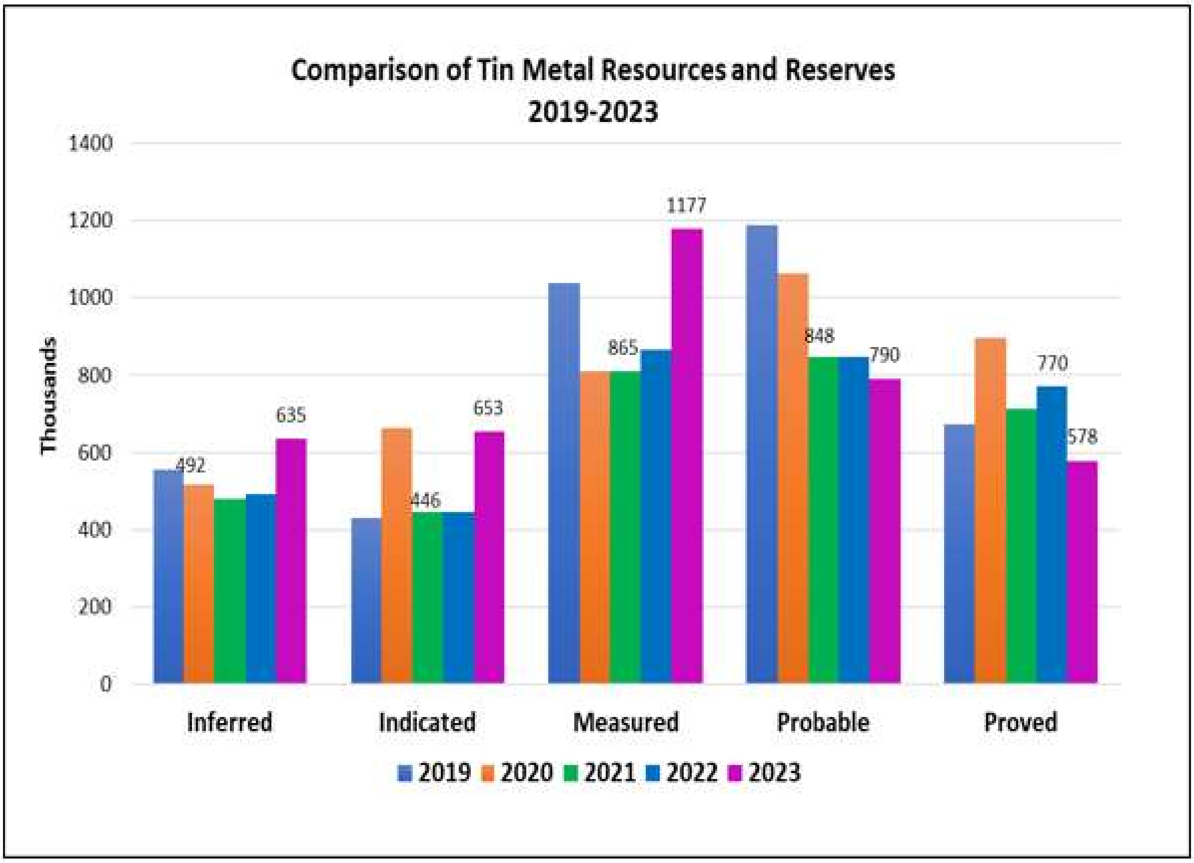

Figure 6.3 Categorical Analysis of Tin Metal Resources and Reserves (2019–2023) (Nursahan, et al., 2024)

One of the most notable developments is the significant rise in Measured resources, which climbed from 865 thousand tons in 2021 to a record 1,177 thousand tons in 2023. Similarly, Inferred and Indicated resources have shown a consistent upward trend, suggesting successful exploration and growing geological knowledge.

However, Probable and Proved reserves – the categories that reflect the most confidence and are closest to commercial production – have declined. Probable reserves dropped from 1,197 thousand tons in 2019 to 790 thousand tons in 2023, while Proved reserves decreased from 890 thousand tons in 2020 to just 578 thousand tons in 2023. This divergence suggests that while more tin is being discovered, less of it is being confirmed as economically extractable under current conditions.

Total Resources Surge, but Confirmed Reserves and Updates Lag

The second graph (Figure 6.4), Total Resources and Reserves for Tin Metal (2019–2023), presents an aggregated view of total tin metal resources and reserves, while also illustrating the amount of data collected and updated annually.

The total tin metal resources surged dramatically in 2023 to 2,465 thousand tons, up from 1,803 thousand tons in 2022. This jump represents a major gain in national tin inventory, driven by intensified exploration and re-evaluation of existing deposits.

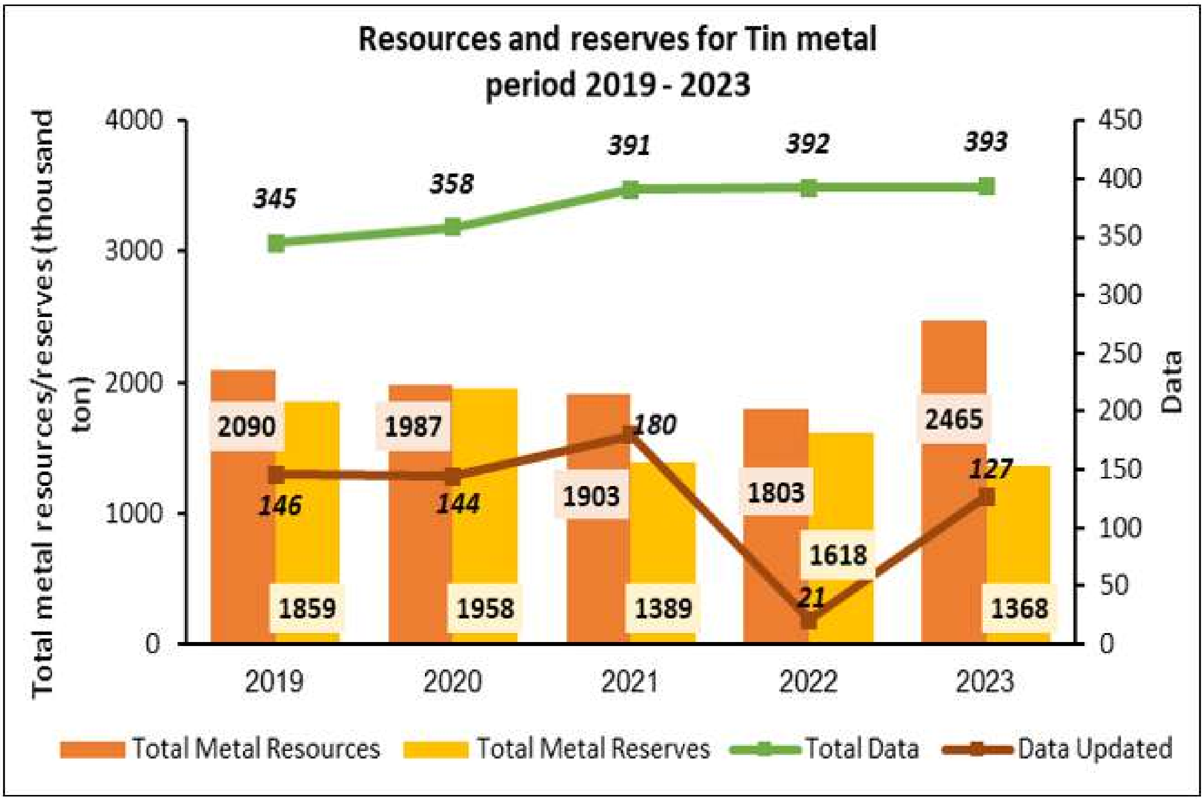

Figure 6.4 Annual Comparison of Tin Metal Resources, Reserves, and Data Updates (2019–2023) (Nursahan, et al., 2024)

Conversely, total reserves continued a downward trend, declining from 1,958 thousand tons in 2020 to 1,368 thousand tons in 2023. This sharp contrast between resource growth and reserve depletion raises concerns about the pace of reserve verification and conversion.

In terms of data management, total data entries increased steadily from 345 in 2019 to 393 in 2023, indicating continuous field activity and geological assessments. However, the number of updated data entries has fluctuated – peaking in 2021 at 180, plummeting to 21 in 2022, then rebounding to 127 in 2023. These inconsistencies may reflect budget constraints, technical limitations, or delays in reserve classification.

Implications and Way Forward

Indonesia’s tin sector is at a crossroads. The growing inventory of inferred and measured resources offers a strong foundation for future development, but the declining reserves highlight the need for more robust confirmation processes and reserve feasibility studies. Without converting more resources into proved and probable reserves, production sustainability could be at risk.

To bridge this gap, stronger investment in reserve exploration, technological upgrades, and regulatory streamlining will be essential. Additionally, consistent and timely updates of geological data will improve transparency and planning across the mining value chain.

In summary, while Indonesia continues to discover more tin beneath its soil, ensuring that these resources can be efficiently and economically brought to the surface remains the next big challenge.

Global Tin Trends (2017–2023) and Indonesia's Strategic Position

Global Tin Market: From Shortage to Surplus

Over the period from 2017 to 2023 (Figure 6.5), the global tin market witnessed a dynamic shift shaped by industrial demand, economic slowdowns, and post-pandemic recovery. In 2020, global tin production dropped sharply to 337 thousand tons due to COVID-19's impact on mining operations. Despite this, consumption remained relatively strong, leading to a temporary supply deficit.

A rebound came swiftly in 2021, with production jumping to 379 thousand tons. However, by 2023, the market began showing early signs of a mild surplus, as global production reached 370 thousand tons while consumption fell to 360 thousand tons. This slight imbalance reflects weakening global demand amid economic uncertainty, inflation, and increasing recycling efforts in electronics and soldering industries.

Indonesia's Tin Industry: Heavyweight in Global Supply

Indonesia, consistently among the world's top tin producers, has an outsized influence on global supply. Most of its tin comes from the Bangka-Belitung Islands, and the country remains highly export-oriented in its approach.

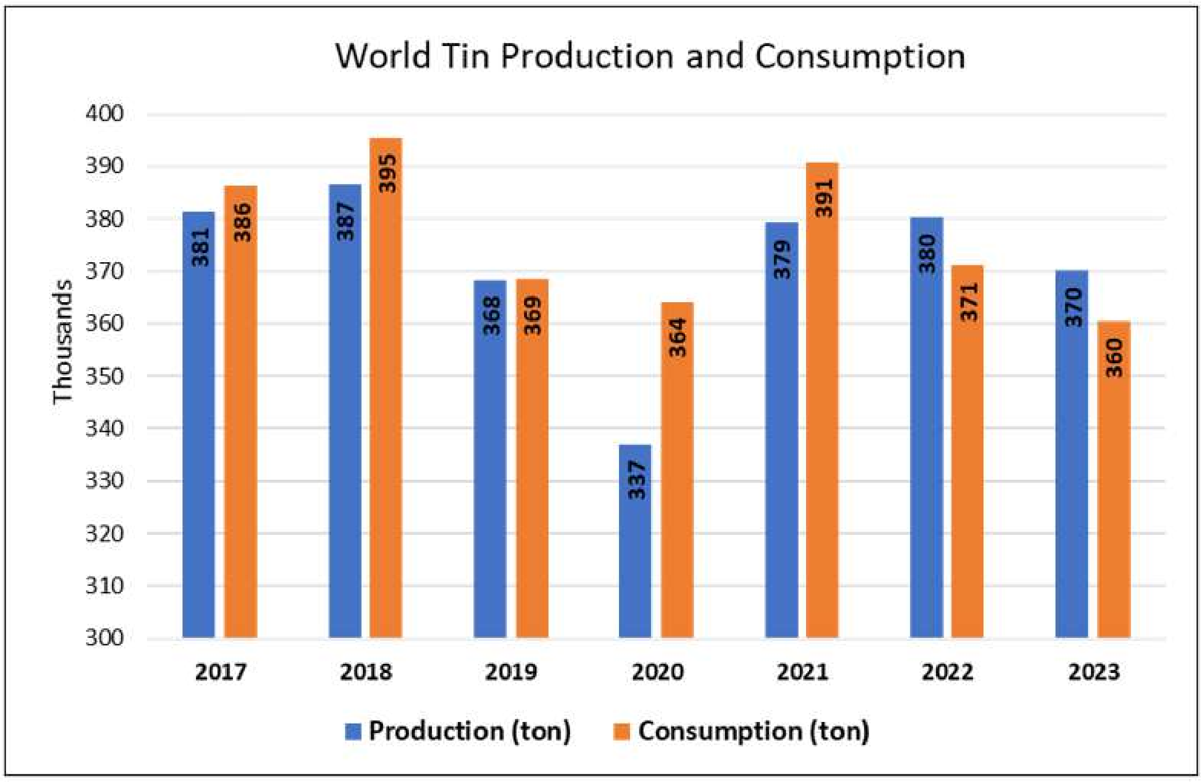

Figure 6.5 Global Trends in Tin Production and Consumption (2017–2023) (USGS, 2018 - 2024)

From 2020 to 2022, Indonesia's tin production remained relatively stable, averaging around 70 to 77 thousand tons annually. In 2023, however, production dropped significantly to about 60 thousand tons. This decline may be linked to tighter government regulations, global price drops, and efforts to push the industry toward downstream processing (Figure 6.6).

Despite the fluctuation in production, exports consistently accounted for over 90% of Indonesia's output. Domestic consumption, on the other hand, has stayed low—hovering at just around 4,000 tons per year. This highlights a critical challenge: Indonesia produces a lot of tin but uses very little of it internally.

Bridging the Gap: Turning Resources into Industrial Strength

Indonesia's reliance on exports makes its tin industry vulnerable to global market swings. With worldwide demand softening and prices stabilizing, the time is ripe for Indonesia to shift its strategy from raw exports to value-added processing.

Government efforts are now focused on:

- Downstream industrialization, such as developing local industries for electronics, solar panels, and electric vehicle batteries.
- Policy reforms, including potential raw tin export restrictions to encourage smelting and advanced manufacturing at home.
- Sustainability enforcement, to ensure that production meets international ESG standards and keeps Indonesia competitive in the long term.

Figure 6.6 Indonesia's Tin Ingots: Production, Export, and Domestic Sales (2019–2022) (MEMR, 2023)

Looking Ahead: Strategic Realignment

As the global tin market heads toward a more balanced—if not oversupplied—state, Indonesia must prepare to reposition itself. Rather than just supplying the world, it has the potential to build a robust domestic ecosystem that processes, innovates, and exports value-added tin products.

By doing so, Indonesia won't just remain a key player—it will become a leader in shaping the future of the global tin industry.

Indonesia's Tin Reserves on a Ticking Clock: 26 Years Remaining at Current Production Rates

Indonesia, one of the world's leading tin producers, is facing a critical timeline regarding the sustainability of its tin reserves. Based on current production trends and reserve data, Indonesia's tin reserves—estimated at 2.23 million tons—are expected to be exhausted by 2046, if annual production continues at the projected rate of 85,000 tons per year (Figure 6.7).

A Closer Look at the Projections

Data sourced from PT Timah and other mining concessions, analyzed by the International Tin Research Institute (ITRI) and CRU in 2020, paints a clear picture: Indonesia's tin production is expected to rise from 78.19 thousand tons in 2020 to a steady output of 85.32 thousand tons per year by 2030, which will remain constant through 2046.

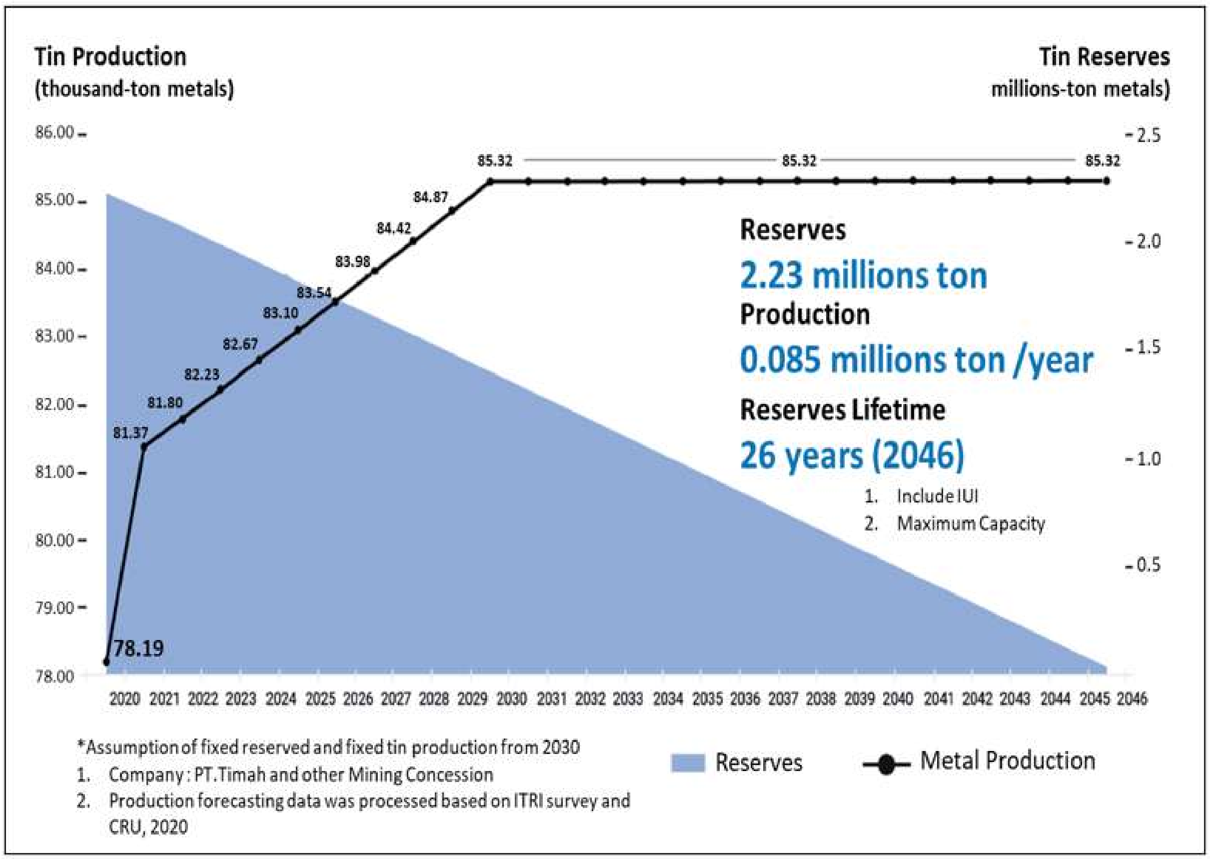

Figure 6.7 Projected Tin Production and Reserve Depletion in Indonesia (2020–2046)

While the production increase signals operational efficiency and demand responsiveness, it comes with a cost—rapid reserve depletion. The chart's projection of reserve decline forms a steep downward slope, emphasizing the non-renewable nature of this vital resource.

Strategic and Economic Implications

This projection has profound implications not only for Indonesia's mining sector but also for its broader economy. Tin is an essential metal used in soldering, electronics, and packaging, and Indonesia's role as a key global supplier means that reserve depletion could ripple through international supply chains.

Locally, the tin industry supports thousands of jobs and contributes significantly to export earnings, particularly from Bangka-Belitung Islands, the country's main tin-producing region. Without significant discovery of new reserves or advancement in tin recycling technologies, Indonesia's position as a leading exporter could decline, potentially impacting national revenue and regional development.

The Need for Urgent Action

The 26-year horizon serves as a stark reminder of the urgency to:

- Explore new reserves, especially offshore and underutilized areas.
- Invest in technological innovation to improve tin recovery and recycling rates.
- Diversify economic reliance on tin by strengthening other sectors, particularly value-added manufacturing and processing of tin-based products.
- Implement sustainable mining practices to prolong reserve life and reduce environmental impacts.

Conclusion

Indonesia's tin industry is entering a critical period. While production capacity is strong and stable, the reserve timeline is finite. This duality highlights the importance of forward-looking policy, technological advancement, and sustainable resource management. The clock is ticking—decisions made in the next few years will determine whether Indonesia can continue to play a dominant role in the global tin market beyond 2046.

Unlocking Indonesia's Offshore Tin Potential and Advancing Downstream Development

Onshore and offshore alluvial tin deposits—particularly around the Bangka and Belitung Islands—continue to hold substantial potential for further development. While dredging methods have been successfully applied in shallow waters over the past few decades, deeper offshore deposits remain largely untapped due to technical limitations. These large, far-offshore tin deposits cannot yet be mined using conventional dredging techniques. However, several private companies in Indonesia are actively exploring the feasibility of using borehole mining methods as a potentially practical and economical solution to access these deeper resources (Global Tin Resources & Reserves Report, 2016).

According to the 2023 Tin Resources and Reserves Balance data (Nursahan et al., 2024), Indonesia's tin reserves in offshore areas are as follows:

- Total Offshore Tin Ore Resources: 3.71 billion m³
- Total Offshore Metallic Tin Resources: 730,915.97 tons
- Total Offshore Tin Ore Reserves: 974.95 million m³
- Total Offshore Metallic Tin Reserves: 334,103.85 tons

These figures demonstrate the vast resource base that remains available—if properly harnessed—to secure the future of Indonesia's tin industry.

In addition to tin minerals, offshore deposits also contain associated valuable minerals, which are concentrated alongside tin due to their similar durability and relatively small differences in specific gravity. These include monazite, xenotime, magnetite, rutile, ilmenite, zircon, and quartz. Such associated minerals can be physically separated from tin using gravity, magnetic, and electrostatic separation techniques, opening opportunities for multi-mineral extraction and increased economic value.

Current Production and Export Landscape

In 2023, Indonesia's tin mining industry produced 93,664 tons of tin ore, which yielded 73,068 tons of refined tin metal. Of this, approximately 68,426 tons—or 93%—was exported, primarily in the form of tin ingots. The remaining volume was processed domestically.

Domestic processing of tin metal is currently undertaken by two key players:

- PT Latinusa (PT Lapis Timah Nusantara) processes approximately 126,000 tons of tin to produce tinplate.
- PT Timah Industri manufactures 6,563 tons of tin chemicals and 611 tons of tin solder annually.

However, due to insufficient domestic supply, PT Latinusa must import tin metal to fulfill its production requirements.

Urgency of Downstream Development (*Hilirisasi*)

The continued export of raw tin metal in large quantities remains a major challenge to Indonesia's goal of industrial downstreaming (*hilirisasi*). Realizing this vision requires a shift toward increased domestic processing and manufacturing of tin derivatives, such as tinplate, solder, chemicals, and electronic components.

This transformation would yield significant economic benefits, including:

- Higher added value from processed products
- Greater job creation across mining, manufacturing, and logistics sectors
- Reduced dependence on imported tin for domestic industries
- Increased foreign investment and infrastructure development
- Strengthened national industrial resilience

If Indonesia could domestically process even a portion of the 93% of raw tin currently exported, the multiplier effect on the economy would be substantial—spanning from increased employment to enhanced technological capacity and industrial growth.

Conclusion

Indonesia stands at a pivotal juncture in its tin industry. With vast untapped offshore resources and growing domestic industrial needs, the country has both the potential and responsibility to move beyond raw commodity exports. Through technological innovation, strategic investment, and strong policy support for *hilirisasi*, Indonesia can transform its tin wealth into sustainable, long-term economic prosperity.

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Nickel-Cobalt

Image: Nickel Ore with Garnierite
Courtesy of: Sulaeman, et al., 2017

Nickel is a chemical element with the symbol Ni and atomic number 28. It is a transition metal that exhibits characteristics of both ferrous and non-ferrous metals. Nickel is considered both siderophile (iron-loving) and chalcophile (sulfur-loving), meaning it readily associates with iron and sulfur in geological environments. As a hard, ductile metal with excellent resistance to oxidation and corrosion, nickel is a critical material for a wide range of industrial applications, including stainless steel production, batteries, metal plating, and superalloys used in aerospace.

Nickel is the second most abundant metal alloying element after manganese. Although it constitutes about 3% of the Earth's core, its concentration in the Earth's crust is relatively low—approximately 0.003%.

Nickel occurs in numerous minerals, though many of these are rare or primarily found in meteorites. Due to its chemical similarity, nickel can substitute for elements like iron and cobalt in a variety of mineral structures. Economically viable concentrations of nickel are found in two primary forms: sulfide deposits and laterite deposits.

The most significant nickel-bearing sulfide mineral is pentlandite, typically found alongside pyrrhotite, chalcopyrite, and pyrite in mafic and ultramafic igneous rocks. In lateritic deposits, which are formed by intense weathering of ultramafic rocks in tropical climates, the key nickel-bearing minerals are garnierite (a nickel-magnesium phyllosilicate) and nickeliferous limonite (a nickel-rich iron oxide).

Cobalt is a chemical element with the symbol Co and atomic number 27. While some cobalt is extracted from primary cobalt minerals such as cobaltite (CoAsS), the majority is produced as a by-product of nickel and copper mining.

Nickel-Cobalt (Ni-Co) laterite deposits, which form through prolonged weathering of ultramafic rocks, are among the most important sources of both nickel and cobalt. The formation of economically viable Ni-Co laterites depends on the presence of a nickel-enriched parent rock and the right climatic and geological conditions to concentrate the metals near the surface.

Occurrences

More than 70% of the world's nickel reserves are found in nickel laterite deposits. However, only about 40% of these laterite reserves have been utilized for nickel production in various forms (Mariana, 2018).

According to Kyle (2010), lateritic nickel deposits typically develop in four main weathering zones: a) Red limonite "iron cap", b) Yellow limonite zone, c) Transition zone, and d) Saprolite zone (Figure 7.1).

In Indonesia, lateritic nickel deposits are predominantly associated with ultramafic rocks, commonly occurring in Southeast Sulawesi and Southeast Halmahera. Smaller occurrences are also found in the Maluku Islands, West Papua, North Papua, West South Sulawesi, and South Kalimantan.

Due to Indonesia's tropical climate, nickel deposits in the country primarily occur as laterites, formed through intensive weathering of ultramafic rocks. This weathering process results in a predictable vertical profile consisting of five distinct zones - from bottom to top: a) Unweathered ultramafic bedrock, b) Weathered bedrock (saprolite), c) Clay-rich layer, d) Limonite zone, and e) Iron cap.

Economic lateritic nickel deposits typically develop in areas with low topographic relief, as variations in elevation can affect the thickness and distribution of the ore body.

The average grade of nickel-cobalt laterites is around 1.3% Ni and 0.04% Co. Deposits with nickel content exceeding 1.5% are classified as medium-grade, while those with over 1.8% Ni are considered high-grade. The formation and quality of nickel laterites are influenced by several geological and environmental factors, including: a) Parent rock composition, b) Climatic conditions, c) Rate of weathering, d) Groundwater drainage, and e) Tectonic setting (Figure 7.2).

According to the U.S. Geological Survey (USGS, 2023), Indonesia has emerged as the world's largest holder of nickel reserves, with an estimated 55 million metric tons as of 2023. This accounts for approximately 42.3% of global nickel reserves, which were estimated at 130 million metric tons. Furthermore, Indonesia solidified its position as the world's leading nickel producer in 2023, contributing approximately 1.8 million metric tons, or 50% of global nickel production.

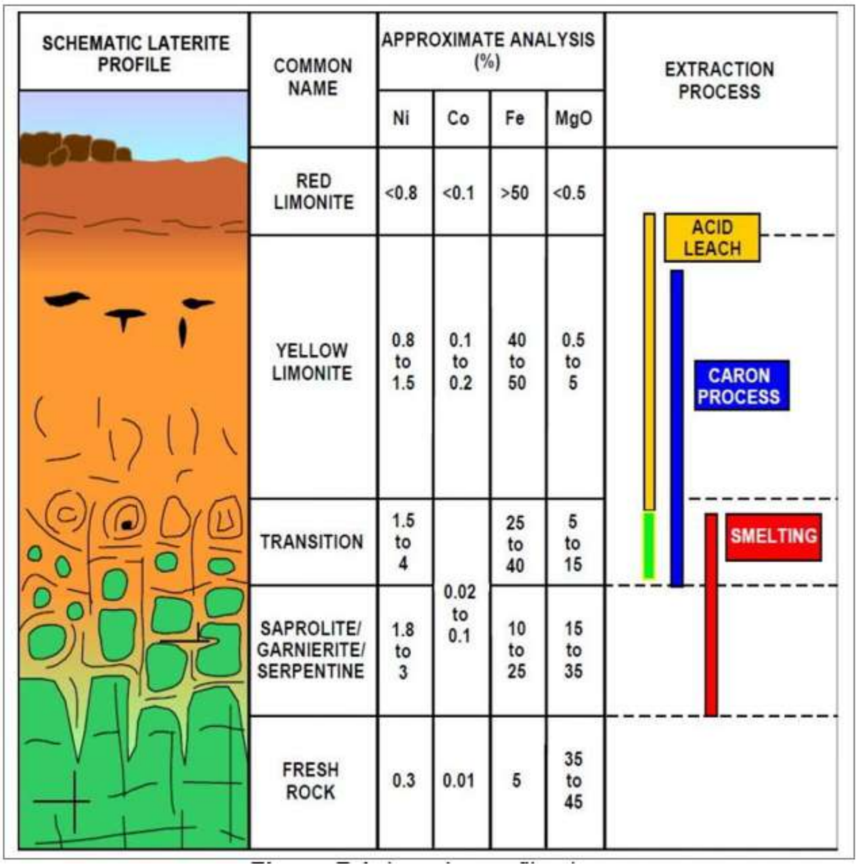

Figure 7.1 Schematic Laterite Profile: Composition and Extraction Processes of Nickel-Bearing Zones (Kyle, 2010)

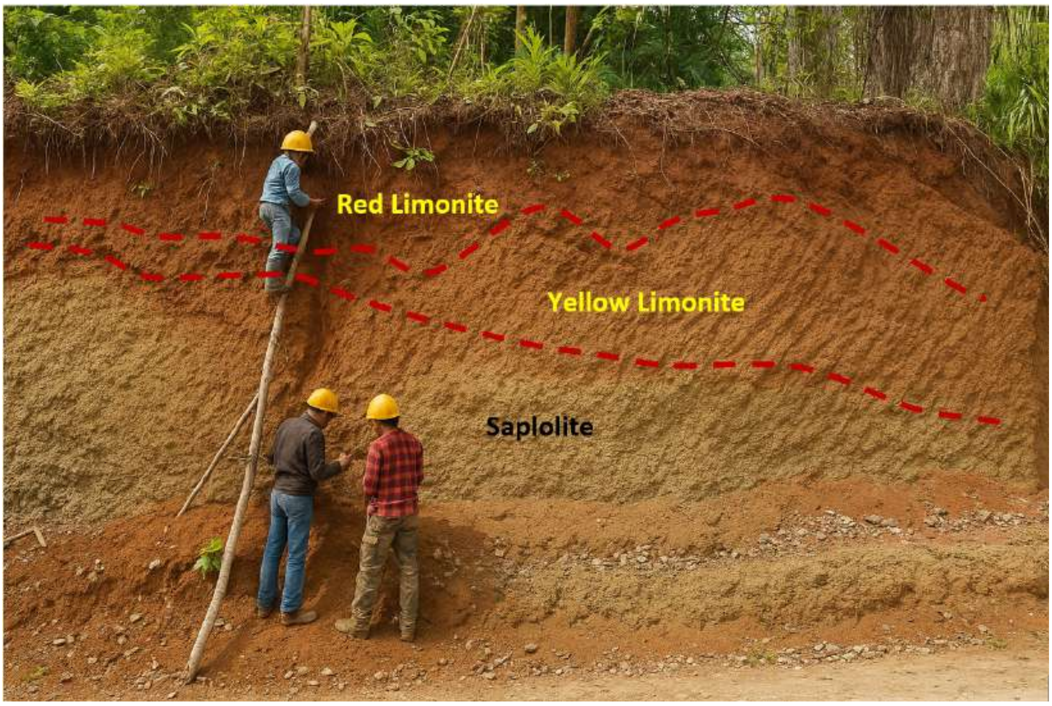

Figure 7.2 Field Exposure of Lateritic Nickel Profile in Gebe Island, North Maluku Showing Red Limonite, Yellow Limonite, and Saprolite Zones (Sulaeman, et al., 2020)

Indonesia's Nickel Resources and Reserves 2023: A Comprehensive Breakdown

The 2023 data on Indonesia's nickel resources and reserves reveal a robust national inventory, showcasing the country's strategic significance in the global nickel supply chain. The graphical distribution (Figure 7.3) of ore (in billion wet metric tons - wmt) and metal content (in million tons) across different resource classifications—Inferred, Indicated, Measured, Probable, and Proven—provides valuable insight into the scale and confidence level of these reserves.

1. Inferred Resources

The Inferred category holds the largest volume of nickel ore, estimated at 8.7 billion wmt, containing 92.2 million tons of nickel metal. This category reflects resources with lower geological confidence but significant potential for future development through further exploration.

2. Indicated Resources

In the Indicated category, the total ore is 6.1 billion wmt, containing approximately 55.65 million tons of nickel metal. These resources are supported by more reliable geological data compared to inferred resources and present a strong foundation for feasibility studies and mine planning.

3. Measured Resources

Measured resources show a further increase in confidence level with 3.8 billion wmt of ore, holding 36.8 million tons of nickel metal. These figures represent resources confirmed through detailed exploration, sampling, and testing, making them a critical part of long-term mine development planning.

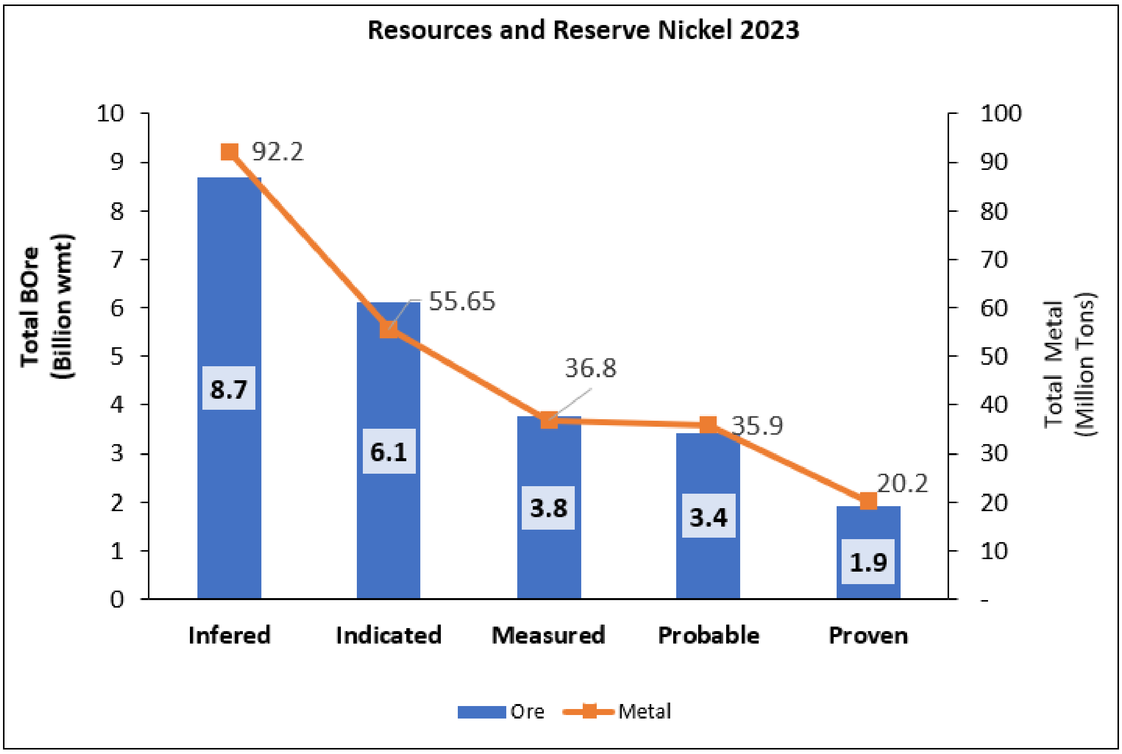

Figure 7.3 Nickel Ore and Metal Resource-Reserve Classification in Indonesia, 2023 (Nursahan, et al., 2024)

4. Probable Reserves

Moving from resources to reserves, the Probable category represents ore with reasonable prospects for economic extraction. This group contains 3.4 billion wmt of ore and 35.9 million tons of nickel metal, indicating a strong conversion of measured and indicated resources into economically viable reserves.

5. Proven Reserves

At the highest confidence level, Prove reserves comprise 1.9 billion wmt of ore and 20.2 million tons of nickel metal. These figures are derived from detailed technical and economic assessments, making them the most reliable category for immediate mining operations.

Strategic Implications

This breakdown highlights that while the largest share of nickel resources lies in the inferred category, a substantial portion has progressed to measured and reserve classifications, reinforcing Indonesia's position as a critical nickel supplier globally. The data also emphasize the country's need to accelerate resource-to-reserve conversion, ensuring that exploration activities are followed by investment in feasibility studies and extraction infrastructure.

As demand for nickel continues to surge—driven by stainless steel production and battery manufacturing for electric vehicles—Indonesia's extensive nickel portfolio underpins its critical role in the energy transition and green economy.

Growth Trends in Indonesia's Nickel Ore Resources and Reserves (2019–2023)

Indonesia has experienced a consistent increase in its nickel ore resources over the past five years, as shown in the graph titled "Nickel Ore Resources and Reserves in Indonesia (2019–2023)" (Figure 7.4). The total nickel ore resources have risen from 11.8 billion wmt in 2019 to 18.6 billion wmt in 2023, highlighting the nation's ongoing exploration success and the strategic importance of nickel for industrial and energy transition goals.

In 2019, Indonesia recorded 11.8 billion wmt of total ore resources and 4.6 billion wmt of ore reserves, with 119 data updates and 318 total data entries. By 2023, these figures rose to 18.6 billion wmt in resources and 5.3 billion wmt in reserves, with 67 data updates from 394 total data entries. This steady growth, despite some fluctuation in the number of data updates, underscores the increasing geological understanding and reporting of nickel deposits across the archipelago.

The total ore reserves have remained relatively stable over the years, ranging from 4.6 to 5.3 billion wmt, indicating ongoing efforts to convert resources into economically viable reserves. Meanwhile, the number of data entries (shown in green) has increased steadily from 318 in 2019 to 394 in 2023, suggesting continuous mapping, drilling, and reporting by mining companies and geological agencies.

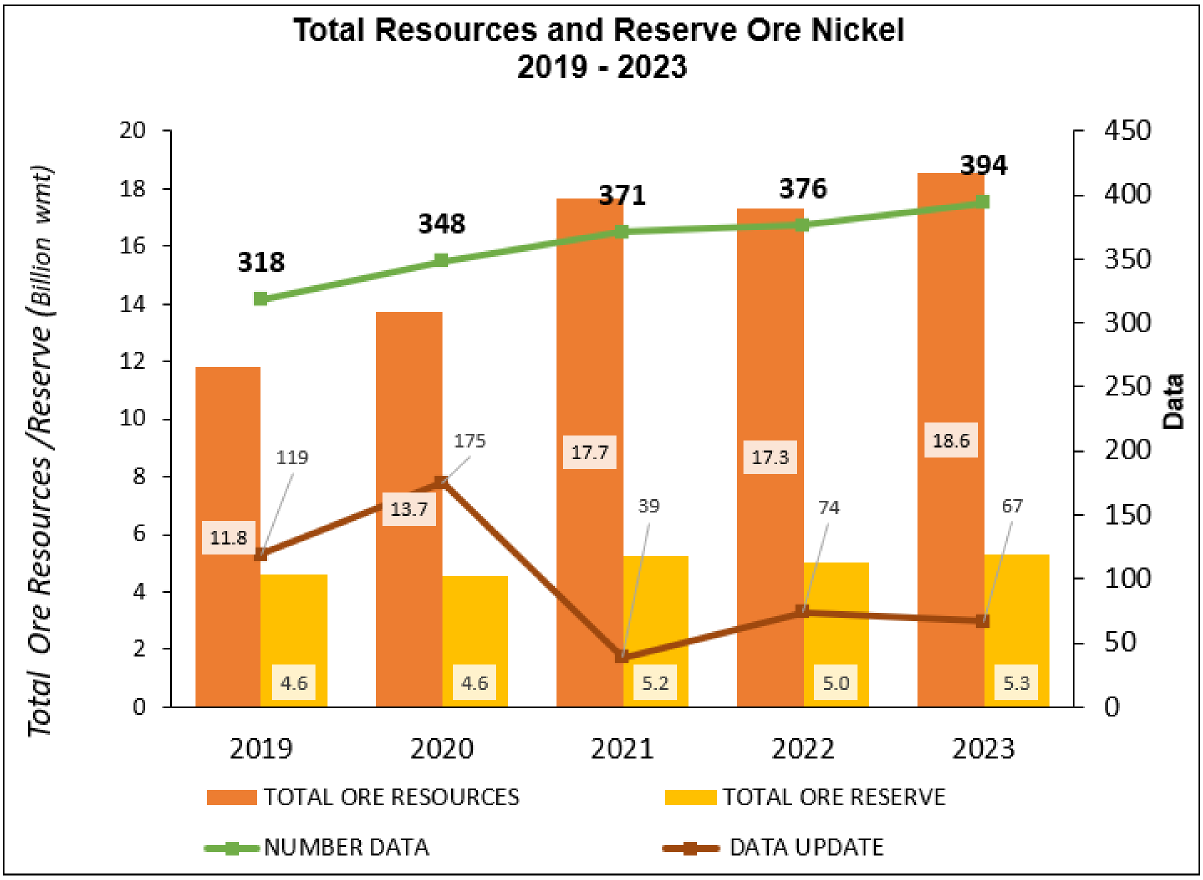

Figure 7.4 Nickel Ore Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

Although the number of new data updates (brown line) peaked in 2020 with 175 entries, a sharp drop occurred in 2021 (39 entries) before recovering slightly in the following years. This fluctuation may be linked to field accessibility, regulatory changes, or shifts in exploration priorities.

This dataset reaffirms Indonesia's position as a global nickel powerhouse and reflects strong national efforts in exploration, resource evaluation, and reserve certification—critical steps in securing long-term supply for the global electric vehicle (EV) and stainless steel industries.

Nickel Metal Resources and Reserves in Indonesia Show Upward Trend Through 2023

Indonesia's nickel metal resources and reserves have shown encouraging growth between 2019 and 2023, underscoring the country's strategic role in the global nickel supply chain. As illustrated in the graph titled "Nickel Metal Resources and Reserves in Indonesia (2019–2023)," (Figure 7.5) the total metal resources have steadily increased from 170 million tons in 2019 to 185 million tons in 2023. Despite fluctuations in reserve figures and data updates, this overall rise signals continued investment and interest in the country's vast laterite nickel potential.

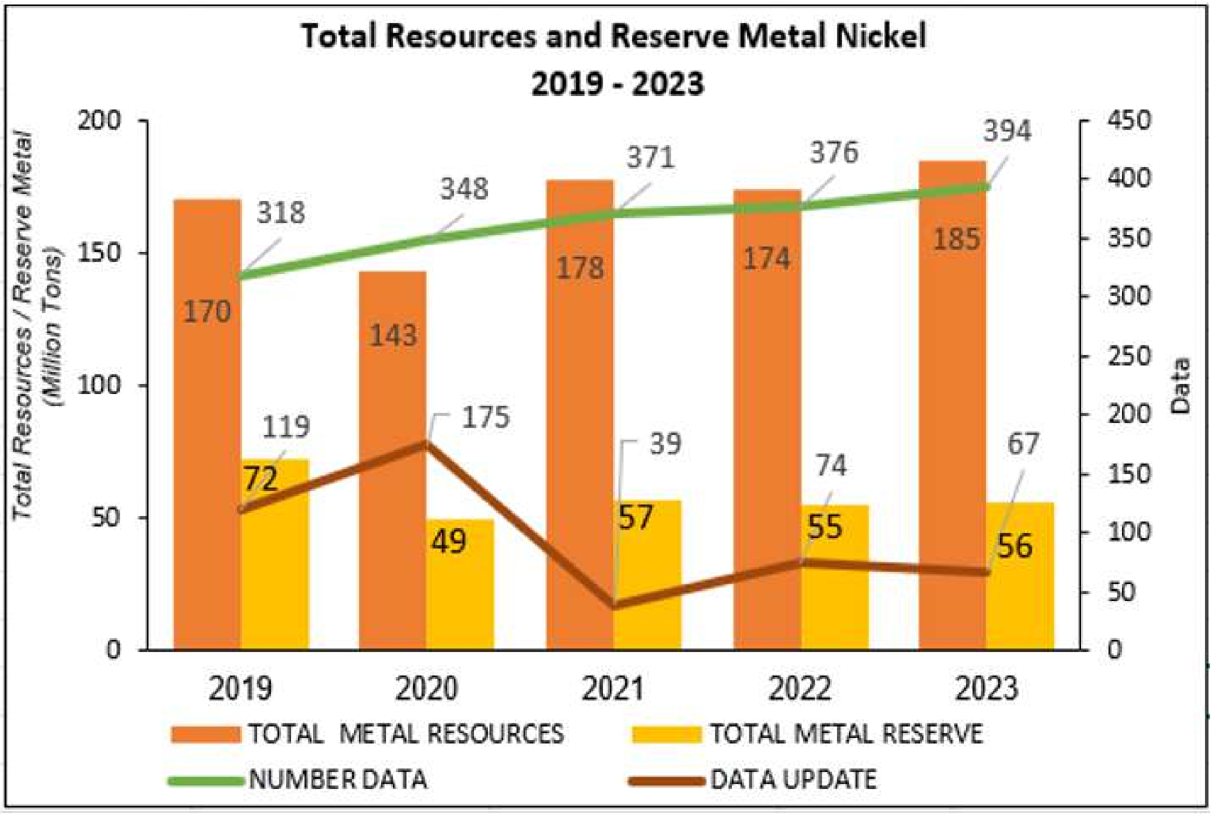

Figure 7.5 Nickel Metal Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

In 2019, total nickel metal resources stood at 170 million tons, with 72 million tons of reserves, 119 data updates, and 318 total data records. A slight dip was observed in 2020, when resources declined to 143 million tons and reserves to 49 million tons, despite a spike in data updates to 175—suggesting reevaluation or reclassification of previous data.

The following years saw a rebound. By 2021, metal resources climbed to 178 million tons, and reserves improved to 57 million tons, although data updates dropped significantly to just 39. In 2022, the figures stabilized at 174 million tons of resources and 55 million tons of reserves, with 74 data updates, indicating a stronger push in exploration activity.

As of 2023, Indonesia's total nickel metal resources peaked at 185 million tons, while metal reserves reached 56 million tons, supported by 67 data updates from 394 recorded datasets—the highest number in the five-year period. This highlights both growing geological knowledge and the progressive integration of new exploration results.

Indonesia’s increasing nickel metal inventory reaffirms its vital position as a leading supplier for stainless steel and battery-grade nickel in the electric vehicle (EV) industry. Continuous exploration and reliable reserve reporting will be key in ensuring sustainable development and long-term resource security.

Indonesia's Cobalt Resources Continue to Expand Despite Reserve Fluctuations (2019–2023)

The graph titled "Cobalt Metal Resources and Reserves in Indonesia (2019–2023)" (Figure 7.6) highlights a significant upward trend in Indonesia's cobalt metal resources over the five-year period, confirming the country's strategic importance in supplying this critical element for battery and clean energy technologies.

From 2019 to 2023, total cobalt metal resources more than doubled—from 4,153 thousand tons in 2019 to 9,267 thousand tons in 2023. This consistent increase reflects extensive exploration efforts and growing interest in Indonesia's laterite nickel-cobalt deposits, particularly with the rise of the electric vehicle (EV) market.

While metal reserves fluctuated, the overall trend remained positive. In 2019, the reserves stood at 1,072 thousand tons, but fell sharply to 564 thousand tons in 2020 and 484 thousand tons in 2021. Slight recovery occurred in 2022 and 2023, where reserves rose to 493 thousand tons and 643 thousand tons, respectively. These shifts may indicate reclassification of reserves, changes in economic viability, or adjustments following more detailed resource evaluations.

Data updates were relatively modest compared to other commodities, with only 2 updates in 2022 and 6 in 2023, indicating either a stabilization in data or slower reporting pace. However, the number of total data records increased steadily from 81 in 2019 to 93 in 2023, demonstrating continued data accumulation and resource documentation.

This upward trajectory in cobalt metal resources places Indonesia as a major emerging player in the global cobalt market. Continued development, responsible mining practices, and investment in processing technologies will be essential for Indonesia to capitalize on its growing cobalt base while maintaining environmental and social standards.

Based on the 2023 summary of nickel resources and reserves, the highest concentrations are found in Southeast Sulawesi, North Maluku, and Central Sulawesi provinces, as illustrated in Figure 7.7. These three regions represent the primary hubs of Indonesia's nickel potential, underscoring their strategic importance in the national mineral landscape. Similarly, the distribution of cobalt resources and reserves is predominantly located in Southeast Sulawesi, followed by North Maluku, West Papua, and Central Sulawesi, highlighting the significant overlap in mineral-rich zones between the two critical battery metals.

Nickel Resources and Reserves by Grade Threshold

The characteristics of nickel grades in Indonesia vary widely, ranging from 0.4% to 2.73%. This diversity plays a significant role in determining the appropriate processing method, with the critical threshold typically set at 1.5% nickel content. According to the Booklet Nikel 2021 by ESDM, nickel ore processing in Indonesia is classified based on this threshold to align with the technological capacities of smelters. Ores with Ni content >1.5% are generally processed using pyrometallurgical methods, while those with Ni <1.5% are used in hydrometallurgical processes (e.g., HPAL).

As of 2023 (Table 7.1), total nickel resources amounted to approximately 184.6 million tons (in nickel metal content). Of this total, 48% or 89 million tons contain Ni > 1.5%, while the remaining 52% (approximately 95.6 million tons) have Ni < 1.5%. This implies that more than half of Indonesia's nickel resources currently fall outside the preferred range for existing pyrometallurgical smelters.

In terms of reserves, the total was recorded at 56.1 million tons of nickel content. A significant majority—67% or 37.5 million tons—have Ni content above 1.5%, aligning with the feedstock requirements of most nickel smelters. The remaining 33%, or 18.5 million tons, consist of low-grade reserves, primarily derived from the limonite zone.

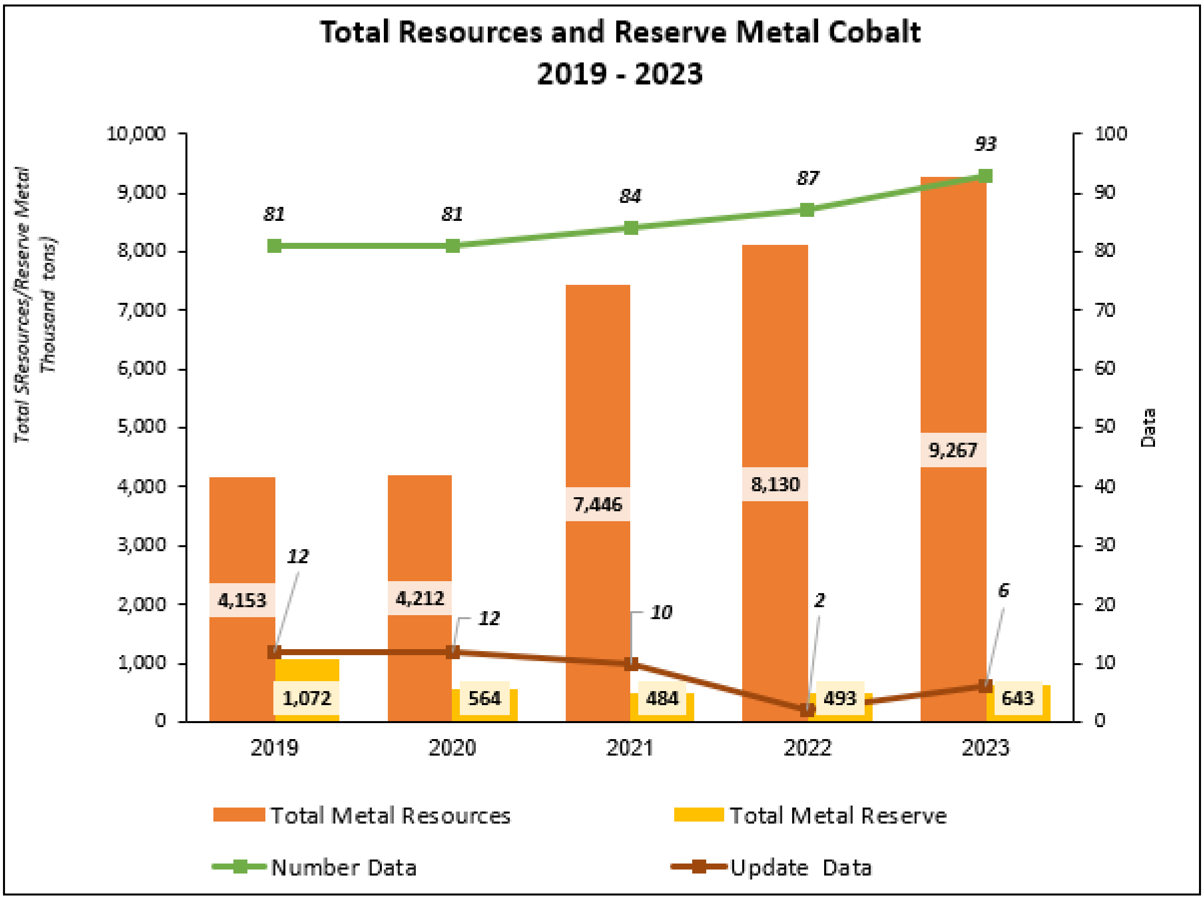

Figure 7.6 Cobalt Metal Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

Table 7.1 Estimation of Nickel Resources and Reserves by Grade Classification (<1.5% Ni and >1.5% Ni) (Nursahan, et al., 2024)

Ni Grade	Resources (Million Tons)						Reserve (Million Tons)			
	Infered		Indicated		Measured		Probable		Proven	
	Ore (wmt)	Metal	Ore (wmt)	Metal	Ore (wmt)	Metal	Ore (wmt)	Metal	Ore (wmt)	Metal
Ni <1,5 %	5,096.91	35.32	3,979.98	29.30	1,970.95	14.00	1,615.06	13.39	446.44	3.61
Ni >1,5%	3,580.86	56.91	2,128.13	26.28	1,793.53	22.79	1,766.23	22.52	1,456.06	16.60
Total	8,677.76	92.23	6,108.12	55.59	3,764.48	36.79	3,381.30	35.91	1,902.50	20.21

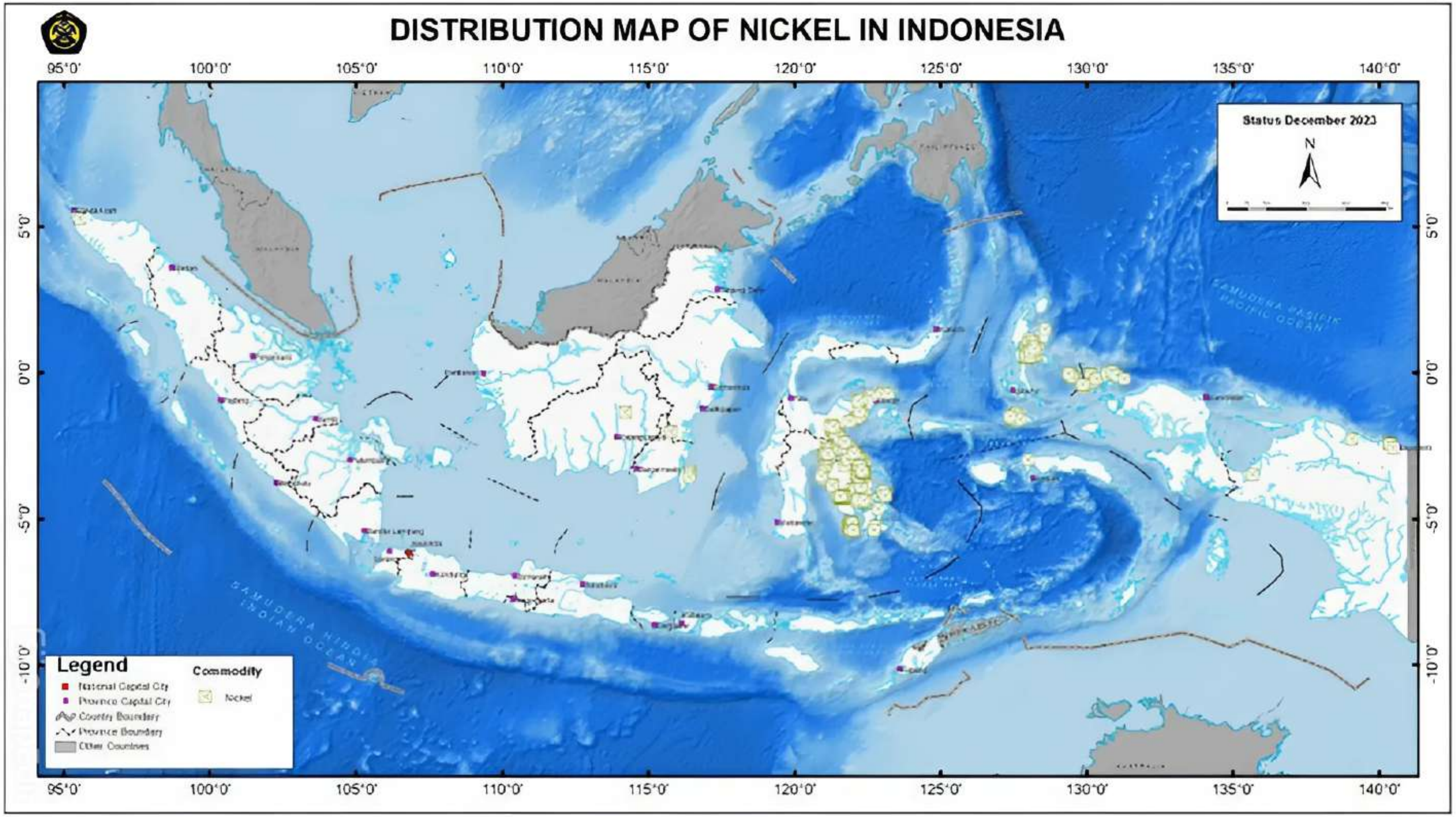

Figure 7.7 Geographical Distribution of Nickel Resources in Indonesia – December 2023 (GAI, 2024)

This distribution highlights two key insights: First, although a large volume of low-grade nickel exists, its economic value and suitability for smelting are more limited. Second, the relatively higher share of high-grade nickel in proven reserves (compared to its share in total resources) suggests ongoing optimization in exploration and reserve reporting to meet processing needs.

This grade-based classification provides a critical foundation for resource planning, smelter development, and national mineral policy—ensuring the alignment of Indonesia's nickel potential with downstream industry requirements.

Nickel Ore Resources by Ore Type and Confidence Category

Nickel ore resources in Indonesia are predominantly classified into two main types: limonite and saprolite, each with distinct characteristics and economic importance (Table 7.2). The classification of these resources is further broken down into inferred, indicated, and measured categories based on the confidence level of geological data and exploration detail.

Saprolite ore contributes the largest share of Indonesia's nickel resources. It holds a total of 115.4 million tons (in nickel metal content), comprising approximately 61.6 million tons of inferred resources, 29.4 million tons indicated, and 24.4 million tons measured. This dominance reflects the richness of saprolite ore in high-grade nickel (typically >1.5%), which is suitable for pyrometallurgical processing—the main method used by most nickel smelters in the country.

In comparison, limonite ore, which contains lower nickel content (<1.5%) and is often processed through hydrometallurgical methods (HPAL), contributes a total of 69.2 million tons. This comprises 30.6 million tons inferred, 26.2 million tons indicated, and 12.4 million tons measured. The relatively balanced distribution across the confidence categories for limonite ore suggests a more mature and well-characterized exploration history.

The total combined resources from both ore types amount to 184.6 million tons, with inferred resources contributing over 92.2 million tons, indicated at 55.6 million tons, and measured resources reaching 36.8 million tons. These figures highlight the significant potential of Indonesia's nickel sector, with saprolite resources being especially critical due to their compatibility with existing smelting infrastructure.

Table 7.2 Nickel Ore Resources by Ore Type and Resource Confidence Level (Tons) (Nursahan, et al., 2024)

Nickel Ore Types	Resources (Tons)						Total Resources	
	Infered		Indicated		Measured			
	Ore (wmt)	Metal	Ore (wmt)	Metal	Ore (wmt)	Metal	Ore (wmt)	Metal
Limonite	3,666,913,200	30,634,711	2,836,903,215	26,223,895	1,379,810,843	12,399,705	7,883,627,257	69,258,311
Saprolite	5,010,849,812	61,597,497	3,271,214,677	29,362,054	2,384,666,382	24,388,874	10,666,730,871	115,348,425
Total	8,677,763,011	92,232,207	6,108,117,892	55,585,949	3,764,477,225	36,788,580	18,550,358,128	184,606,736

In terms of overall composition, saprolite constitutes approximately 58% of Indonesia's total nickel ore resources, while limonite accounts for around 42% (Figure 7.8). When viewed from the reserves perspective, saprolite dominates with about 62%, compared to 38% for limonite (Figure 7.9). These proportions emphasize the strategic importance of both ore types in shaping Indonesia's nickel industry.

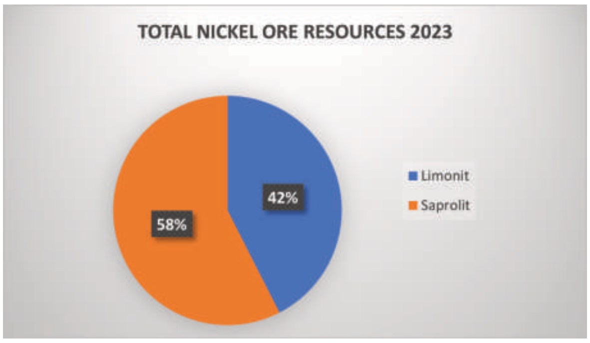

Figure 7.8 Nickel Ore Resource Composition in Indonesia (2023) (Nursahan, et al., 2024)

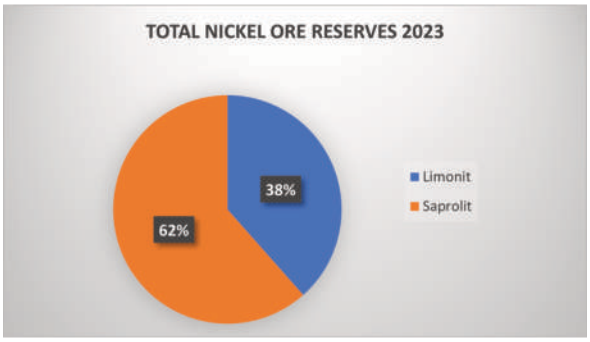

Figure 7.9 Nickel Ore Reserves Composition in Indonesia (2023) (Nursahan, et al., 2024)

Effective management of these resources is crucial for aligning with the country's downstream processing objectives. Saprolite, typically containing higher nickel content (>1.5% Ni), is primarily used in pyrometallurgical processes—particularly for the production of ferronickel and nickel pig iron (NPI), which are essential in stainless steel manufacturing. On the other hand, limonite ore, with its lower nickel content (<1.5% Ni), is more suitable for hydrometallurgical processes such as High-Pressure Acid Leach (HPAL), a critical method for producing battery-grade nickel sulfate used in electric vehicle (EV) batteries.

Balancing the extraction and processing of both saprolite and limonite is vital to ensure the sustainability of Indonesia's nickel supply chain. The dominance of saprolite in reserves suggests a strong near-term support for smelter operations focused on high-grade processing. Meanwhile, the significant presence of limonite highlights opportunities for expanding HPAL projects, particularly as demand for EV batteries rises globally.

Strategic planning in resource allocation, investment in refining technologies, and regulation of export policies are key elements in optimizing the economic value of both nickel ore types while preserving long-term national resource security.

Indonesia's Nickel Industry Growth (2018–2023) in Comparison with USGS Data

Indonesia has emerged as a dominant force in the global nickel industry, demonstrating significant growth in both production and reserves between 2018 and 2023. This trend is clearly reflected in data from the United States Geological Survey (USGS) and national sources (Figure 7.10).

In 2018, Indonesia produced approximately 606,000 metric tons of nickel, placing it among the top producers globally. This figure steadily increased in subsequent years, reaching 853,000 metric tons in 2019 and slightly dipping to 771,000 metric tons in 2020 due to global market fluctuations.

However, production rebounded strongly in 2021 with over 1 million metric tons, followed by a sharp rise to 1.6 million tons in 2022—a 54% year-on-year increase largely driven by the commissioning of new nickel pig iron (NPI) and stainless steel facilities. By 2023, Indonesia’s nickel production had reached 1.8 million metric tons, contributing to nearly 50% of global output, further solidifying its leading position.

Reserve figures also reflect Indonesia's growing prominence. From 2018 to 2022, USGS data consistently reported Indonesia’s nickel reserves at approximately 21 million metric tons. However, in 2023, a substantial revision raised this figure to 55 million metric tons, making up around 42% of the global nickel reserves, which totaled 130 million metric tons that year. This increase is attributed to expanded exploration efforts, improved data classification, and resource re-evaluations.

Indonesia’s impressive growth in both production and reserves is underpinned by strategic government policies, particularly the export ban on unprocessed nickel ores introduced in 2020, which spurred investment in domestic processing and smelting industries. The country's industrial parks in Sulawesi and other resource-rich regions have become hubs for nickel-based value chains, including components for electric vehicle batteries.

In conclusion, Indonesia’s combination of regulatory foresight, resource abundance, and downstream development has positioned it as the cornerstone of the global nickel supply chain. Continued emphasis on sustainable and value-added processing will be critical for maintaining this momentum and ensuring long-term economic and environmental benefits.

Figure 7.10 Trends in Nickel Production and Reserves in Indonesia (2018–2023) (Nursahan, et al., 2024 and modified 2019 - 2024 USGS data)

Nickel Smelting Boom Raises Concerns Over Saprolite Reserve Sustainability

Indonesia's aggressive expansion in nickel downstreaming is reshaping the global nickel landscape. A recent snapshot of the country's nickel ore demand and reserve resilience reveals both impressive industrial growth and looming sustainability challenges.

As of 2024, the nation is developing 131 nickel smelters, including 110 pyrometallurgical and 21 hydrometallurgical units. These smelters—spanning operational, under-construction, and planned facilities—collectively project an annual nickel ore demand of 438.3 million tons (Table 7.3).

The pyrometallurgy segment, dominant with 110 smelters, will account for the lion's share of this demand: 387.2 million tons annually. This method processes saprolite ore (with Ni > 1.5%) to produce nickel pig iron, feeding into Indonesia's robust stainless steel industry. On the other hand, hydrometallurgy, used in just 21 smelters, processes limonite ore (Ni < 1.5%) for battery-grade materials, meeting growing electric vehicle (EV) demands.

While the nickel downstreaming strategy is central to Indonesia's economic transformation, resource depletion looms large. At current consumption rates, saprolite reserves of 3.2 billion tons could be exhausted in just 9 years, reaching critical depletion by 2032. In contrast, limonite reserves (1.67 billion tons) are more resilient, with a projected lifespan of 17 years or until 2040 (Table 7.4).

The disparity in reserve life between these two ore types has prompted calls for policy interventions. Controlling the development pace of pyrometallurgical smelters and optimizing ore utilization are now vital for ensuring long-term sustainability. Failure to balance industrial ambition with geological constraints may jeopardize Indonesia's strategic position in the global nickel value chain.

Table 7.3 Nickel Ore Demand by Smelter Type and Development Stage (GAI, 2024, Menkomarves, 2024)

Category	Operation (units)	Construction (units)	Plan (units)	Total (units)	Ore Demand - Operation (Mt)	Ore Demand - Construction (Mt)	Ore Demand - Plan (Mt)	Ore Demand - Total (Mt)
Pyrometallurgy	45	37	28	110	136.1	88.4	162.7	387.2
Hydrometallurgy	5	3	13	21	27	18	60	105
Total	50	40	41	131	160.9	104	172.3	438.3

Table 7.4 Estimated Lifespan of Nickel Ore Reserves by Processing Method (Nursahan, et al., 2024, DGMC,2024)

Processing Type	Grade Ni	Ore Reserve (Mt)	Annual Demand (Mt)	Estimated Reserve Life
Pyrometallurgy	>1.5%	3,222	387.2	~9 years (until 2032)
Hydrometallurgy	<1.5%	1,674	105	~17 years (until 2040)

In light of these findings, the government is urged to prioritize reserve exploration and reassessment, incentivize hydrometallurgical development aligned with green technology, and implement stricter oversight on smelter construction aligned with national ore availability.

As Indonesia stands at the heart of the global nickel revolution, its ability to manage ore consumption and promote sustainable practices will define the future of the country's mineral economy.

Conclusion

Indonesia has rapidly emerged as the world's leading nickel producer, accounting for over 50% of global supply in recent years. This growth is driven primarily by surging demand for electric vehicle (EV) batteries, stainless steel production, and the country's aggressive downstream policy that bans raw ore exports in favor of domestic processing. With nickel ore production reaching 1.8 million metric tons in 2023, and reserves jumping from 21 million to 55 million tons (2022–2023), the country has become a cornerstone in global energy transition supply chains.

However, this exponential growth raises serious sustainability and resource management concerns. Based on current smelter demand projections — over 438 million tons in total (operational, under construction, and planned) — high-grade saprolite reserves (>1.5% Ni) used in pyrometallurgical processing may be exhausted within 9 years if no new reserves are added, pushing the depletion year to 2032. In contrast, low-grade limonite ores (<1.5% Ni) for hydrometallurgy (HPAL) have an estimated reserve life until 2040.

This looming resource strain has economic and strategic implications. The Ministry of Investment and Coordinating Ministry for Maritime Affairs and Investment (Kemenkomarves) have highlighted the urgency to control ore consumption and balance investments between the two processing streams. Overreliance on pyrometallurgical smelters, which dominate the landscape with 110 units planned versus only 21 hydrometallurgical units, may accelerate resource depletion and increase vulnerability to price shocks and environmental degradation.

From an economic perspective, nickel has become a top contributor to Indonesia's export value, contributing more than USD 30 billion in 2023, a significant rise from under USD 7 billion in 2019. The government's downstreaming initiative not only boosts export earnings but also creates jobs and attracts billions in foreign direct investment (FDI), particularly from China and Korea.

Yet, to sustain this momentum, Indonesia must adopt a holistic resource governance model, which includes strategic ore zoning and production quotas, acceleration of exploration for new reserves, greater emphasis on hydrometallurgical capacity building, environmental restoration policies in mining regions, and enhanced fiscal incentives for recycling and circular economy initiatives

By addressing these challenges, Indonesia can secure its position not just as a nickel superpower, but as a global leader in responsible and sustainable mineral development in the era of green energy.

Indonesia's Strategic Role in the Global Nickel Supply Chain

As the world intensifies efforts toward energy transition and technological advancement, the importance of critical minerals—particularly nickel—has soared. Used widely in electric vehicle (EV) batteries, stainless steel, and various clean technologies, nickel has become central to the global energy future. Yet, as illustrated by the IEA's 2019 data (Figure 7.11), a clear imbalance remains: while countries like Indonesia dominate extraction, others, especially China, retain the lead in processing capacity.

Indonesia has positioned itself at the forefront of this evolving mineral economy. The government's decision to mandate downstream processing through Law No. 3 of 2020—which amended Law No. 4 of 2009 on Mineral and Coal Mining—marks a transformative moment. Reinforced by Ministerial Regulation No. 1 of 2014, this policy prohibits the export of raw mineral ores and demands in-country value addition through smelting and refining.

Driving Investment and Industrial Expansion

The accelerated ban on nickel ore exports since January 2020 has sparked rapid growth in the domestic industry. By 2023, the number of operational nickel smelters reached 53, a remarkable leap from just 15 in 2022 (Santoso et al., 2023). This surge in investment has been accompanied by a diversification of nickel-based products: in addition to ferronickel (FeNi), nickel pig iron (NPI), and nickel matte, Indonesia now produces mixed hydroxide precipitate (MHP), mixed sulphide precipitate (MSP), and stainless steel, with plans to manufacture nickel sulfate, pure nickel (nickel powder), and battery precursors (Tiammar, 2021)

These efforts signal a deeper ambition: to build an integrated domestic supply chain that supports EV battery production and other high-value industries. According to the IEA (2021), Indonesia is already the world's largest nickel producer, and its reserves—especially of limonite ore (2.8 billion wet metric tons with $<1.7\%$ Ni content)—are critical to producing Class 1 nickel, which requires high-purity processing using HPAL (High-Pressure Acid Leaching) technology.

Global Demand, Market Surplus, and Price Volatility

Global nickel production reached 3.14 million tons in 2022, with consumption slightly lower at 3.03 million tons, creating a surplus of 114,000 tons. Indonesia was a key contributor to this surplus through its production of low-grade nickel such as NPI and FeNi, leading to downward pressure on global prices.

This trend continued in 2023, with the surplus widening to 222,000 tons, and is projected to hit 239,000 tons in 2024. Much of the excess stems from the slowdown in China's stainless steel sector—historically the largest consumer of nickel (65%)—due to the country's sluggish economic recovery and declining real estate activity.

Meanwhile, EV batteries accounted for about 15% of global nickel demand in 2022. This figure is expected to rise sharply: Wood Mackenzie (2022) forecasts that by 2040, batteries will account for 40% of all nickel consumption, pushing total demand to 6 million tons per year—double today's levels (Figure 7.12).

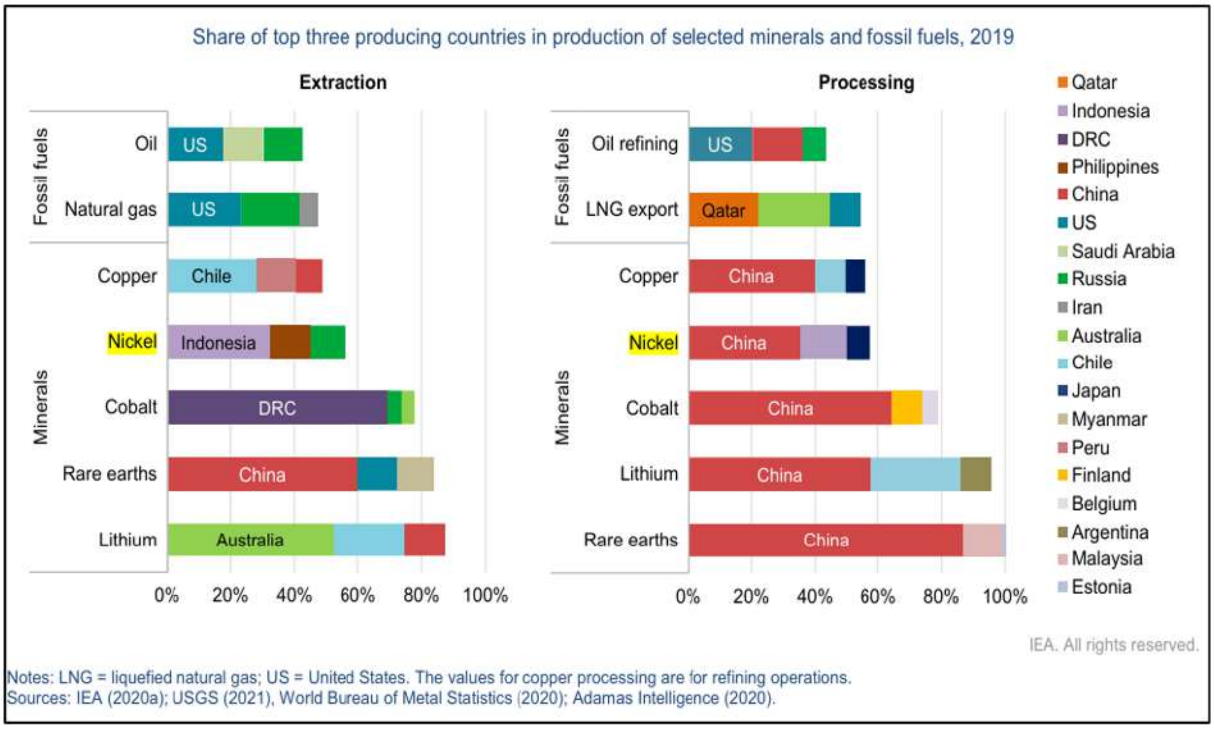

Figure 7.11 Global Disparities in Extraction and Processing of Strategic Minerals and Fossil Fuels (2019) (IEA,2021)

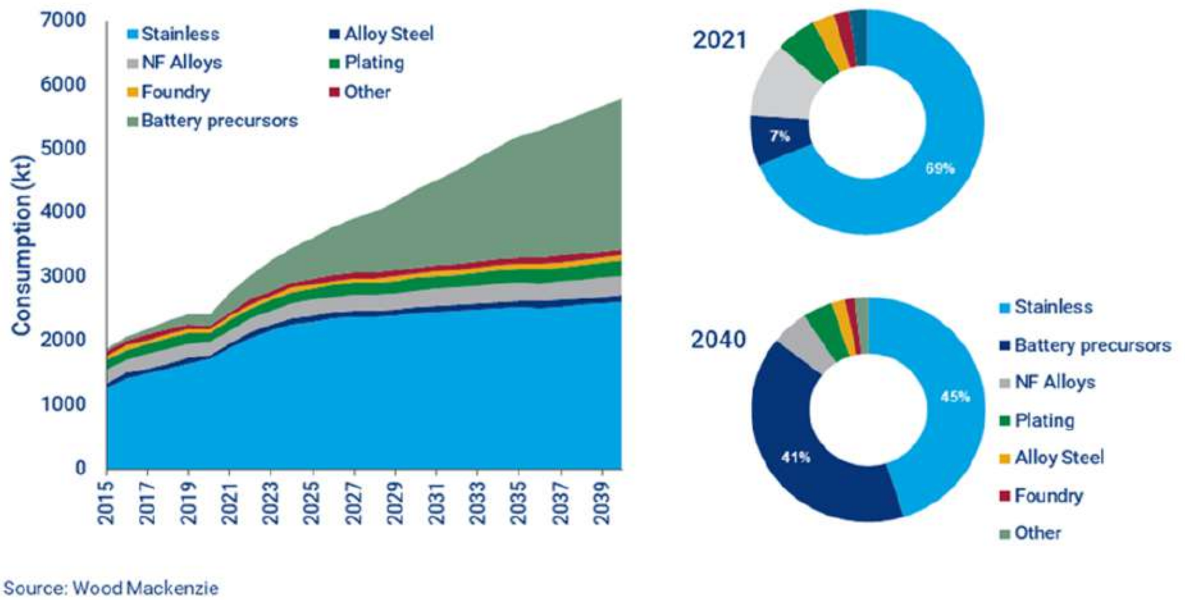

Figure 7.12 From Stainless Steel to EV Batteries: Global Nickel Demand Projection (2015–2040) (Wood Mackenzie, 2022)

Technological Shifts and Strategic Leverage

Despite the current surplus, long-term demand fundamentals remain strong. New HPAL facilities in Indonesia continue to boost MHP output, while the conversion of NPI to nickel matte, led by firms like Tsingshan, has further expanded the country's technical capabilities (Trytten, 2021). These advancements enable Indonesia to produce the Class 1 nickel essential for high-performance EV batteries.

Moreover, the government aims to internalize the use of all domestic NPI and FeNi, reducing reliance on exports and supporting global price stabilization. Such control over supply and export policy gives Indonesia increasing leverage over global nickel markets.

Indonesia's Influence on the Market

Still, challenges persist. The emergence of lithium iron phosphate (LFP) batteries, which require no nickel, is creating headwinds. Combined with a ballooning global surplus, these dynamics have triggered a decline in nickel prices. After peaking at US$25,833.73/ton in 2022, prices fell to US$21,521.12 in 2023, and are projected to drop further to around US$20,000 in 2024 (Andrianto, 2024) (Figure 7.13). Nonetheless, the World Bank anticipates a rebound to US$20,500 in 2025, driven by robust EV sales (Arakawa, 2024).

Indonesia, one of the world's largest nickel producers, has been central to these shifts. Its implementation of stricter export regulations aimed at bolstering domestic processing has reduced the global availability of raw nickel. This approach, driven by the desire to add value through local processing, has had the side effect of intensifying short-term price volatility, particularly noticeable in the 2021 and 2022 surges.

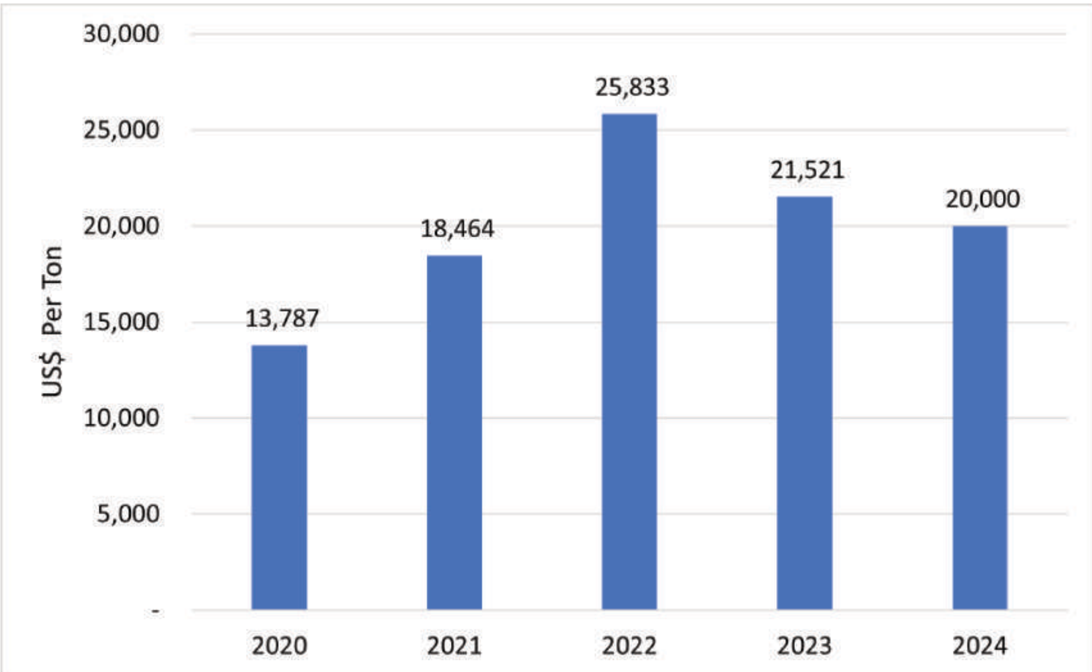

Figure 7.13 Nickel Price Trends: 2020–2024 (Andrianto, 2024)

The country's policies have also had a wider geopolitical impact. As a major holder of nickel reserves, any change in Indonesian production or export strategy sends ripples through the global market. Investors and manufacturers closely track these decisions, and even subtle policy shifts can lead to noticeable changes in market sentiment or speculative behavior.

Future Outlook: From Raw Producer to Processing Powerhouse

The interplay between surging demand—driven by the accelerating adoption of electric vehicles and renewable energy technologies—and Indonesia's dynamic policy landscape ensures that nickel will remain a pivotal commodity in the global economy. As the world's largest producer of nickel, Indonesia's regulatory decisions—ranging from mining governance and export restrictions to the promotion of domestic downstream processing—are set to continue shaping international nickel prices and supply chains.

Simultaneously, advancements in mining technologies and the growing emphasis on nickel recycling are poised to recalibrate global market dynamics. These innovations may help ease some of the volatility experienced in recent years by introducing new sources of supply and improving the efficiency of resource utilization.

In retrospect, the evolution of nickel prices from 2020 to 2024 tells a compelling story of economic recovery, industrial transformation, and geopolitical influence. For investors, manufacturers, and policymakers alike, Indonesia's central role serves as a powerful reminder of the interconnectedness of global commodity markets and the profound impact of domestic policy choices.

Looking ahead, it will be crucial to examine how Indonesia's strategic trajectory aligns with or diverges from those of other major nickel-producing nations. Equally important is assessing how emerging breakthroughs—particularly in recycling technologies and alternative battery chemistries—might reshape the supply landscape, offering fresh insights into the future of the nickel industry.

Indonesia's growing smelting capacity and upstream integration are beginning to reshape the global nickel landscape. According to Prakash (2024), continued investments in refining will see Indonesia's processed nickel output rival China's by 2030, signaling a dramatic power shift in the industry.

Conclusion

Indonesia's regulatory push for downstream processing has fundamentally changed its role in the global nickel market—from a raw material supplier to a potential processing powerhouse. While the market faces short-term volatility, driven by oversupply and technological shifts, Indonesia's long-term outlook remains strong. With continued investment, strategic policymaking, and technological innovation, Indonesia is poised to shape the global nickel industry well into the next decade.

Nickel is a critical component for EVs, stainless steel, and emerging technologies, with Indonesia rapidly positioning itself as a key global supplier.

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8

Iron

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Image: Iron Ore
Courtesy of: https://geologylearn.blogspot.com/2015/03/iron-ore.html

Iron is estimated to constitute approximately 32.07% of the Earth's total mass, with its abundance ranging from about 5% in the Earth's crust to as much as 80% in the planet's core (Morgan and Anders, 1980, as cited in Clout and Manuel, 2015). The three most common iron ore minerals—magnetite, hematite, and goethite—together account for more than 99% of the world's iron ore resources.

Magnetite (Fe_3O_4) is typically found in metasedimentary and magmatic iron deposits, while hematite (Fe_2O_3) is commonly formed through the oxidation of magnetite in near-surface environments. Goethite (α-FeOOH), an iron oxyhydroxide, is considered the most prevalent iron ore mineral in sedimentary and metasedimentary deposits that have undergone near-surface alteration (Clout and Manuel, 2015).

The vast majority of mined iron ore is used in the production of steel, as raw iron alone lacks the strength and hardness required for construction and industrial applications. To enhance its properties, raw iron is alloyed with elements such as tungsten, manganese, nickel, vanadium, and chromium, resulting in steel—a material crucial to industries such as construction, automotive manufacturing, and transportation, including trucks, trains, and railway infrastructure.

Although the non-steel applications of iron ore are minimal, the above examples underscore the vital role of iron ore in modern infrastructure and industry. While there is no true substitute for iron, steel can also be produced from recycled scrap iron, providing a sustainable alternative to raw ore. Although recycled iron contributes only a small portion of global steel production, steel itself has a recycling rate exceeding 67%, significantly higher than that of many other materials. Should the economics of steel production shift, recycling iron may become a more cost-effective and environmentally friendly alternative to primary extraction from ore.

Occurrences

Primary Iron

Primary iron ore is commonly found in skarn deposits, which form through contact metasomatic mineralization between intermediate igneous intrusions and surrounding volcanic or limestone country rocks. In some instances, iron ore also occurs in fractures of basement rocks like gabbro within granitic bodies, or as vein-type mineralization in volcanic settings.

In Indonesia, most primary iron ore deposits are associated with skarn systems hosted by volcanic and limestone rocks, typically exhibiting economic grades above 40% total Fe, with magnetite and hematite as the dominant minerals. These magnetite-hematite skarn deposits, formed due to contact metamorphism, are located in various regions such as Aceh, South Sumatra, West Sumatra, Lampung, Bangka-Belitung, Jambi (Figure 8.1), Riau Islands, West Java, West and East Nusa Tenggara, Kalimantan, Sulawesi, and North Maluku. Although some deposits have high iron content (often over 60%), their sporadic and scattered distribution means they are generally small in size, with uncertain economic potential.

Figure 8.1 Skarn-type iron ore deposits in the Jambi area (Nursahan, 2005)

A notable exception is found in Padang Ganting, West Sumatra, where primary iron ore occurs in hydrothermal veins. Another variant is the Volcanogenic Massive Sulphide (VMS)-type deposit located in Kendawangan, West Kalimantan, hosted in zeolitic green tuff, pillow lava, and barite rocks (Figure 8.2) (Subandrio and Kuswanto, 2010 in Idrus, 2014).

Figure 8.2 VMS type iron ore deposits in Kendawangan, West Kalimantan (Subandrio and Kuswanto, 2010)

Iron Sand

Iron sand is a coastal sediment containing iron-rich particles, primarily titanomagnetite and rutile, deposited as sand dunes along coastal plains. These sands result from the accumulation of both light and heavy minerals through wave and wind action. The sands consist mainly of magnetite, hematite, and ilmenite, along with secondary minerals such as pyrite, marcasite, chalcopyrite, chromite, and quartz, plus trace elements like manganese, magnesium, zinc, sodium, potassium, nickel, copper, lead, arsenic, antimony, tungsten, tin, and vanadium.

Macroscopically, the sand appears gray to black, is very fine-grained (75 to 150 microns), has a density of 2.99 to 4.23 g/cm³, and a degree of magnetism ranging from 6.40% to 27.16%. These deposits typically originate from basaltic and andesitic source rocks.

In Indonesia, potential iron sand resources are found along the coasts of Sumatra, Java, Nusa Tenggara, Sulawesi, Maluku, and Papua. A significant deposit is located in Lunyuk District, Sumbawa, West Nusa Tenggara (Figure 8.3), investigated by CMCGR in 2021 and 2024. The survey revealed total Fe content of up to 55.97%, titanium content of 5.89%, and vanadium ranging from 3,030 to 4,930 ppm. The magnetism degree reached 52.6%, and the deposit is believed to have originated from andesitic-basaltic rocks in the northern region.

Figure 8.3 Iron Sand Deposits in Lunyuk District, Sumbawa, West Nusa Tenggara (Nugraha, et al., 2021)

Iron Laterite

Iron laterite is a weathered soil and rock rich in iron, commonly formed under hot, humid tropical conditions. The bright rust-red color is due to the high presence of iron oxides. In Indonesia, lateritic iron ore is often a by-product of lateritic nickel deposits, found in Sulawesi, Maluku, and Papua. Typically, the upper limonite layer is iron-rich with low nickel content, while the underlying saprolite contains more nickel and less iron.

An example of economic lateritic iron ore occurs on Sebuku Island, South Kalimantan, where deposits formed through weathering and supergene enrichment of peridotite rocks. This has resulted in thick lateritic layers that are mined by PT Sebuku Iron Laterite Ore (SILO) (Figure 8.4) (Idrus et al., 2022).

Figure 8.4 PT. SILO's iron laterite mine on Sebuku Island (https://images.bisnis-cdn.com/posts/2014/04/01/216055/130628_pertambangan.jpg)

Sedimentary Iron Deposits

Sedimentary iron deposits form through chemical sedimentation, sometimes accompanied by mechanical processes like weathering. One important type is the Banded Iron Formation (BIF), consisting of thin to medium layers of iron oxide, iron carbonate, or siliceous iron minerals interbedded with chert or jasper. BIFs are typically associated with submarine volcanism during the Precambrian, and are often located in cratonic or continental shield areas. Globally, around 90% of iron ore production comes from cherty BIFs (Guilbert and Park, 1986).

In Indonesia, sedimentary iron deposits are found in Trenggalek Regency, East Java (Figure 8.5), where the ore is hosted in Carboniferous sedimentary layers of sandstone and mudstone, interspersed with volcanic rocks. The presence of glauconite, a mineral indicative of marine sedimentary environments, supports this genesis (Muhamad, A.H. in Idrus, 2014).

Figure 8.5 Sedimentary iron deposits in Kalitelu-Trenggalek, East Java (Idrus, 2014)

Another notable deposit exists in Gunung Kancil, Tanggamus Regency, Lampung Province, where a small-scale Algoma-type BIF occurs. The ore is composed of fine to medium-grained magnetite and hematite, alternating with quartz layers forming a foliated structure. The band thickness typically ranges from 20 to 50 mm (Subandrio and Tabri, 2006 in Idrus, 2014).

Trends in Indonesia’s Primary Iron Ore Resources, Reserves, and Data Updates (2019–2023)

Indonesia's primary iron ore industry has witnessed a substantial increase in total ore resources over the past five years, as reflected in the latest geological data spanning from 2019 to 2023 (Figure 8.6). According to the data, ore resources have more than doubled, rising from 3.61 billion tons in 2019 to 7.85 billion tons in 2023. This sharp growth reflects expanded exploration activities and better identification of potential iron ore deposits throughout the country.

Meanwhile, ore reserves—which indicate the economically extractable portion of resources—remained relatively stable, hovering around 1.7 billion tons from 2020 to 2022, before slightly declining to 1.22 billion tons in 2023. The gap between growing resources and relatively stagnant reserves suggests that while more iron ore is being identified, not all of it meets the current economic or technical feasibility standards for extraction.

Interestingly, the number of total datasets collected annually—represented by the green line—also shows a positive trend, increasing from 155 in 2019 to 175 in 2023. This indicates ongoing efforts in geological surveys and data collection, likely facilitated by national mineral exploration initiatives.

However, the number of updated datasets—crucial for maintaining accurate, real-time resource information—has not followed the same trend. After peaking at 22 updates in 2020, data revisions sharply declined to just 2 updates in 2022, before modestly rising again to 9 updates in 2023. This inconsistency may point to challenges in data validation processes, resource reclassification, or a slowdown in field verification activities.

In summary, while Indonesia has made significant strides in mapping its primary iron ore potential, the relatively slow growth in ore reserves and inconsistent data updates highlight areas where further improvement is necessary. Strategic investments in exploration technology, reserve feasibility studies, and regular data verification will be critical for transforming identified resources into productive and economically viable assets.

Indonesia's Primary Iron Ore Potential: A Provincial Analysis of Resources and Reserves

Indonesia possesses substantial primary iron ore deposits, with distribution spanning nearly all major islands. This section presents an analysis of primary iron ore resources and reserves based on the latest provincial data, applying an exclusive classification system—in which reserves are not included as part of resources, but treated as separate, economically viable quantities (Figure 8.7).

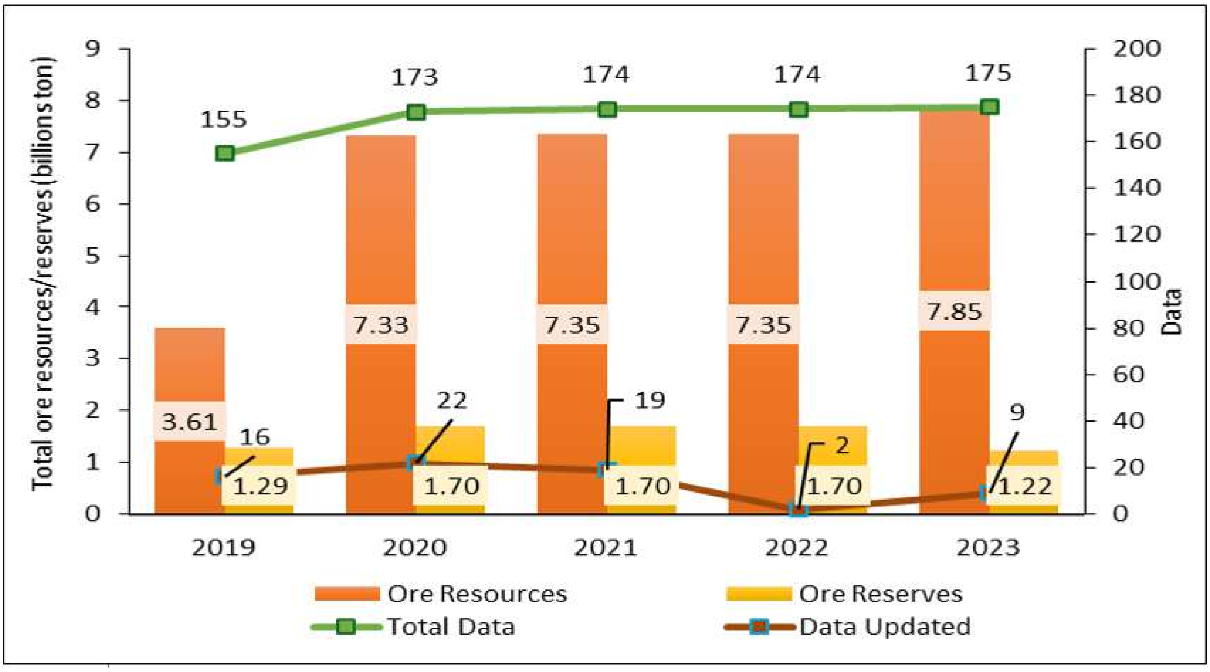

Figure 8.6 Trends in Indonesia's Iron Ore Resources, Reserves, and Data Updates (2019–2023) (Nursahan, et al., 2024)

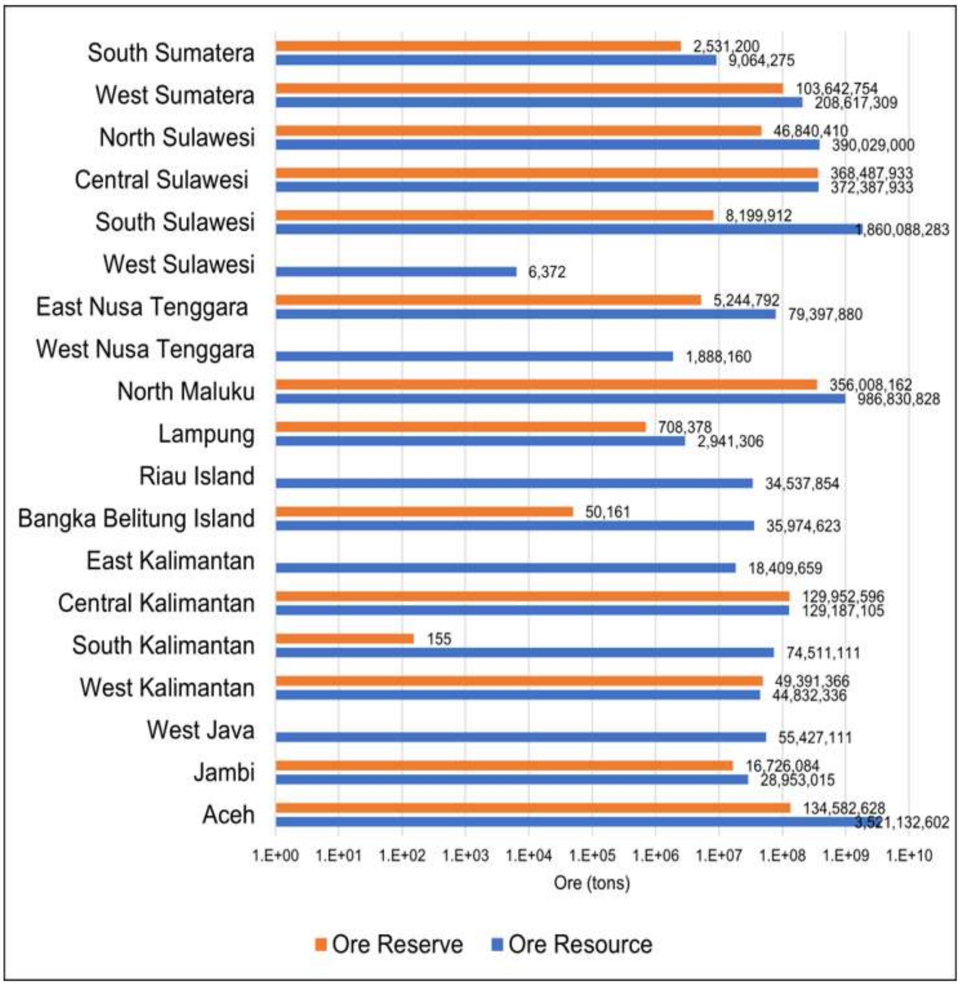

Figure 8.7 Indonesia's iron ore resources and reserves by province (Nursahan, et al., 2024)

National Overview

Among all provinces, Aceh stands out as the region with the largest primary iron ore resources, totaling more than 3.52 billion tons of ore and over 1.3 billion tons of contained metal. Despite its geological richness, the proven reserves in Aceh amount to just over 134 million tons of ore. This gap indicates that while exploration has defined substantial quantities of ore, the economic feasibility of extraction remains to be confirmed for much of it.

South Sulawesi follows closely with over 1.86 billion tons of ore resources. However, less than 10 million tons have been categorized as reserves, pointing to similar exploration-development gaps. In contrast, North Maluku not only has a significant 986 million tons in resources but also reports over 356 million tons of reserves—suggesting this province has advanced significantly in converting its geological potential into economically viable mining opportunities.

Regional Disparities and Progress

Central Sulawesi and North Sulawesi both have hundreds of millions of tons in primary iron ore resources. Central Sulawesi's reserve figure nearly matches its resource total, suggesting a strong case for development. Meanwhile, North Sulawesi also shows an encouraging reserve-to-resource ratio, with nearly 47 million tons of reserves from 390 million tons of total resources.

In contrast, regions like West Java, East Kalimantan, and Riau Islands have documented resources but show no reserve data. This may imply early-stage exploration or a lack of economic feasibility studies. Provinces such as Central Kalimantan and West Kalimantan show remarkable reserve volumes that either match or even exceed the reported resources, which may reflect updated classifications or focused economic evaluations.

Interpretation and Outlook

The data underscores both the richness of Indonesia's primary iron ore landscape and the uneven pace of mineral development across the archipelago. In some provinces, exploration has far outpaced reserve classification, while in others, detailed technical and economic evaluations have led to robust reserve figures. For instance, Central Kalimantan has almost identical values for both ore resources and reserves—an indicator of mature assessment and likely development readiness.

The provinces of West Sumatra, West Nusa Tenggara, and East Nusa Tenggara also contribute moderate volumes of primary iron ore resources and reserves. Notably, Central Kalimantan and North Maluku are among the few provinces showing clear signs of both geological richness and technical readiness for mining.

Conclusion

Indonesia's primary iron ore inventory is both vast and underutilized. The country holds potential not just for domestic steel production but also as a strategic supplier in the global iron market. However, the discrepancy between identified resources and classified reserves highlights the need for further exploration, feasibility studies, and investment in mining infrastructure. As more provinces move from early-stage exploration to economic validation, Indonesia's position in the global mining sector could grow significantly in the coming decades.

Five-Year Growth of Laterite Iron Resources and Reserves in Indonesia

The graph (Figure 8.8) illustrates a notable increase in Indonesia's laterite iron ore resources and reserves over the five-year period from 2019 to 2023. Total ore resources rose steadily from 4.62 billion tons in 2019 to 7.87 billion tons in 2023, signaling a strong momentum in exploration and reporting activities across the country. This growth reflects not only the intensity of field investigations but also the expanding geographic coverage of laterite iron discoveries.

While the volume of ore reserves also grew—from 1.54 billion tons in 2019 to 1.65 billion tons in 2023—the pace has been comparatively slower. This suggests a gap between the identification of geological potential and the formal economic evaluation needed to classify reserves. The difference may be attributed to limited feasibility studies, lack of metallurgical testing, or delayed investment decisions that prevent resource conversion into reserves.

The number of locations reporting laterite iron increased substantially, from 101 sites in 2019 to 186 sites in 2023. This trend points to widening exploration coverage and improved national inventory mapping. However, the data updated annually has not increased significantly—fluctuating between 12 and 21 entries per year—highlighting potential limitations in data integration, reporting mechanisms, or institutional capacity for mineral data verification.

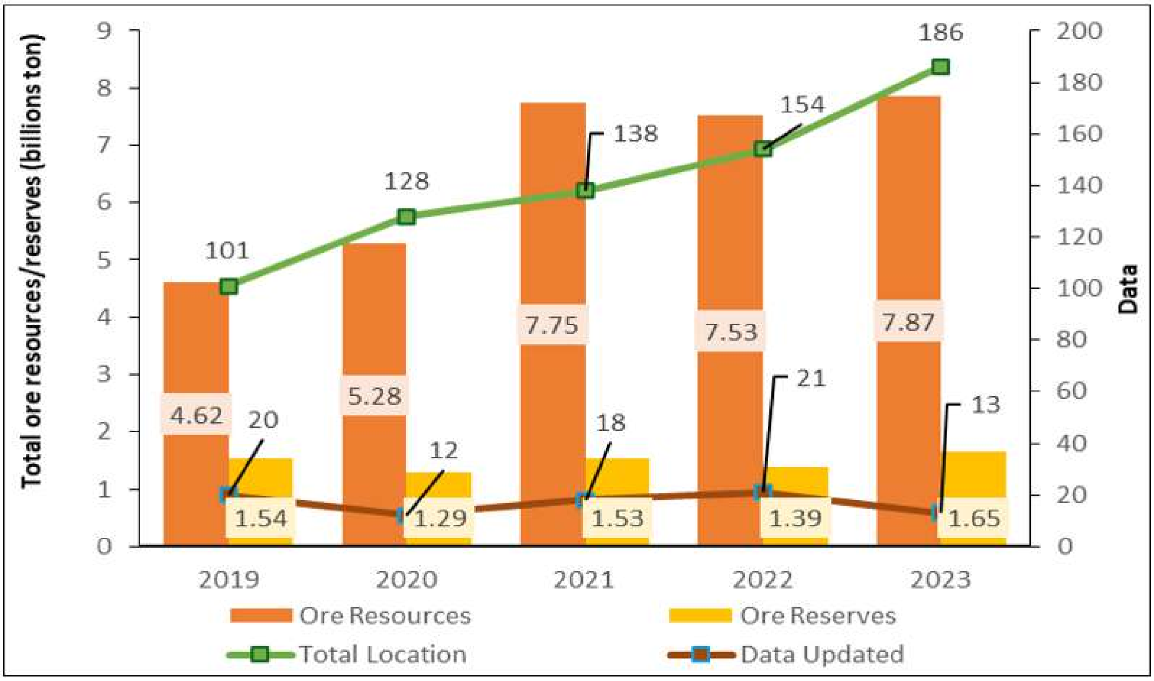

Figure 8.8 Trends in Laterite Iron Ore Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

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This five-year trend underscores the progress made in recognizing Indonesia's lateritic iron potential but also exposes the need for stronger resource-to-reserve conversion mechanisms. Strengthening regulatory frameworks, improving technical assessments, and investing in capacity building for geological agencies could help bridge the resource–reserve gap. With better governance and data transparency, Indonesia can move toward more strategic management of its iron ore sector to support industrial growth and sustainable mineral development.

Lateritic Iron Ore Resources and Reserves in Indonesia: A Regional Assessment

Indonesia possesses substantial lateritic iron ore resources, distributed across various provinces, with some regions also showing strong reserve potential. This analysis is based on the latest dataset (Figure 8.9), using an exclusive classification system that treats resources and reserves independently.

North Maluku and Maluku: Resource Giants

North Maluku tops the list with over 2 billion tons of ore resources, followed closely by Maluku with approximately 1.89 billion tons. While North Maluku has more developed reserves—368 million tons, or about 18% of its resources—Maluku still shows a relatively low reserve maturity, with only 8% of its resources classified as reserves.

Southeast and Central Sulawesi: Growing Hubs

Southeast Sulawesi ranks third, boasting 1.74 billion tons of ore resources and over 300 million tons of reserves. Central Sulawesi follows with nearly 577 million tons of resources and 201 million tons in reserves—highlighting one of the most promising reserve-to-resource ratios (35%) in the country.

South and Central Kalimantan: High Reserve Conversion

South Kalimantan presents a unique case with an impressive 94% reserve-to-resource ratio, where 389 million tons of reserves almost match its 412 million tons of resources. Central Kalimantan and West Kalimantan also show strong ratios—60%

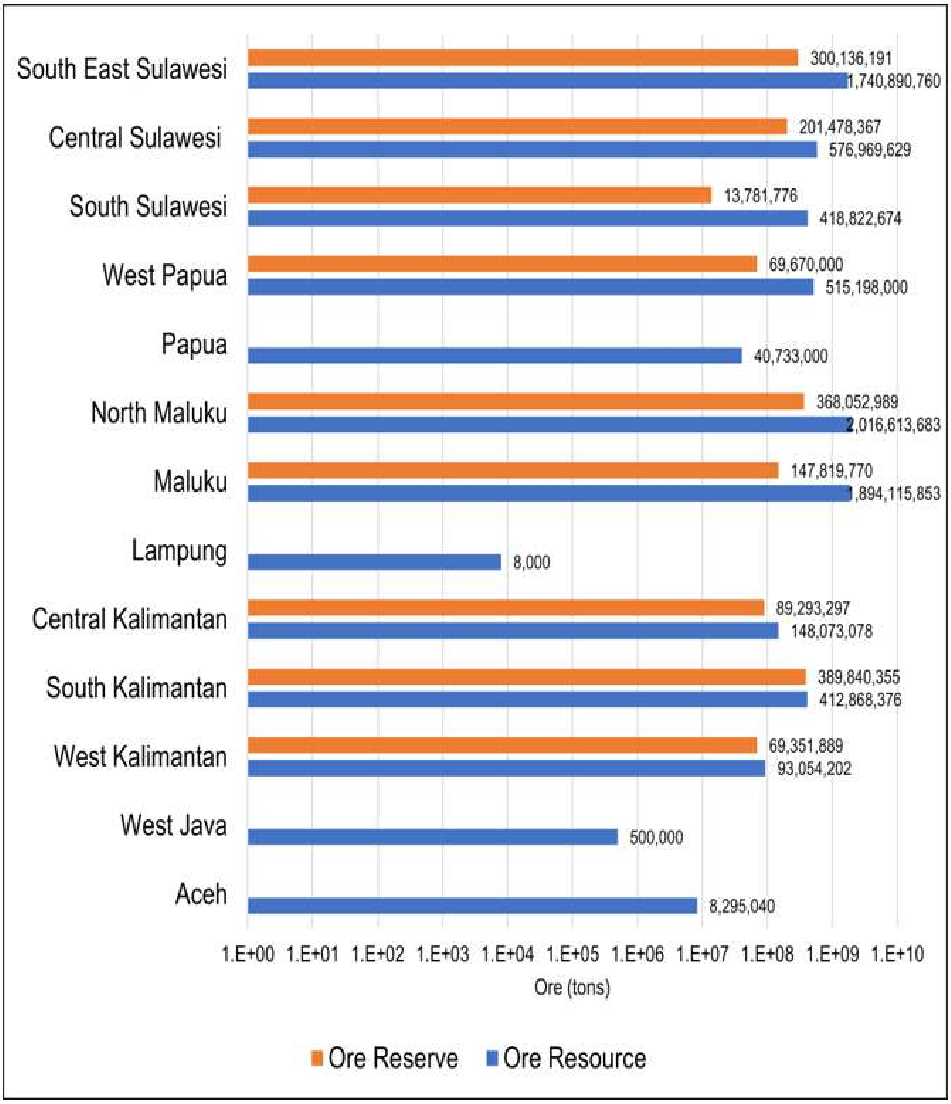

Figure 8.9 Distribution of Lateritic Iron Ore Resources and Reserves by Province in Indonesia (Nursahan, et al., 2024)

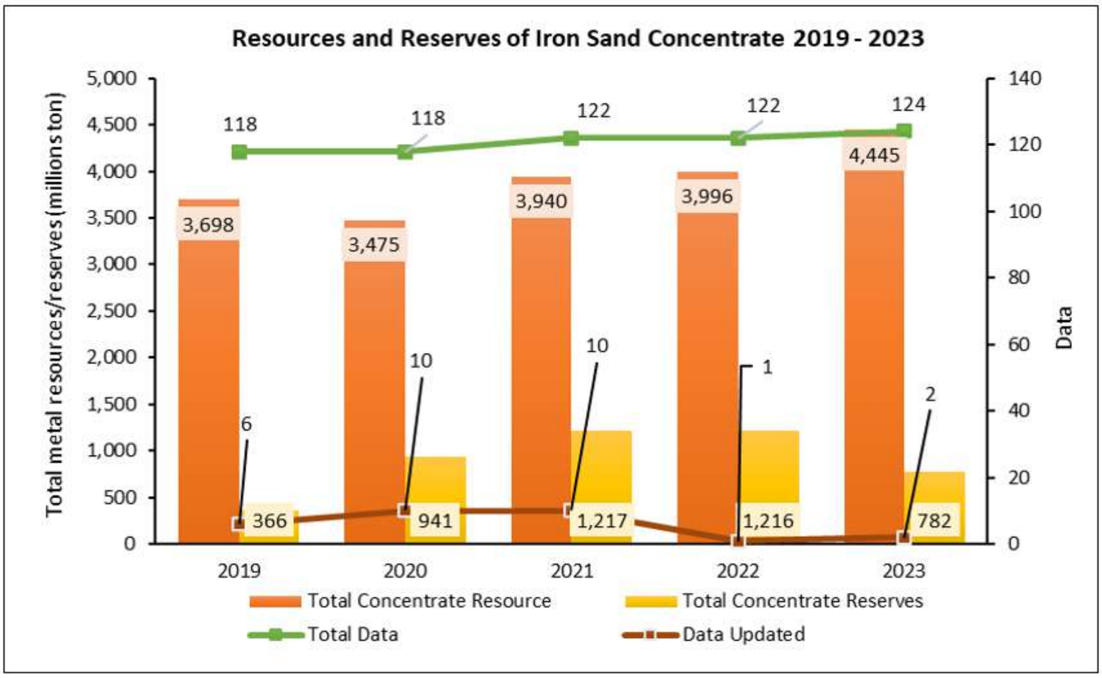

Figure 8.10 Trends in Resources and Reserves of Iron Sand Concentrate in Indonesia (2019–2023) (Nursahan, et al., 2024)

and 75%, respectively—reflecting mature and potentially active mining sites.

Underexplored Eastern Regions

Despite having considerable resource figures, Papua and West Papua have relatively underdeveloped reserves. Papua, for instance, holds over 40 million tons of ore resources but no registered reserves. West Papua, although richer in reserves with 69 million tons, still presents untapped potential compared to its total 515 million tons of resources.

Western Indonesia: Smaller but Significant

Provinces like Aceh, West Java, and Lampung report minimal resource quantities and no reserves, indicating either early exploration stages or limited lateritic potential.

Conclusion

The regional distribution of lateritic iron ore in Indonesia reveals a concentration of resources in eastern provinces like North Maluku, Maluku, and Sulawesi, with Kalimantan emerging as a leader in reserve development. These insights are crucial for guiding future investments, exploration strategies, and regional mineral policies.

Indonesia's Iron Sand Concentrate: A Five-Year Trend Analysis

The iron sand concentrate industry in Indonesia has shown both resilience and fluctuation between 2019 and 2023, as captured in the graph titled "Resources and Reserves of Iron Sand Concentrate 2019–2023" (Figure 8.10). This graph illustrates the total volume of metal contained in iron sand

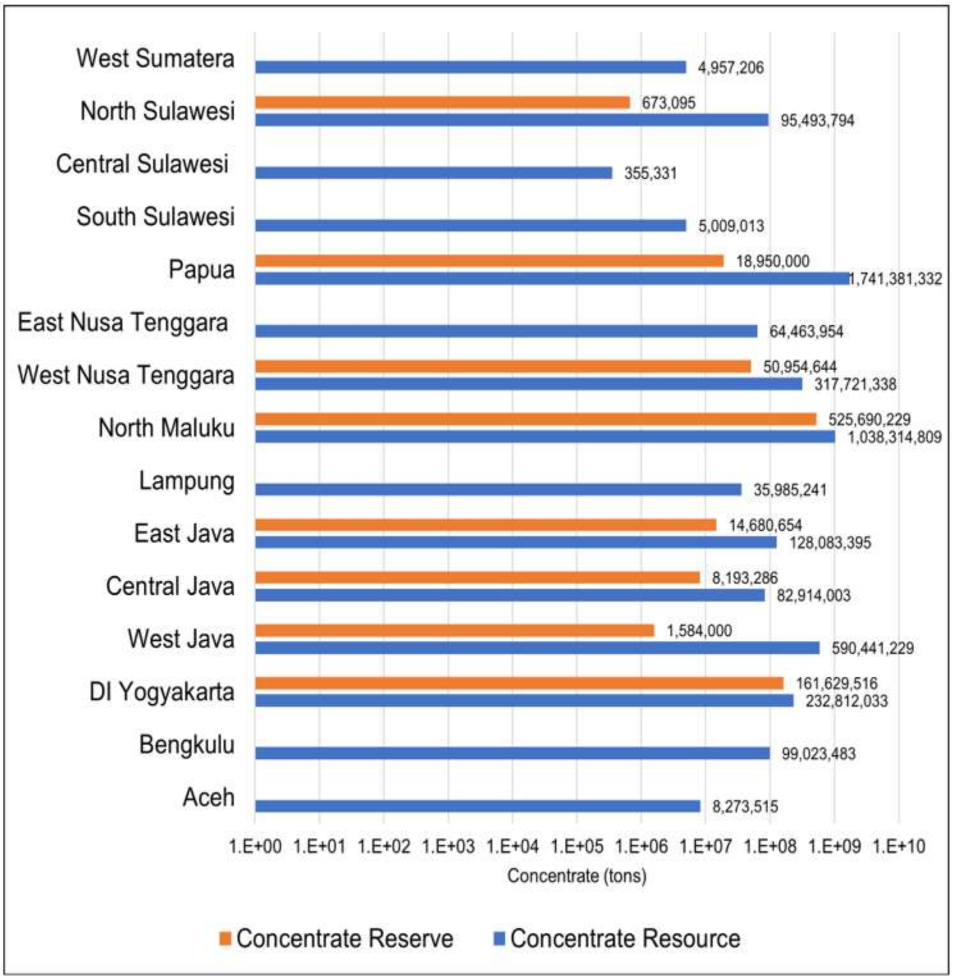

Figure 8.11 Distribution of Iron Sand Concentrate Resources and Reserves by Province in Indonesia (Nursahan, et al., 2024)

concentrate resources and reserves over a five-year period, measured in millions of tons, alongside the number of datasets collected and updated.

Growth in Resources

From 2019 to 2023, total concentrate resources increased steadily from 3,698 million tons to 4,445 million tons. This upward trajectory, representing a 20.2% growth, indicates sustained exploration activity and expansion of known deposits. The consistent increase also reflects improvements in geological mapping and reporting systems, as well as possibly favorable conditions for iron sand extraction.

Volatility in Reserves

Unlike resources, the reserves of iron sand concentrate experienced considerable variation. Starting at 366 million tons in 2019, reserves surged to 1,217 million tons in 2021, before dropping to 782 million tons in 2023. These shifts could be attributed to changing economic feasibility, revisions in classification standards, or reassessment of technical extraction conditions. The sharp decline in 2022–2023 may also highlight challenges in upgrading resources to reserve status, which often requires more rigorous economic and technical evaluation.

Data Reporting and Quality

The number of total datasets remained relatively stable, rising slightly from 118 in 2019 to 124 in 2023, signifying consistent data collection and monitoring by relevant institutions. However, the number of updated datasets saw a dramatic drop — from 10 in 2020 and 2021 to just 1 in 2022, and only 2 in 2023. This trend may reflect reduced field activity, possible delays in data processing, or prioritization of other minerals.

Conclusion

While the overall iron sand concentrate resource base in Indonesia has grown, reserve figures do not exhibit the same consistency. The disparity between resources and reserves, combined with declining update frequency, signals a need for renewed exploration initiatives, improved classification methodologies, and more frequent updates to maintain data relevance. As demand for iron and steel materials grows, ensuring accurate and current data on this strategic commodity will be vital for sustainable development and investment planning.

Iron Sand Concentrate Resources and Reserves in Indonesia: A Provincial Perspective

Indonesia possesses vast deposits of iron sand concentrate, spread unevenly across the archipelago (Figure 8.11). The latest data reveals Papua as the most resource-rich province, with approximately 1.74 billion tons of iron sand concentrate. North Maluku follows with over 1.03 billion tons, while West Java holds a significant 590 million tons. These three provinces together make up more than 65 percent of Indonesia's total known iron sand concentrate resources, underscoring the heavy regional concentration of this commodity.

West Nusa Tenggara, DI Yogyakarta, and East Java also report substantial resources, at 317 million, 232 million, and 128 million tons respectively. These figures highlight the potential for expanded development, especially in regions where mining infrastructure and industrial support are already present or being developed.

However, not all provinces with large resources report high reserves. North Maluku stands out with over 525 million tons of reserves, the highest in the country, indicating a well-developed understanding of its economically viable deposits. DI Yogyakarta is also notable for its 161 million tons of reserves, which suggests strong progress in resource assessment and mine planning. West Nusa Tenggara has just over 50 million tons of reserves, and East Java follows with 14 million tons, both indicating some level of project advancement.

In contrast, Papua, despite its massive resources, lists only 18.9 million tons of reserves. This disparity may reflect limited infrastructure, ongoing exploration, or regulatory hurdles that delay the conversion of resources into extractable reserves. Similar patterns are seen in other provinces like Bengkulu, Aceh, and Lampung, where significant resource figures are not yet accompanied by reserve estimates.

Smaller provinces such as West Sumatra, South Sulawesi, and Central Sulawesi contribute only marginally to the national totals, with low resource values and no current reserves reported. While their immediate impact is limited, these areas could play supporting roles in regional supply chains or act as strategic reserves for future development.

Overall, Indonesia's iron sand concentrate potential is substantial but not fully realized. A stronger focus on exploration, resource classification, and investment readiness will be critical to transforming these geological assets into economic value. As demand for iron-related materials continues to grow, particularly for domestic infrastructure and green technology manufacturing, these deposits may become increasingly important to the national economy.

A Comparative Analysis of Indonesia's Iron Ore Deposits: Economic, Social, Technical, and Environmental Perspectives

Indonesia's iron ore sector is marked by three major deposit types: primary iron ore, lateritic iron ore, and iron sand concentrate. Each presents distinct characteristics, opportunities, and challenges from economic, social, technical, and environmental standpoints. As Indonesia seeks to harness its mineral wealth for sustainable industrial development, understanding the comparative strengths and limitations of each deposit type is critical.

Economic Perspective

Primary Iron Ore

Economically, primary iron ore boasts the highest volume of resources, with over 7.85 billion tons reported in 2023. However, reserve conversion remains limited, with just 1.22 billion tons confirmed as economically extractable. This discrepancy suggests a need for improved feasibility studies and cost-effective mining technologies. Provinces like North Maluku and Central Kalimantan show strong potential due to high reserve-to-resource ratios, indicating a better prospect for near-term mining investments.

Lateritic Iron Ore

Lateritic iron ore also demonstrates robust economic potential, with 7.87 billion tons of resources and 1.65 billion tons in reserves. Provinces such as South Kalimantan and Southeast Sulawesi display excellent reserve conversion rates, reflecting both geological richness and economic viability. The relatively high iron content in some lateritic ores supports domestic steel production, although the processing cost is generally higher than primary ores.

Iron Sand Concentrate

Iron sand concentrate has shown consistent resource growth, reaching 4.45 billion tons in 2023. However, reserves have fluctuated, peaking in 2021 and then declining. These reserves are highly dependent on international market prices and downstream investment. North Maluku and DI Yogyakarta are standouts in terms of reserve development, offering viable economic returns due to established infrastructure and processing capacity.

Social Perspective

Primary Iron Ore

Primary iron ore mining tends to be located in inland or mountainous regions, potentially impacting remote and indigenous communities. In Aceh, South Sulawesi, and North Maluku, social issues may include land use conflict, labor dynamics, and the need for community engagement in project planning. The long mine life of primary ore deposits can provide lasting economic benefits if managed inclusively.

Lateritic Iron Ore

Lateritic iron projects are often found in Eastern Indonesia, including Sulawesi and Maluku, regions with lower development indices. These projects offer opportunities for job creation, regional development, and skill transfer. However, without inclusive policies, communities risk being marginalized. Social license to operate remains a critical issue in underdeveloped areas where expectations for economic upliftment are high.

Iron Sand Concentrate

Iron sand mining typically occurs in coastal areas, affecting fishing communities and tourism sectors. In provinces like DI Yogyakarta and East Java, community opposition has emerged due to perceived threats to livelihoods and coastal erosion. Effective stakeholder engagement and benefit-sharing mechanisms are essential to mitigate social tensions.

Technical Perspective

Primary Iron Ore

Technically, primary iron ore mining and beneficiation are well-established globally, and Indonesia has made progress in geological surveying. However, the challenge lies in converting resources into reserves. Many deposits require advanced geotechnical studies, metallurgical testing, and infrastructure development (e.g., roads, rail).

Lateritic Iron Ore

Lateritic iron ore presents greater technical challenges due to its complex mineralogy. Smelting and processing require high-temperature and energy-intensive methods, which can deter investment. Nevertheless, the rising demand for low-grade ores in certain industrial applications and the proximity of deposits to nickel laterite mines offer integration opportunities.

Iron Sand Concentrate

Iron sand mining is relatively simple, often using surface mining or dredging. However, separation of iron concentrate from sand requires magnetite processing technologies, and fine particles can cause processing losses. The fluctuating reserve figures indicate that more consistent classification and testing standards are needed.

Environmental Perspective

Primary Iron Ore

Primary ore mining generally involves large-scale land clearing and potential deforestation, especially in regions like Central Kalimantan and Aceh. Habitat disruption, biodiversity loss, and water contamination from tailings pose significant environmental concerns. Stringent environmental assessments and proper mine closure plans are crucial to minimize impacts.

Lateritic Iron Ore

Lateritic iron ore mining often occurs in ecologically sensitive tropical zones. Surface stripping can cause rapid erosion, landslides, and sedimentation in rivers. The high energy demand of laterite processing adds to its carbon footprint. Environmental management plans must address soil rehabilitation, water runoff control, and greenhouse gas emissions.

Iron Sand Concentrate

Iron sand mining has direct environmental impacts on coastal and marine ecosystems. Shoreline alteration, sediment plume, and disruption of marine biodiversity are common concerns. Inadequate reclamation has led to long-term beach erosion and declining fish populations. Environmental regulation and real-time monitoring are necessary to ensure coastal resilience.

Conclusion

Indonesia's diverse iron ore landscape offers vast economic opportunities—but realizing these fully demands a balanced development approach:

- Primary iron ore shows long-term potential, but faces feasibility and environmental hurdles.
- Lateritic iron ore holds promise in reserve conversion and regional development, yet presents processing and ecological challenges.
- Iron sand concentrate is attractive for quick development, but its environmental sensitivity and data reliability need improvement.

A strategic mix of technological investment, community partnership, environmental stewardship, and regulatory support is key to unlocking Indonesia's iron ore sector sustainably. By integrating economic ambitions with social inclusion and environmental responsibility, Indonesia can position itself as a responsible leader in the global iron supply chain.

Indonesia's Iron and Steel Industry: Trade Dynamics, Growth Outlook, and Environmental Challenges

Trade Patterns: A Two-Way Dependency

Indonesia's iron and steel trade reflects a dual character—serving as both a growing exporter and a persistent importer. In 2023, the country exported approximately 7.1 million tons of iron and steel, with China, Taiwan, and India among the main destinations. On the other hand, it imported similar volumes primarily from China, Japan, and South Korea (Figure 8.12).

The pie charts and bar graphs illustrate that China remains Indonesia's largest trading partner in both directions. While this relationship supports industry scale, it also signals a structural dependence that could pose strategic risks if global trade dynamics shift.

Domestic Growth Driven by Infrastructure

National steel production has steadily increased, rising from 6.2 million tons in 2015

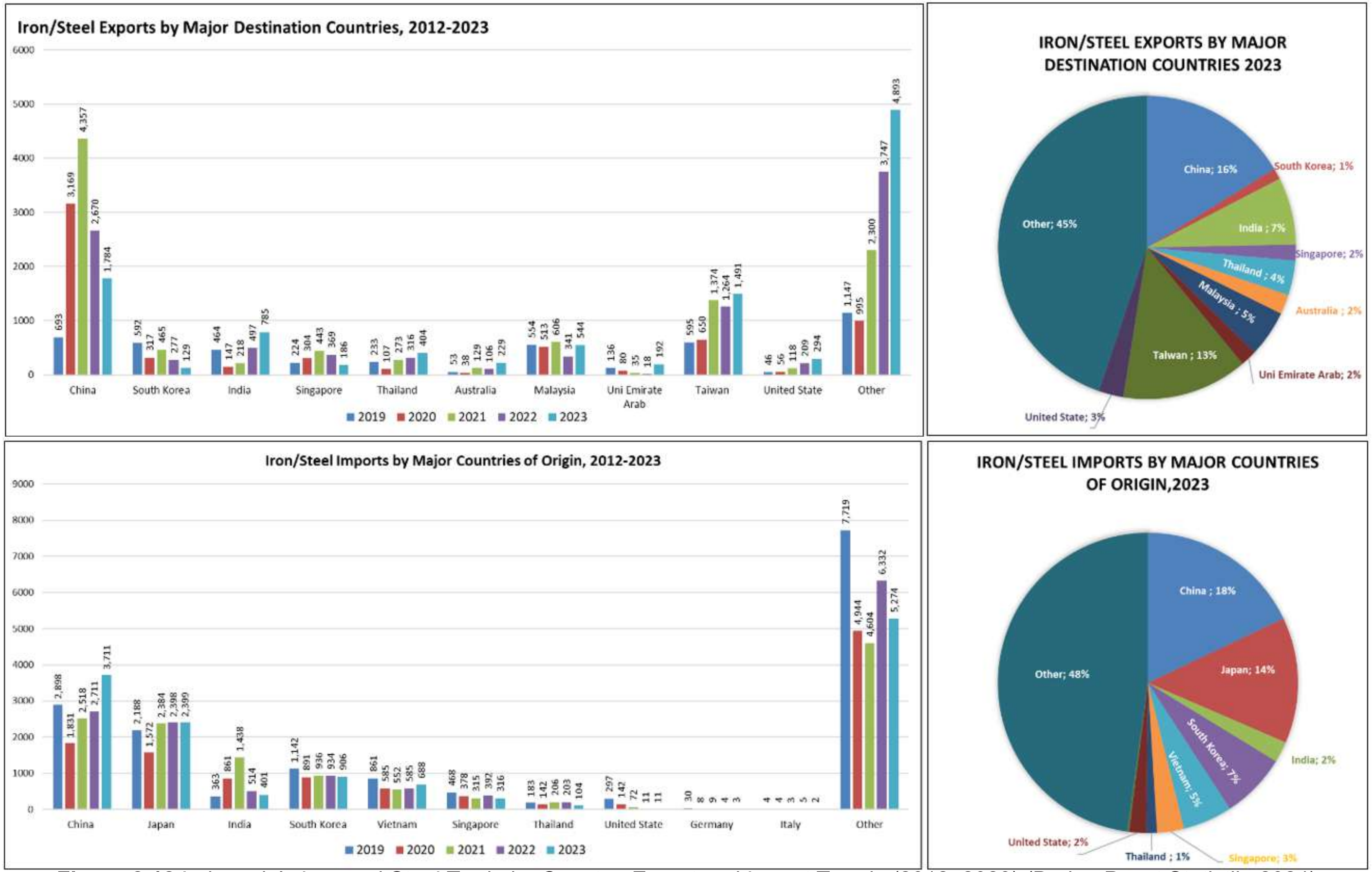

Figure 8.12 Indonesia's Iron and Steel Trade by Country: Export and Import Trends (2012–2023) (Badan Pusat Statistik, 2024)

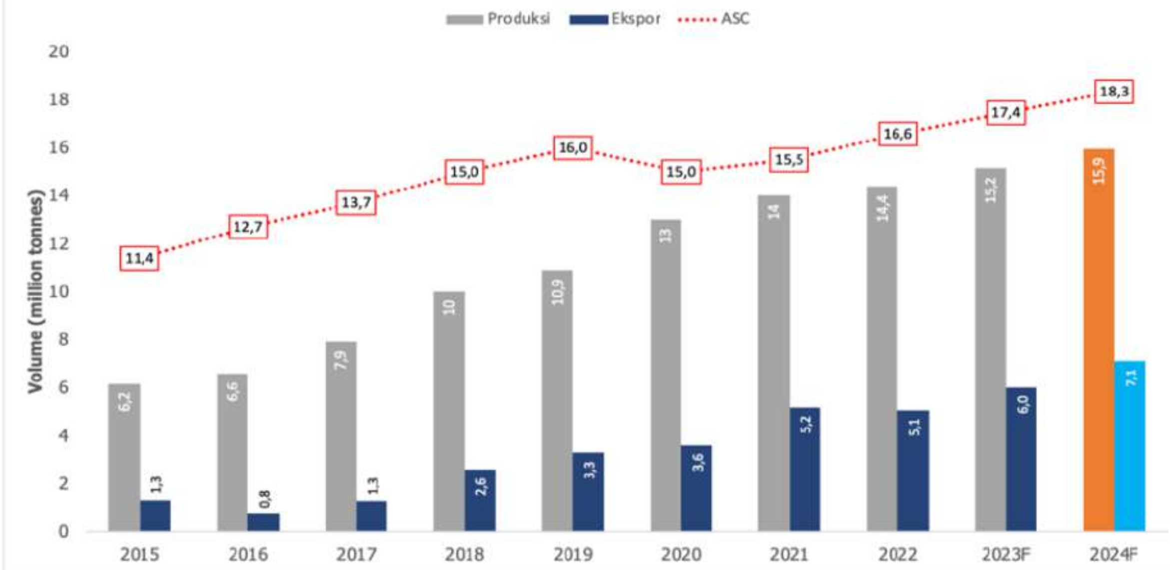

Figure 8.13 National Steel Consumption, Production, and Export Projection (2015-2024) (IISIA, 2024)

to a projected 15.9 million tons in 2024. Meanwhile, apparent steel consumption is forecast to reach 18.3 million tons in the same year (Figure 8.13). This expansion is largely fueled by infrastructure and construction projects, which account for nearly 78% of domestic steel use.

Despite this growth, Indonesia's per capita steel consumption—around 33 kg per year—lags behind that of neighboring ASEAN countries (Sofia, 2024). And although exports have climbed significantly, national production is still insufficient to meet rising domestic demand. This shortfall means Indonesia will continue relying on imports unless production capacity is scaled up rapidly (Simorangkir, 2021).

Challenges in Raw Material Supply

Indonesia's domestic iron ore supply remains limited in both quality and volume. While national demand for iron ore stands at nearly 18 million tons annually, domestic production accounts for only about 2–3 million tons. To bridge this gap, the country relies heavily on imports from Australia, Brazil, and Canada.

To reduce this reliance, the government has initiated policies aimed at increasing the use of local iron sand and lateritic iron ore. Technological improvements—especially in smelting processes like direct reduction using coal-based rotary kilns—are being encouraged to help absorb and process local materials more efficiently. Additionally, the development of smelters is being pushed to enhance value-added output and increase industrial resilience (Vinnilya, 2024, Fitri, et al., 2022).

Another aspect involves optimizing by-products from iron sand, such as titania (TiO_2) and vanadium pentoxide (V_2O_5), which hold significant economic value. These minerals, often overlooked, could provide new industrial opportunities if supported by proper refining technologies and investment.

Environmental Dimensions of Industry Growth

The ongoing industrial expansion brings serious environmental concerns. Iron ore and sand extraction often disturbs sensitive ecosystems, particularly coastal and forested areas. Uncontrolled mining can lead to soil erosion, water pollution, and habitat loss.

Moreover, the steelmaking process, especially when based on coal, is a major contributor to carbon emissions. In the absence of clean energy solutions, the environmental footprint of Indonesia's steel industry is expected to grow in tandem with its output.

Efforts to address these issues are slowly gaining ground. Cleaner production technologies—such as electric arc furnaces and energy-efficient smelters—are being introduced, though adoption remains limited. Reclamation and environmental monitoring practices in mining operations are also being encouraged to reduce long-term ecological impact.

Conclusion

Indonesia's iron and steel sector stands at a critical juncture. Trade activity is robust, production and consumption are on the rise, and the government is taking steps to strengthen domestic capacity. Yet, challenges remain in the form of raw material dependence and environmental degradation.

Balancing industrial growth with environmental responsibility will be key to the sector's long-term success. The transition to greener technologies and more sustainable resource management is not just an option—it is a necessity.

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Bauxite

Image: Bauxite, East Kotawaringin, Central Kalimantan
Courtesy of: Faisal, et al., 2023

The term bauxite was first coined by Berthier in 1821 to describe aluminium oxide-rich deposits found in *Les Baux*, near Avignon in southern France. Over time, the term evolved to refer to sedimentary rocks with a relatively high aluminium (Al) content, low iron (Fe) content, and minimal or no free quartz (SiO_2).

Bauxite is a heterogeneous material composed mainly of aluminium oxide-bearing minerals, accompanied by varying amounts of iron oxide, silica, and titanium. The aluminium oxide is typically found as boehmite ($Al_2O_3 \cdot H_2O$) and gibbsite ($Al_2O_3 \cdot 3H_2O$). In general, bauxite ore contains between 45% and 65% Al_2O_3, 1% to 12% SiO_2, 2% to 25% Fe_2O_3, over 3% TiO_2, and 14% to 36% water. Iron is present in the form of hematite or goethite, silica appears as clay and free quartz, and titanium as leucoxene or rutile.

Bauxite is the primary ore used in the production of aluminium—an essential metal in modern industry, second only to iron. It also plays a critical role in the refractory and chemical industries.

Genesis of Bauxite in Indonesia

According to Ramadhan et al. (2014), several geological processes can give rise to bauxite deposits. These include magmatic processes, where alumina forms in alumina-rich igneous rocks; hydrothermal processes, where it is a product of hydrothermal alteration in rocks like trachyte and rhyolite; and metamorphic processes, which are considered non-economic in terms of alumina potential. However, the most significant process is intense chemical weathering, which produces residual deposits known as bauxite.

Lateritic Bauxite Profile: A Stratigraphic and Geochemical Narrative

The formation of lateritic bauxite profiles in tropical and subtropical regions is a significant geological process driven by prolonged chemical weathering under intense climatic conditions. These profiles are the result of interactions among lithology, hydrology, geochemistry, and time, and they represent the Earth's ability to selectively concentrate economically valuable minerals through natural mechanisms.

Stratigraphy and Composition

A typical lateritic bauxite profile is vertically differentiated into several distinct zones, each with its own compositional and textural characteristics (Figure 9.1). At the surface lies the **organic layer**, composed of decomposed vegetation and humus. Although this layer holds no direct economic value, it is ecologically essential, acting as the interface between biological activity and mineral weathering.

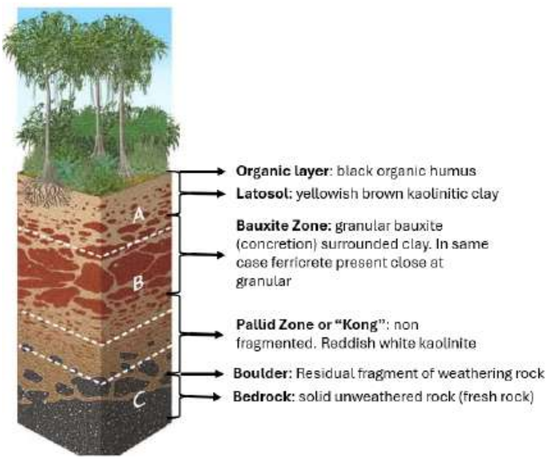

Figure 9.1 Typical Lateritic Bauxite Profile in Indonesian Deposits (Sunjaya, D. et al., 2019)

Beneath the organic cover is the **latosol horizon**, characterized by a yellowish-brown coloration and composed primarily of **kaolinitic clay**. This layer forms under conditions of extreme leaching, where mobile elements such as sodium, potassium, and calcium are removed, while relatively immobile oxides—particularly iron and aluminium—begin to accumulate. The latosol zone marks the upper portion of the weathering profile and serves as a transitional phase toward ore-grade mineralization.

The most economically significant layer is the **bauxite zone**, defined by the presence of **granular concretions of bauxite** embedded in a clay matrix. This zone may also include **ferricrete**—a cemented iron-rich crust—especially in areas where lateral and vertical drainage is restricted. The dominant aluminium-bearing minerals in this zone include **gibbsite ($Al_2O_3·3H_2O$)** and **boehmite ($Al_2O_3·H_2O$)**, with aluminium oxide contents typically ranging from 45% to 65%. This concentration forms the principal resource base for aluminium production, which is of strategic importance in industrial, construction, aerospace, and technological sectors.

Underlying the bauxite zone is the **pallid zone**, also referred to as the **Kong zone**. This horizon is predominantly composed of **kaolinitic clay** with a light reddish to white hue. The material is fine-grained, easily dispersible in water, and generally devoid of economic mineralization. Despite its low aluminium content, the pallid zone is an important marker in resource delineation and reflects a significant degree of leaching and alteration.

The subsequent **boulder zone** comprises residual fragments of rock that resisted the weathering process. These remnants provide valuable clues to the composition and structural integrity of the original parent rock. Finally, the sequence terminates at the **bedrock**, which remains unaltered and consists of source lithologies such as **syenite**, **nepheline-rich rocks**, or **shale**. The mineralogical composition of the bedrock largely determines the nature and extent of aluminium enrichment in the overlying zones.

Formation Process and Resource Implications

The genesis of bauxite deposits through lateritization is closely linked to tropical climatic regimes with high rainfall and elevated temperatures. These conditions foster intense hydrolysis and leaching, processes that are essential for the concentration of aluminium oxides and the removal of silicates, alkalis, and other soluble components. The development of a lateritic profile is thus a function of both geochemical equilibrium and prolonged surface exposure, often spanning millions of years.

Globally, the vast majority of bauxite—approximately 85%—is refined into alumina, which is then smelted into aluminium metal (International Aluminium Institute, n.d.). Depending on ore quality, the production of aluminium typically requires between four and six tons of bauxite, yielding roughly two tons of alumina through the Bayer process. This alumina is then subjected to the Hall-Héroult electrolysis process, resulting in the production of roughly one ton of primary aluminium. The sustainability and strategic importance of this material are underscored in recent assessments by the European Commission, which emphasize the environmental, socio-economic, and circular economy considerations tied to bauxite and aluminium supply chains (Georgitzikis et al., 2021).

Conclusion

The lateritic bauxite profile exemplifies the complex interplay between geological processes and resource formation. Each horizon within the profile—from the biologically active organic surface to the inert, unweathered bedrock—offers insight into the conditions under which aluminium ore accumulates. Understanding these profiles not only enhances exploration and extraction strategies but also contributes to sustainable resource governance in the face of rising global demand for aluminium.

Bauxite Resources and Reserves in Indonesia

In Indonesia, bauxite resources are predominantly associated with lateritic deposits formed through intensive weathering in tropical environments. These deposits are mainly distributed across the Riau Islands, Bangka Belitung Islands, West Kalimantan, and Central Kalimantan (Figure 9.2).

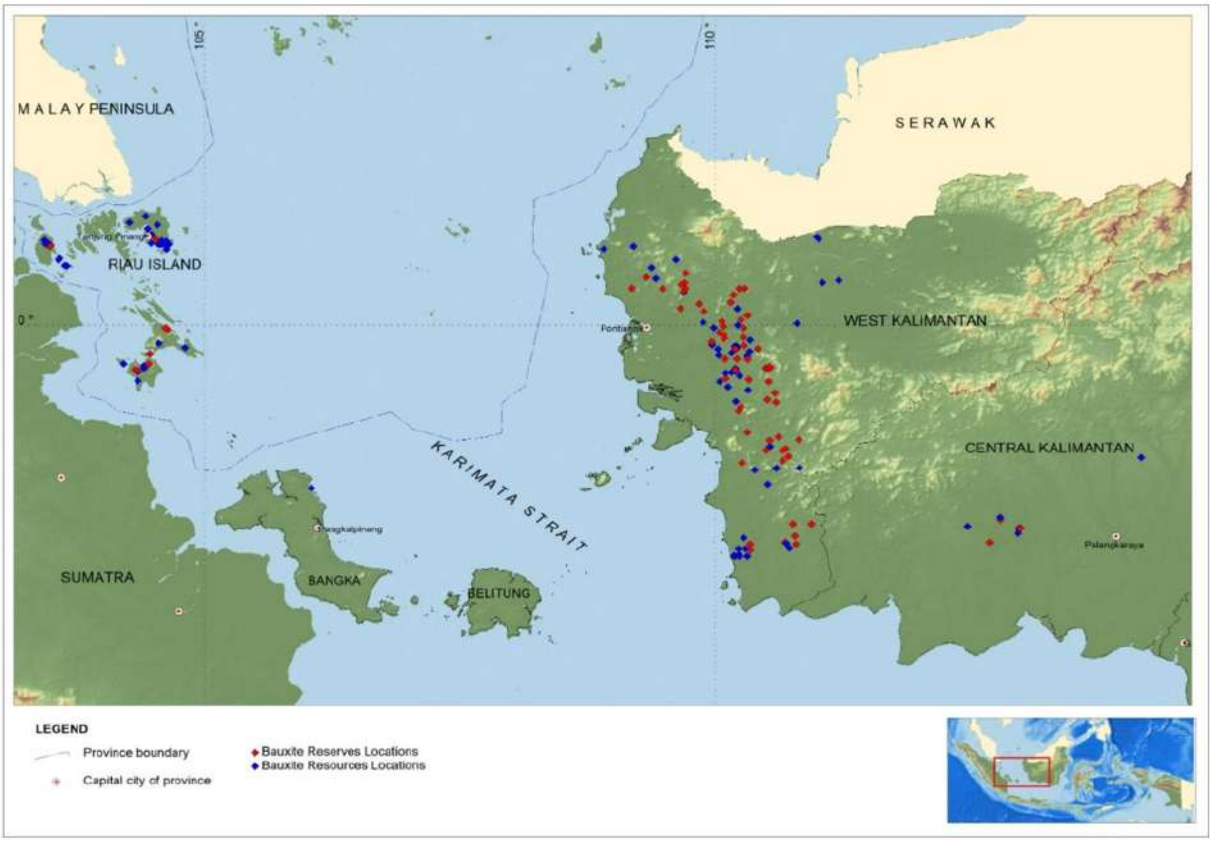

Figure 9.2 Geographic Distribution of Bauxite Resources and Reserves in Riau Islands, West Kalimantan, and Central Kalimantan (Nursahan et al., 2024)

In the Riau Islands, particularly on Bintan Island, bauxite is generally found as a lateritic horizon with thicknesses varying between two and ten meters, averaging around four meters. This bauxite layer comprises scattered concretions embedded within hard clay, where the concretions typically range in size from 2.5 to 10 centimeters. The dominant mineral constituents include gibbsite and goethite, while the silica content remains relatively low. Clay makes up about one-fifth to two-fifths of the total mass of the laterite. These characteristics reflect a highly matured weathering profile with significant economic potential due to the high aluminium hydroxide concentration and low silica impurities (Muliyana et al., 2023).

In West Kalimantan, the Landak region hosts bauxite that is formed within andosol and catena soil systems, often derived from the in situ weathering of local igneous rocks. The characteristics of the bauxite are strongly influenced by the parent lithology. For example, granodiorite bedrock produces a coarse-textured, brick-red lateritic soil with embedded quartz grains, typically one to three millimeters in size. This type of deposit is commonly found within saprolite zones, with thicknesses reaching up to ten meters. In contrast, weathering of quartz diorite results in darker brown soils that contain yellowish lateritic material. These soils often exhibit signs of groundwater seepage and are interspersed with clay layers, fresh rock fragments, and pockets of silica sand. The thickness of such weathered profiles typically ranges from two to eight meters (Muliyana et al., 2023).

Further east, in the East Kotawaringin area of Central Kalimantan, bauxite is formed atop volcanic and clay-rich basement rocks. These deposits develop over altered volcanic breccias composed of andesite and dacite. The overlying sedimentary layers, rich in oxidized hydrated aluminosilicates, form extensive lateritic soils where silica and iron oxides precipitate as concretions. These concretions contribute to the textural diversity of the bauxite, which includes forms such as hollow tabular bodies, pisolitic grains, sub-rounded fragments, and hollow lumps. In areas such as Cempaga Hulu and Telawang, deposit thicknesses vary from just over two meters to nearly six meters, reflecting variable weathering intensities and geologic controls (Faisal et al., 2023).

Indonesian bauxite is commonly classified into crude bauxite, known as wet metric ton crude bauxite (wmtcbx), and washed bauxite, or wet metric ton washed bauxite (wmtwbx). The ratio of washed to crude bauxite—referred to as the concretion factor—is a key parameter in determining ore usability. While some mining companies report this figure explicitly, many do not, resulting in the application of a standard assumption of 50 percent. After beneficiation, the washed bauxite undergoes drying and chemical analysis to determine its aluminium oxide (Al_2O_3) content, as well as levels of silica (SiO_2), iron oxide (Fe_2O_3), and titanium oxide (TiO_2). The final alumina yield is derived by multiplying the Al_2O_3 content by the dry weight of the washed bauxite. In instances where both wet and dry metric tonnage data are available, the average moisture content in raw bauxite is typically assumed to be around 15 percent (Muliyana et al., 2023).

This comprehensive understanding of Indonesia's bauxite resources—spanning geological characteristics, mineralogical profiles, and processing factors—provides a solid foundation for evaluating its strategic role in both domestic and global aluminium supply chains.

Evaluating Indonesia's Bauxite Potential: Insights from Resource and Reserve Classifications

Indonesia, with its abundant bauxite deposits, holds strategic importance in the global aluminium supply chain. This section examines the distribution and classification of Indonesia's bauxite resources and reserves, highlighting the disparity between exploration and extraction-ready deposits. Based on recent data, it underscores the implications for future development, industry potential, and strategic planning.

Introduction

Indonesia's role in the global bauxite and aluminium supply chain continues to grow, driven by its vast lateritic bauxite deposits spread across multiple regions. As the demand for aluminium intensifies globally—due to its applications in transportation, construction, packaging, and renewable energy—the accurate assessment and classification of bauxite deposits become critical for sustainable development and investment decisions.

Resource and Reserve Distribution

An analysis of the national classification of Indonesia's bauxite shows that indicated resources dominate, reaching approximately 2.96 billion tons of bauxite ore (Figure 9.3). This category also yields the highest volume of recoverable alumina metal at 471 million tons, indicating a relatively high degree of geological confidence supported by sufficient exploration data.

In contrast, inferred resources, while substantial at 2.43 billion tons of ore, are less certain geologically and technologically, suggesting these areas require further investigation. Measured resources, considered the most reliable, contribute 2.09 billion tons of ore and about 395 million tons of alumina, highlighting a solid base for future reserve conversion.

When turning to reserve classifications, the decline becomes evident. Probable reserves total 1.77 billion tons, while proven reserves are at 1.01 billion tons. Corresponding alumina contents are 339 million and 192 million tons, respectively. This notable gap between the resource and reserve categories reflects either a lack of technical-economic studies or infrastructural and regulatory challenges that hinder reserve certification and exploitation.

Implications and Strategic Outlook

The difference in volume between resources and reserves is not uncommon but is particularly telling in the Indonesian context. It suggests that a significant portion of the country's bauxite potential is currently underutilized. This underlines the need for enhanced exploration efforts, feasibility studies, and reserve upgrading programs. It also suggests that substantial opportunities exist for new investments, especially in refining and downstream processing industries.

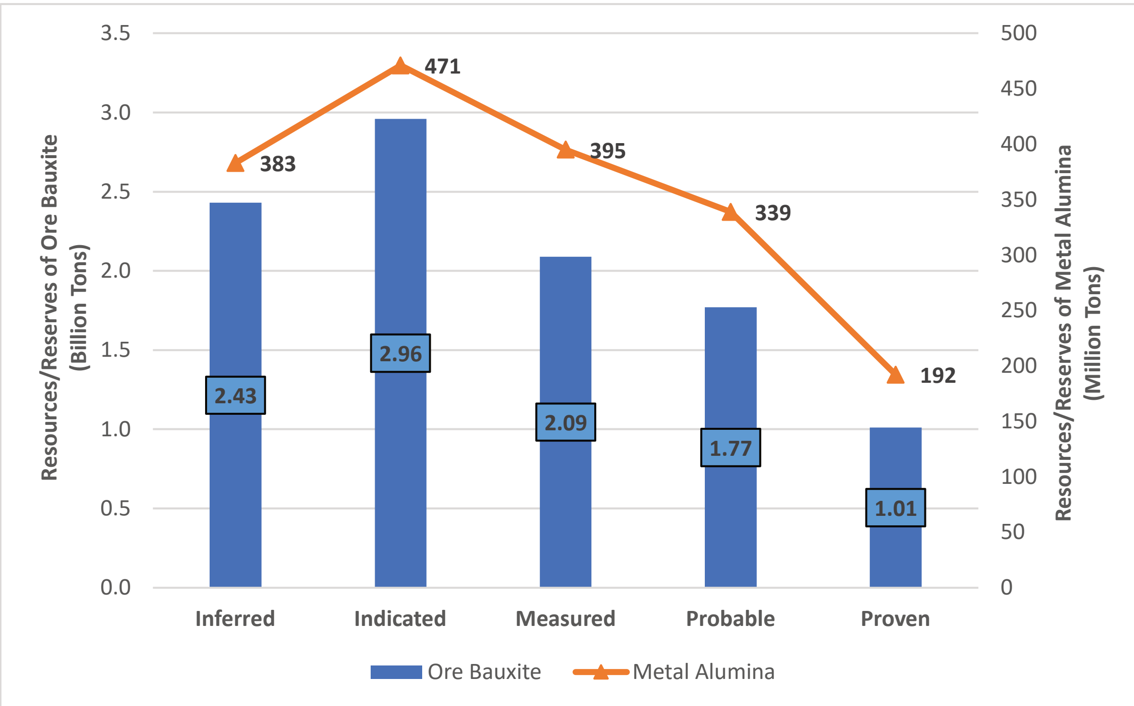

Figure 9.3 Classification of Indonesia's Bauxite Resources and Reserves by Ore and Alumina Content (Nursahan, et al., 2024)

The alumina yield across classifications remains relatively stable, suggesting efficient potential for aluminium production once the ore is processed. On average, the ratio between bauxite ore and alumina content aligns with global industrial benchmarks, further validating the commercial value of these deposits.

Conclusion

Indonesia's bauxite classification profile reveals a country with immense untapped potential. While resources are abundant and widely distributed, the transition to proven reserves remains limited. To realize this potential, national policies must prioritize geological research, infrastructure development, and investment facilitation. Doing so will not only strengthen Indonesia's position in the global aluminium market but also promote value-added mineral development that benefits the broader economy.

Trends in Bauxite and Alumina Resources and Reserves in Indonesia (2019–2023)

Indonesia has experienced a dynamic shift in its bauxite and alumina resources and reserves over the five-year period from 2019 to 2023. The data, drawn from national resource inventory reports, reflects both positive growth in geological potential and notable challenges in reserve conversion and exploration updates.

Growth in Bauxite Resources Amid Stagnant Reserves

Between 2019 and 2023, Indonesia's total bauxite resources rose significantly, increasing from 3.88 billion tons to 7.48 billion tons. This growth underscores the country's increasing geological endowment and exploration coverage. However, the reserves — economically extractable portions — did not show a parallel increase. After reaching 3.22 billion tons in 2021, the reserves declined to 2.78 billion tons in 2023, suggesting a lag in updating reserve status or delays in technical and economic evaluations (Figure 9.4).

The discrepancy between resource growth and reserve stagnation may indicate the need for enhanced reserve classification efforts, including feasibility studies and updated geological modeling. Furthermore, it reflects the time lag between discovery and economic validation in the mining sector.

Alumina Trends Mirror Bauxite Patterns

Alumina (Al_2O_3), the refined product from bauxite ore, showed a similar pattern. Resources peaked at 1,799 million tons in 2020, dropped sharply to 1,094 million tons in 2021, and recovered slightly to 1,249 million tons in 2023. Meanwhile, reserves declined from 947 million tons in 2020 to 531 million tons in 2023, again emphasizing the gap between discovery and economic development (Figure 9.5).

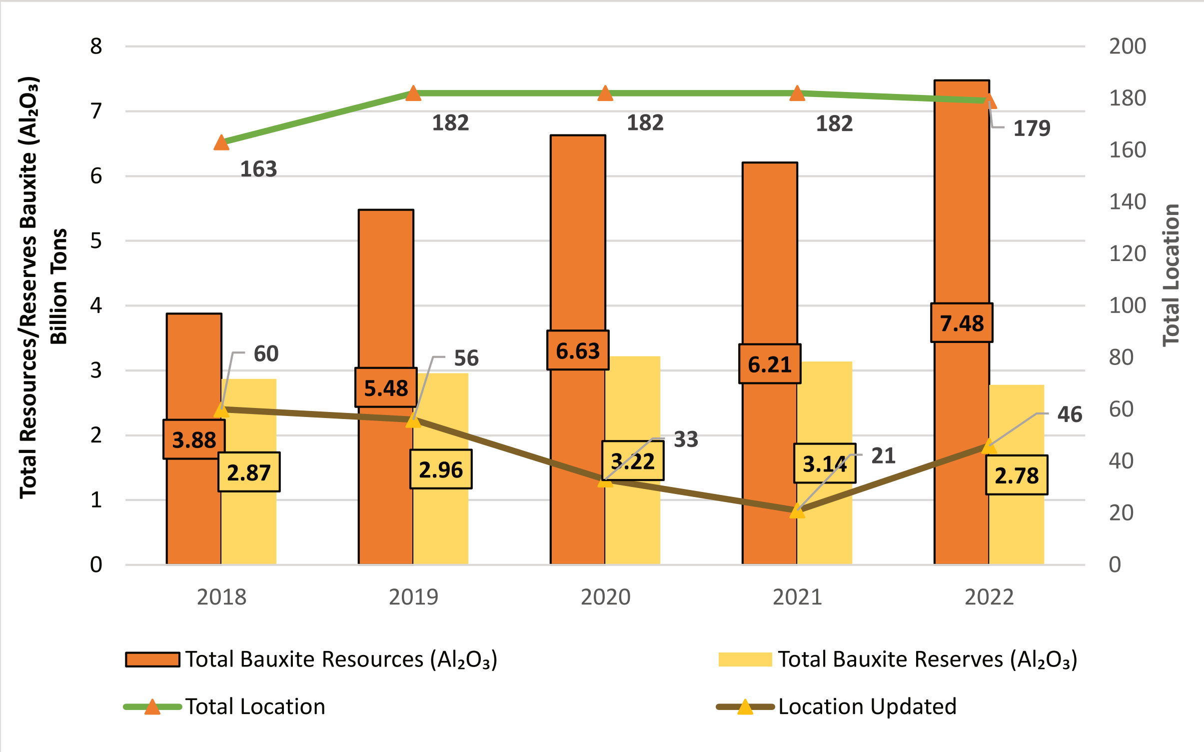

Figure 9.4 Trends in Total Bauxite (Al_2O_3) Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

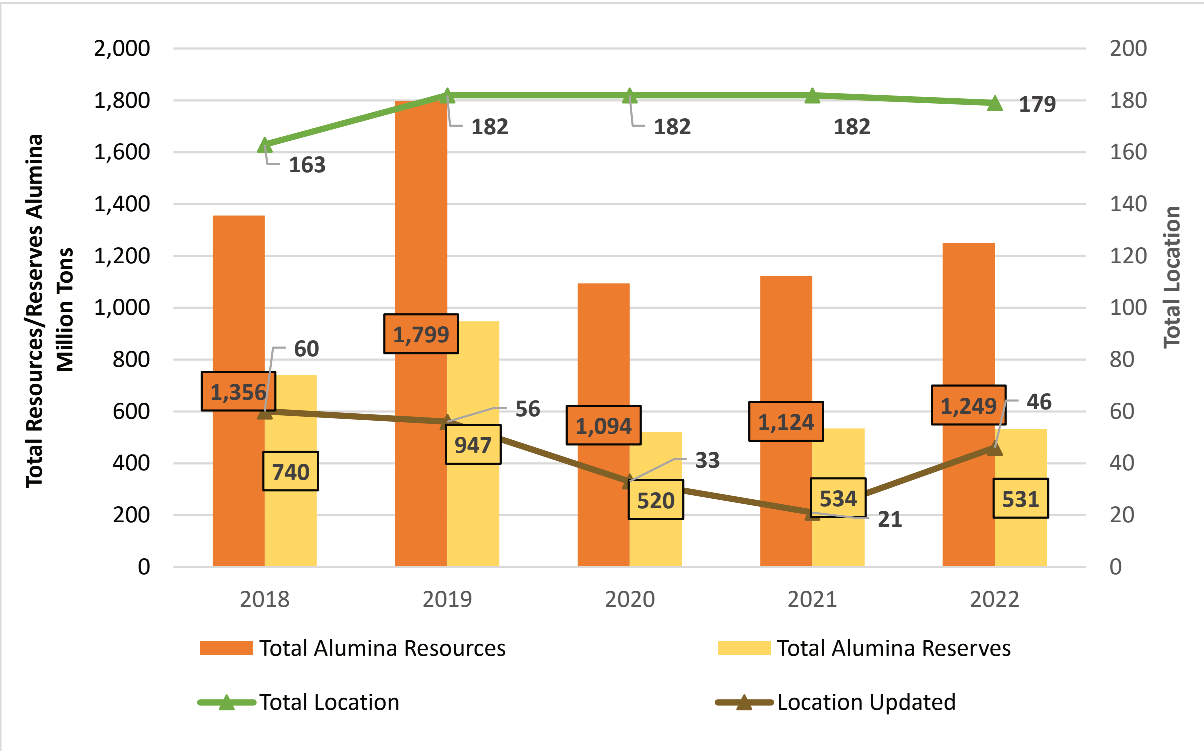

Figure 9.5 Fluctuation of Total Alumina Resources and Reserves in Indonesia (2019–2023) (Nursahan, et al., 2024)

These trends suggest a dependency between reserve reporting and the number of actively updated locations. Indeed, the number of updated locations decreased sharply from 60 in 2019 to just 21 in 2022, before increasing again to 46 in 2023. Despite the total number of identified locations remaining stable (around 180), the lack of regular updates has impacted reserve reporting consistency.

Implications for Industry and Policy

The increase in bauxite resources signals promising prospects for Indonesia's mineral industry. However, without proportional growth in reserves, these potentials remain largely untapped. The observed fluctuations emphasize the importance of consistent geological updating and reserve classification.

Policy support in the form of incentivizing exploration, easing permitting processes for feasibility studies, and promoting downstream alumina processing could help convert more resources into viable reserves. With the global demand for bauxite and alumina expected to rise, ensuring the alignment between exploration results and economic development is crucial for Indonesia's role as a major player in the global aluminum value chain.

Indonesia's Bauxite Profile: A High-Grade Edge in the Global Market

Indonesia is rapidly emerging as a prominent force in the global bauxite sector. Its abundance of high-grade bauxite—classified by aluminum oxide (Al_2O_3) content—positions the country as a competitive player, especially as international demand for alumina and aluminum continues to rise. A comparison with other leading bauxite-producing nations such as Australia, Guinea, and China highlights both Indonesia's strengths and areas for strategic development.

Indonesia's Strength: High-Grade Dominance

Indonesia's bauxite deposits are distinguished by a high proportion of ore with Al_2O_3 content exceeding 46%. These high-grade reserves are especially concentrated in the indicated and probable categories, suggesting both geological confidence and economic viability. This level of quality allows for more efficient alumina production, as high-grade ore requires less energy and processing to extract aluminum (Figure 9.6).

In contrast, Guinea—currently the world's largest bauxite exporter—holds vast bauxite reserves but primarily of medium to low-grade ore (around 40–45% Al_2O_3). While Guinea leads in volume, Indonesia has the advantage in ore quality, which is a significant factor in refining efficiency and cost competitiveness (USGS, 2023; World Bank, 2022).

Medium and Low-Grade Distribution

Indonesia also holds considerable medium-grade bauxite (Al_2O_3 between 42% and 46%), primarily in the measured and indicated categories. This mirrors the grade range commonly found in Australia, which is another top global producer. However, Australia has more extensively developed downstream capabilities, including alumina refineries and aluminum smelters, backed by stable infrastructure and policy frameworks (Geoscience Australia, 2023).

Indonesia's low-grade bauxite (<38.5% Al_2O_3), on the other hand, remains limited and economically marginal. China, for comparison, has large reserves of low- to medium-grade bauxite and heavily depends on imports, particularly from Guinea and Australia, to feed its massive refining capacity (China Mining Association, 2022).

Challenges: Data Gaps and Exploration Needs

A significant proportion of Indonesia's resources—especially inferred and indicated—lack detailed grade classification. This limits the ability to fully assess the economic value and long-term potential of the ore bodies. Enhanced geological surveys and geochemical analysis are needed to upgrade resource confidence and ensure that reserves can be efficiently utilized.

By contrast, countries like Australia and Brazil have more mature exploration databases and transparent geological reporting systems, which support investment decisions and long-term planning (CRU Group, 2023).

Strategic Potential

Indonesia's advantage lies in its ability to supply high-grade ore in large quantities. With increasing investment in domestic alumina refining—especially following export restrictions on raw bauxite—the country is poised to move up the value chain.

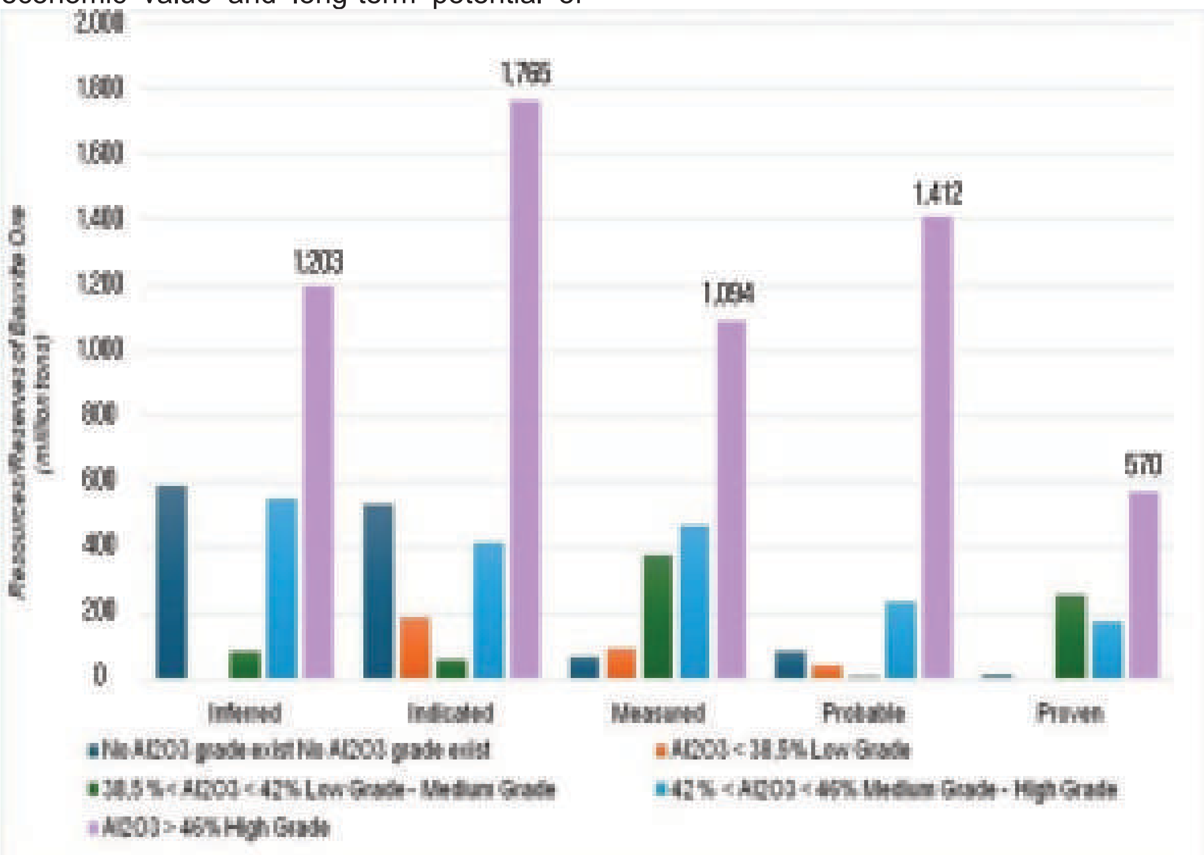

Figure 9.6 Resources/Reserves of Bauxite Ore by Al_2O_3 Grade and Confidence Level (million tons) (Nursahan, et al., 2024)

Compared to China, which is heavily reliant on imported ore for its refining industry, Indonesia has the opportunity to build a more self-sufficient and sustainable bauxite-to-aluminum ecosystem. Guinea, while dominant in exports, lacks sufficient infrastructure and local refining capacity, which Indonesia is actively working to improve (Indonesian Ministry of Energy and Mineral Resources, 2024).

Conclusion

While Indonesia may not yet surpass Guinea or Australia in total bauxite volume, it holds a strategic advantage in ore quality and untapped potential. By addressing data gaps and accelerating development of its refining sector, Indonesia can position itself not just as a supplier of raw material, but as a leader in the global aluminum value chain.

The combination of high-grade reserves, growing infrastructure, and favorable policy directions suggests a bright future for Indonesia's bauxite industry—one that could rival and eventually surpass some of the traditional giants in the years ahead.

Regional Distribution and Analysis of Bauxite Resources and Reserves in Indonesia

Indonesia holds significant bauxite resources and reserves, with distribution spread across several provinces (Figure 9.2). Based on the 2023 data, the total bauxite resources in the country amount to approximately 7.47 billion tons of ore and 1.26 billion tons of metal content. Reserves stand at 2.77 billion tons of ore and 531 million tons of metal (Table 9.1).

West Kalimantan emerges as the dominant region in terms of both resources and reserves. The province holds over 5.63 billion tons of bauxite ore resources and 999 million tons of metal content. In terms of reserves, West Kalimantan also leads with 2.26 billion tons of ore and 433 million tons of metal. The large measured and indicated categories in this region reflect significant exploration activities and investment focus.

Central Kalimantan follows with approximately 479 million tons of bauxite ore resources and 86 million tons of metal. It has reserves amounting to 202 million tons of ore and 40 million tons of metal. Although lower in total than West Kalimantan, the region still contributes meaningfully to Indonesia's overall bauxite portfolio.

Table 9.1 Bauxite Ore Resources and Reserves by Province (Nursahan, et al., 2024)

Province	Ore Resources (million tons)	Metal Content in Resources (million tons)	Ore Reserves (million tons)	Metal Content in Reserves (million tons)
West Kalimantan	5,630	999	2,260	433
Central Kalimantan	479	86	202	40
Riau Islands	1,360	172	312	58
Bangka Belitung Islands	3.1	0.369	–	–
Total	**7,472.10**	**1,257.40**	**2,774**	**531**

The Riau Islands contribute over 1.36 billion tons of ore resources and 172 million tons of metal. With a relatively smaller reserve base of 312 million tons of ore and 58 million tons of metal, the region shows strong potential, especially in the inferred and probable resource categories.

Meanwhile, Bangka Belitung Islands report only 3.1 million tons of inferred ore resources and 369 thousand tons of metal, with no measured or indicated categories or reserves reported.

This distribution illustrates Indonesia's concentration of bauxite resources in Kalimantan, especially West Kalimantan, highlighting it as a strategic area for further development and investment. Future focus may involve optimizing reserves into production and exploring underutilized areas such as the Riau Islands for expanded operations.

Projected Lifespan of Bauxite Reserves

Indonesia's bauxite sector stands at a critical juncture as the country ramps up production capacity to meet domestic processing targets and international demand. Based on the updated reserve estimate of 2.78 billion tons and a projected constant annual production rate of 41.3 million tons starting in 2024, the country's bauxite reserves are expected to be exhausted by the year 2092. This projection, covering the period from 2023 to 2092, highlights a lifespan of approximately 67 years for current reserves under a full-capacity extraction model.

The production trend demonstrates a significant increase from 13.88 million tons in 2023 to 41.3 million tons in 2024, maintaining that rate in the following years. This flat production trajectory assumes the utilization of full industrial capacity as permitted under the Industrial Business Permit. The graphical representation accompanying this analysis shows a steadily declining reserve profile, as indicated by the bar chart, which corresponds to the volume of bauxite extracted over time (Figure 9.7).

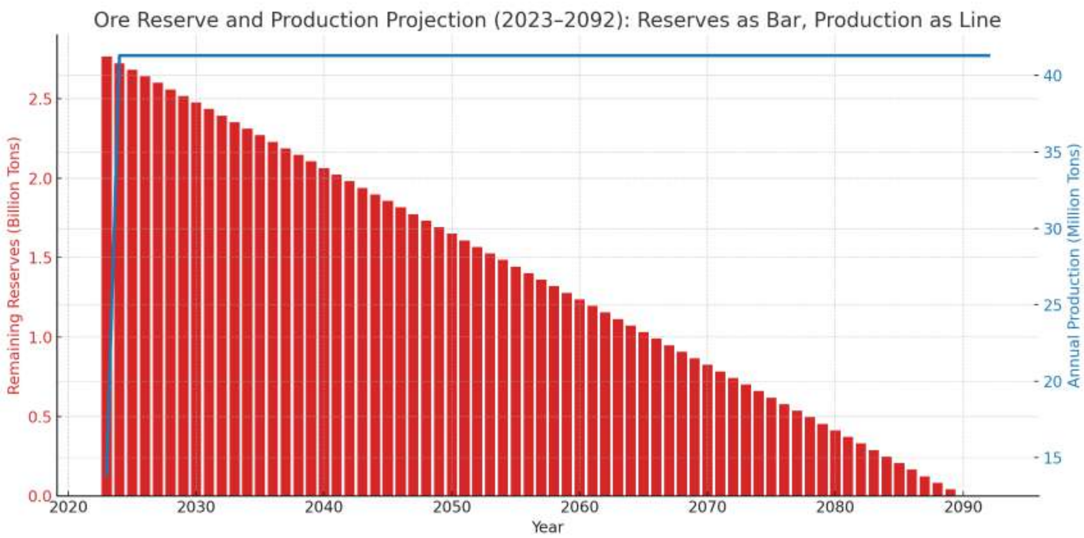

Figure 9.7 Bauxite Ore Reserve Depletion and Production Trend (Nursahan, et al., 2024)

This reserve depletion scenario signals a need for urgent policy attention. While Indonesia currently holds a strong resource base, its longevity is finite. Continued extraction at peak levels, without parallel efforts in exploration and reserve expansion, would lead to complete depletion within less than seven decades. The implications of such a trend are far-reaching, affecting not only the upstream mining industry but also downstream sectors such as alumina refining and aluminum production.

Strategic planning becomes essential in light of these projections. Policymakers and industry stakeholders must consider enhancing exploration activities, reclassifying inferred and indicated resources into proven reserves, and encouraging technological innovation that allows more efficient resource utilization. Additionally, integrating sustainability frameworks into mining operations and promoting circular economy practices could help extend the economic life of existing reserves.

In conclusion, this projection illustrates the urgency of adopting a balanced and forward-looking mineral management strategy. With reserves likely to last until only 2092 under current production assumptions, Indonesia must move decisively to secure its long-term bauxite supply and maintain its strategic position in the global aluminium value chain.

Indonesia's Strategic Shift in Bauxite Processing

Indonesia is undergoing a significant transformation in its mineral processing strategy, as evidenced by the changes brought about by Law No. 3 of 2020 concerning Mineral and Coal Mining. With the prohibition of raw bauxite exports coming into effect on June 10, 2023, the government is aiming to harness greater economic value by processing bauxite domestically into alumina and eventually aluminium. Historically, the country exported millions of tons of raw bauxite—a practice that yielded relatively modest returns compared to the much higher value of imported aluminium. For example, in 2022, despite exporting 17 million tons of bauxite for US$622 million, Indonesia imported only around 724,000 tons of aluminium, which was valued at US$2.4 billion (BPS, 2023). This stark difference highlights the missed opportunity of not capturing more value through local processing.

The new approach is designed to address this imbalance by encouraging the transformation of raw bauxite into higher-value products. Processing the ore into alumina, and ultimately aluminium, promises not only to bring in greater export earnings but also to reduce dependency on imported materials—a strategic move aimed at boosting domestic industrial capacity. This shift is expected to have a ripple effect on several sectors, including construction, transportation, packaging, and clean energy industries, all of which are increasingly reliant on aluminium (Wardianingsih & Riyono, 2023).

Advanced purification technology in bauxite processing not only facilitates the production of alumina but also enables the extraction of valuable by-products, such as rare earth elements (REE), vanadium (V), and gallium

(Ga). These by-products, which are present in concentrations higher than the average found in the earth's crust, have significant potential to enhance strategic industries.

However, the initiative is not without its challenges. Presently, Indonesia operates only two smelters, which cannot handle the large quantities of bauxite now restricted from export. Recognizing the need for increased capacity, plans are underway to build 12 new smelters in West Kalimantan. The financial investment required for each new smelter is substantial, estimated at around US$1.2 billion. This significant capital requirement has made it difficult for domestic banks to provide financing due to the long-term returns on such investments, prompting the government to seek foreign investment to bridge this gap (Wardianingsih & Riyono, 2023).

Another key challenge is the intensive energy demand required for processing bauxite. The production of alumina and aluminium is highly energy-consuming; for instance, producing one million tons of alumina requires roughly 611,000 tons of coal, and manufacturing the same volume of aluminium demands a dedicated 2,000 MW power plant. West Kalimantan, the province rich in bauxite reserves, lacks sufficient energy resources, including fossil fuels, geothermal power, or hydropower. Addressing this energy supply shortfall is crucial for the success of the domestic processing initiative (Liun & Nurlaila, 2021).

Data from 2023 indicate that Indonesia's bauxite deposits are primarily concentrated in a few key provinces: West Kalimantan, the Riau Islands, and Central Kalimantan. This spatial distribution is closely tied to the geological processes that form bauxite—specifically, the intense weathering of granitic and volcanic rocks originating from aluminum-rich basement formations. To sustain these bauxite reserves and possibly expand their exploitation, it is crucial to intensify exploration activities along lateritic paths in both brownfield and greenfield areas. These efforts should be guided by integrated datasets that include metallic-bearing formations, bauxite resource and reserve assessments, and updated survey databases to effectively identify potential bauxite-rich zones. The key areas are documented as follows: West Kalimantan covers approximately 2,575,021 hectares, Central Kalimantan spans about 328,002 hectares, and the Riau Islands comprise roughly 184,558 hectares.

The overarching goal of these reforms is to transform Indonesia from a raw material exporter to a prominent player in the value-added mineral processing sector. By fostering domestic production capabilities and attracting significant foreign investments, the country aims to capture higher export revenues, create jobs, and stimulate industrial innovation. However, achieving these benefits will depend largely on overcoming substantial infrastructure challenges, particularly the need for reliable energy supplies and the mobilization of financial resources.

In summary, Indonesia’s ban on raw bauxite exports marks a bold strategic pivot designed to maximize the economic benefits derived from its abundant mineral resources. By moving up the value chain through domestic processing, Indonesia not only hopes to enhance its export earnings but also to spur sustainable industrial development that could serve as a model for other resource-rich nations.

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10

REE
(Rare Earth Elements)

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Image: REE Minerals
Courtesy of: https://agmetalminer.com/wp-content/uploads/2023/05/njnjn.jpg.

According to Government Regulation No. 96 of 2021 on the Implementation of Mineral and Coal Mining Business Activities, Article 2 Paragraph B classifies rare earth elements (REEs) and monazite as metal minerals. This discussion focuses on the definition, occurrence, genesis, resources, and key issues related to REEs.

In addition, based on the Ministry of Energy and Mineral Resources (MEMR) Decree No. 296.K/MB.01/MEM.B/2023 concerning the Determination of Commodities Classified as Critical Minerals, and MEMR Decree No. 69/MB.01/MEM/2024 concerning Strategic Minerals, REEs are recognized as both critical and strategic commodities in Indonesia.

REEs are a group of 17 elements from the lanthanide series—lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu)—in addition to yttrium (Y) and scandium (Sc), which have similar chemical properties. These elements are generally categorized into Light Rare Earth Elements (LREEs), from La to Sm, and Heavy Rare Earth Elements (HREEs), from Eu to Lu (Figure 10.1).

Due to their unique chemical characteristics, REEs play a crucial role in high-technology applications such as computers, smartphones, televisions, lasers, missile systems, and electric vehicles. Their essential role in clean energy technologies, coupled with the limited and uneven distribution of deposits, has led to their classification as critical raw materials (George et al., 2015).

China currently dominates the global REE supply chain, both in terms of resources and production, making other countries heavily reliant on Chinese exports (Dickson, 2015; USGS, 2020). Approximately 95% of the world's REE supply comes from three primary minerals: bastnaesite, monazite, and xenotime (Tombal, 2023). In China, bastnaesite $[(Ce,La)CO_3F]$ is the primary REE source, typically containing about 30% La, 50% Ce, 4% Pr, and 15% Nd.

A list of commercially significant REE-bearing minerals is provided in Table 10.1 (Jordens et al., 2013). Among the most important are bastnaesite, xenotime, and monazite, which dominate global REE resources (Jha et al., 2016; Meshram & Pandey, 2019). In Indonesia, the most common REE-hosting minerals include allanite, bastnaesite, parisite, xenotime, monazite, and florencite.

Monazite and bastnaesite are the main sources of LREEs, primarily containing cerium, lanthanum, and neodymium. However, some monazite may have slightly lower lanthanum content with higher proportions of neodymium and HREEs. In contrast, xenotime is typically rich in HREEs such as yttrium, dysprosium, erbium, ytterbium, and holmium (Harben, 2002).

It is also important to note that monazite often contains radioactive elements, including thorium (Th) and uranium (U), which pose specific challenges in handling and processing (Andreoli et al., 1994; Hussain et al., 2020; Su et al., 2021; Dostal & Gerel, 2023).

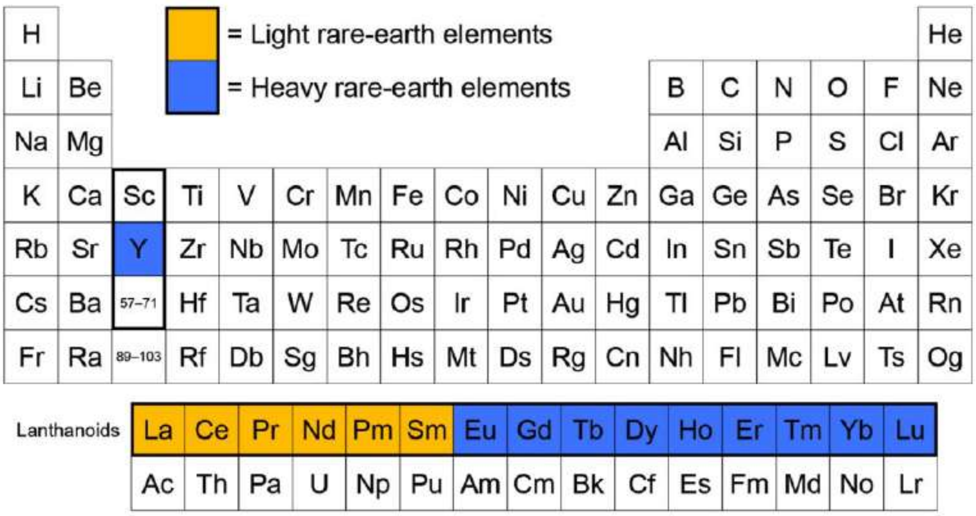

Figure 10.1 Distribution and Classification of Rare Earth Elements (REEs) in the Periodic Table, Highlighting Light REEs (LREEs) and Heavy REEs (HREEs) (Adapted from Rare Earths: A Review of the Market, Supply Chain, and Key Issues by Innovation News Network, 2022. https://www.innovationnewsnetwork.com/wp-content/uploads/2022/01/1-RareEarthsPeriodic-Fig.1-1024x576.jpg)

Table 10.1 List of commercially significant REE-bearing minerals (Walter et al., 2010 in Jordens et al., 2013)

Mineral	Formula	Approximate REO %
Aeschynite-(Ce)	$(Ce,Ca,Fe,Th)(Ti,Nb)_2(O,OH)_6$	32
Allanite-(Ce)	$(Ce,Ca,Y)_2(Al,Fe^{3+})_3(SiO_4)_3OH$	38
Apatite	$(Ca,Ce)_5(PO_4)_3(F,Cl,OH)$	19
Bastnäsite-(Ce)	$(Ce,La)(CO_3)F$	75
Brannerite	$(U,Ca,Y,Ce)(Ti,Fe)_2O_6$	9
Britholite-(Ce)	$(Ce,Ca)_5(SiO_4,PO_4)_3(OH,F)$	32
Eudialyte	$Na_4(Ca,Ce)_2(Fe^{2+},Mn,Y)_2ZrSi_8O_{22}(OH,Cl)_2$ (?)	9
Euxenite-(Y)	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$	24
Fergusonite-(Ce)	$(Ce,La,Nd)NbO_4$	53
Gadolinite-(Ce)	$(Ce,La,Nd,Y)_2Fe^{2+}Be_2Si_2O_{10}$	60
Kainosite-(Y)	$Ca_2(Y,Ce)_2Si_4O_{12}CO_3 \cdot H_2O$	38
Loparite	$(Ce,La,Na,Ca,Sr)(Ti,Nb)O_3$	30
Monazite-(Ce)	$(Ce,La,Nd,Th)PO_4$	65
Parisite-(Ce)	$Ca(Ce,La)_2(CO_3)_3F_2$	61
Xenotime	YPO_4	61
Yttrocerite	$(Ca,Ce,Y,La)F_3 \cdot nH_2O$	53
Huanghoite-(Ce)	$BaCe(CO_3)_2F$	39
Cebaite-(Ce)	$Ba_3Ce_2(CO_3)_5F_2$	32
Florencite-(Ce)	$CeAl_3(PO_4)_2(OH)_6$	32
Synchysite-(Ce)	$Ca(Ce,La)(CO_3)_2F$	51
Samarskite-(Y)	$(Y,Ce,U,Fe^{3+})(Nb,Ta,Ti)_3O_{16}$	24
Knopite	$(Ca,Ti,Ce_2)O_3$	NA

Occurrences

Global Rare Earth Element (REE) resources originate from both primary and secondary deposit types. Based on data from leading REE-producing countries, particularly China, primary deposits include carbonatite- and alkaline igneous rock-hosted REE deposits, hydrothermal deposits, and iron-REE deposits. Secondary deposits encompass placer deposits (both terrestrial and marine), laterites, and ion-adsorption clays.

Various producing REE deposits are predominantly found in China, with additional significant occurrences in Europe and the

Americas. Figure 10.2 illustrates the global distribution of known REE mineralizations (Chen, P. et al., 2024). The world's REE reserves are highly concentrated in a few countries, including China, Vietnam, Brazil, Russia, India, Australia, the United States, Greenland, Tanzania, Canada, and South Africa (Zhou et al., 2017; Balaram, 2019).

Global REE production is primarily sourced from primary REE deposits hosted in carbonatites, alkaline igneous rocks, placers, and ion-exchange clays. China continues to dominate both global REE reserves and production (Figure 10.3).

In Indonesia, REE occurrences are mainly identified in monazite minerals found as by-products within alluvial tin deposits. Based on investigations by the Geological Agency, Indonesia hosts various REE deposit types, including:

- Granite-related REE deposits (Bangka Belitung)
- Hydrothermal REE-Sn deposits (Bangka Belitung)
- Placer deposits (Bangka Belitung and Kalimantan)
- Laterites
- Ion-adsorption clays (Bangka Belitung, North Sumatra, Kalimantan, and West Sulawesi)

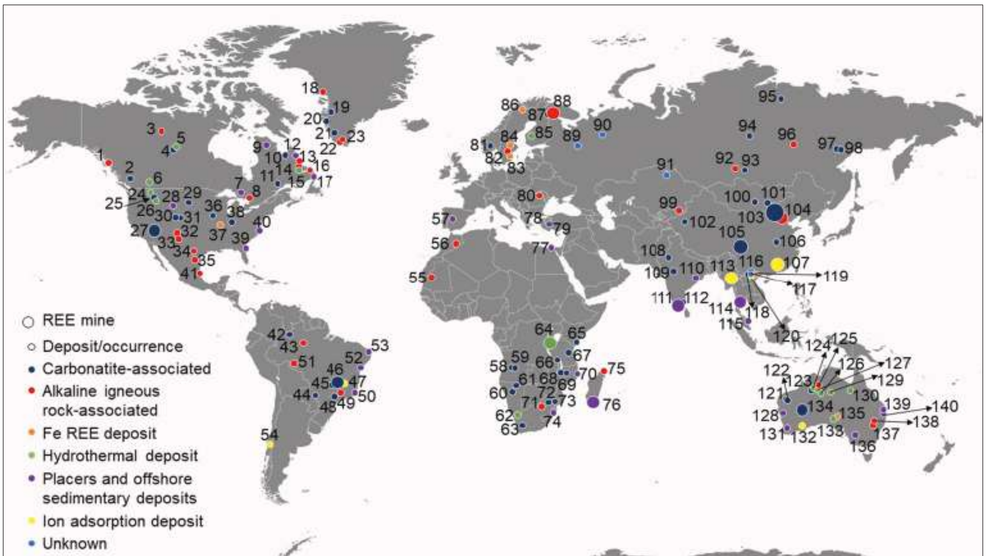

Figure 10.2 Known global REE mines and deposits. (Chen, P. et al., 2024)

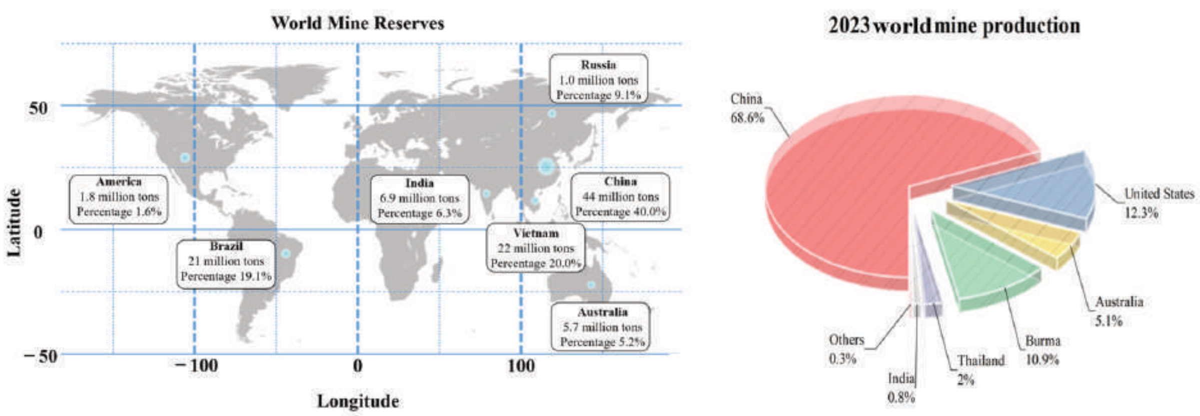

Figure 10.3 World rare earth reserves and 2023 world rare earth production. (Li. et al., 2024)

Among these, the discovery of ion-adsorption clay-type REE deposits is particularly promising. These deposits are notably free of radioactive elements and are relatively easier to process compared to other deposit types. While some resource estimates exist, the mineable reserves for these Indonesian REE deposits remain largely undetermined.

Globally, the REE deposits currently considered economically viable include:

- Bastnäsite (approximately 72% REO)
- Monazite (60–70% REO)
- Xenotime (53–65% REO)
- Cerianite ($(Ce,Th)O_2$, containing 60–70% REO)
- Fergusonite ($(Y,REE)NbO_4$, containing 31–44% REO)

The geological conditions in Indonesia are highly conducive to the formation of ion-adsorption or regolith-hosted REE deposits, which are products of intensive rock weathering processes. These deposit types can form in alkaline rocks and through low-temperature processes related to erosion and weathering (Goodenough et al., 2017).

Importantly, REE extraction from low-temperature deposits—especially ion-adsorption types—is simpler and less energy-intensive compared to hard-rock mining (Wall et al., 2017).

In Indonesia, two major types of REE deposits have been identified:

Placer deposits

These are concentrations of heavy minerals resistant to weathering, transported and deposited along rivers and coastal areas. The key REE-bearing minerals in Indonesian placer deposits include monazite, xenotime, and zircon, often found in association with tin ores. These placers are particularly abundant in the Riau Islands, Bangka Belitung, and West Kalimantan, forming part of the southern extension of the Asian Tin Belt.

Residual (lateritic) deposits

Formed through intense tropical weathering, these deposits result from the decomposition of silicate minerals, the leaching of mobile elements (e.g., calcium and magnesium), and the residual enrichment of immobile elements like iron and aluminium.

Ion-adsorption-type deposits emerge from the chemical weathering of granite and the subsequent adsorption of REEs onto clay minerals such as kaolinite and halloysite (Yang et al., 1981; Ishihara and Sato, 1982; Huang et al., 1990; Murakami and Ishihara, 2008). Besides granite, these deposits can also form from the weathering of volcanic and metamorphic rocks (Sanematsu et al., 2011; Huo et al., 2019).

Globally, ion-adsorption-type deposits are mainly distributed across tropical and subtropical regions with high rainfall, including Southern China, Vietnam, Madagascar, and Indonesia.

Global Overview of Rare Earth Element Resources

According to the United States Geological Survey (USGS) report published in 2024, the world's REE reserves are heavily concentrated in a few countries. China leads by a wide margin, possessing approximately 44 million tons of REE reserves — accounting for around 38.6% of the world's total. Following China are Vietnam (22 million tons), Brazil (21 million tons), Russia (10 million tons), and India (6.9 million tons). Other significant contributors include Australia, the United States, Greenland, Tanzania, and Canada. Collectively, these nations control global reserves estimated to exceed 114 million tons (Table 10.2).

In terms of production, China continues to dominate the market, contributing about 70% of the global supply with an output of 210,000 metric tons in 2023. The United States and Australia follow, with 14.3% and 6% shares, respectively.

The leading deposit types globally include carbonatite-hosted REE deposits, alkaline igneous rock-hosted deposits, ion-adsorption clays, and placers. Among these, hard-rock carbonatite and alkaline rock deposits represent the majority of current economic production, although ion-adsorption deposits are gaining attention due to their lower environmental impact and simpler processing requirements.

Indonesia's Emerging REE Potential

Indonesia's Geological Agency has been systematically investigating REE potential since 2011. By 2022, significant progress has been made in identifying inferred resources across Sumatra, Kalimantan, and Sulawesi (Figures 10.4).

Indonesia's total estimated REE ore resources currently stand at 136,205,309 tons, with approximately 118,650 tons of contained REE metals. These resources are largely classified as inferred, indicating early-stage exploration that requires further detailed investigation to establish measured and indicated categories.

Table 10.2 World REE Reserves and Production (USGS, 2024)

Country	Reserves 2023 (Tons)	Production 2022 (Tons)
China	44,000,000	210,000
Vietnam	22,000,000	4,300
Russia	10,000,000	2,600
Brazil	21,000,000	80
India	6,900,000	2,900
Australia	5,700,000	18,000
United States	1,800,000	42,000
Greenland	1,500,000	—
Tanzania	890,000	—
Canada	830,000	—

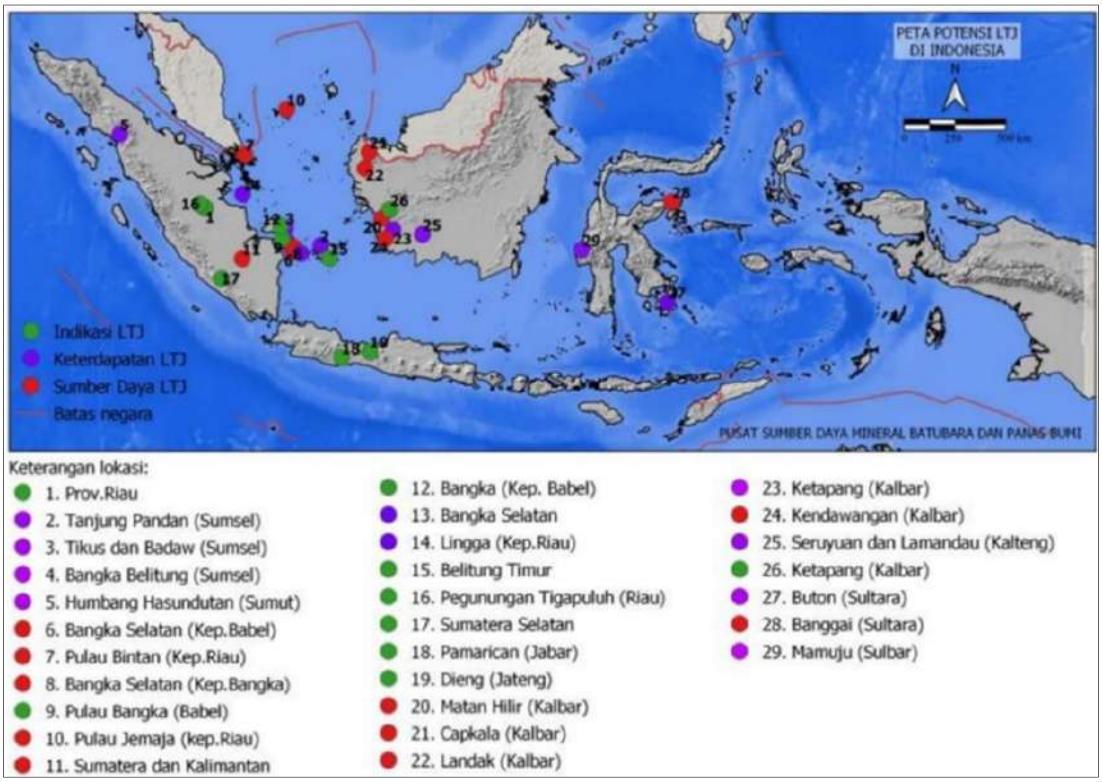

Figure 10.4 Identification Map of Potential REE Resources (2011–2019 Investigation) (GAI, 2022)

Major discoveries include:

Bangka Belitung: Placer deposits, associated with tin mining activities, containing REE-bearing minerals such as monazite, xenotime, and zircon.

North Sumatra (Parmonangan, North Tapanuli): Lateritic REE deposits derived from the weathering of granite rocks, with grades reaching up to 1,500 ppm (Faisal, et al., 2022).

West Sulawesi (Mamuju, Takandeang Prospect): Ion-adsorption type deposits within volcanic rocks, recording the highest soil sample grade at 6,012 ppm and rock sample grade at 3,346 ppm (Sulaeman et al., 2022).

Estimates of specific deposits are substantial, with South Bangka's Keposang Block alone hosting over 56 million tons of REE ore and West Sulawesi’s Takandeang area containing over 67 million tons.

Comparative Analysis: Indonesia vs. Global Resources

Indonesia’s current resource base remains modest compared to the established global leaders (Table 10.3). However, the geological nature of Indonesia’s REE deposits — particularly the prevalence of ion-adsorption types — presents significant strategic advantages. These deposits are notably easier and less costly to mine and process compared to hard-rock carbonatite ores and carry fewer environmental risks, especially in terms of radioactive waste.

Table 10.3 Comparative Overview of Global and Indonesian Rare Earth Element (REE)

Aspect	Global (USGS, 2024)	Indonesia (GAI, 2024)
Total REE Reserves	~114 million tons	118,650 tons of contained REE metal (inferred category)
Leading Deposit Types	Carbonatites, alkaline rocks, placers, ion-adsorption clays	Ion-adsorption clays, placers, laterites
Dominant Producers	China, USA, Australia	No commercial production yet; exploration stage
Processing Ease	Hard-rock deposits (complex) + clays (easy)	Predominantly ion-adsorption types (easier, low-radioactivity)
Resource Status	Proven, Measured, Indicated	Mostly Inferred
Strategic Advantage	Large reserves, established industry	Favorable geology, low-radioactivity deposits, future potential

Strategic Outlook for Indonesia

While Indonesia is still in the early stages of REE resource development, its potential should not be underestimated. The country's extensive tropical weathering environment, coupled with favorable geology, positions it uniquely to develop ion-adsorption type REE deposits similar to those that underpin China's dominance in heavy REE production.

Continued exploration efforts, resource upgrading, technological development, and strategic investment partnerships will be critical for Indonesia to fully realize its REE potential. Given the increasing global push toward green technologies and the need for diversified REE supply chains, Indonesia could emerge as an important future contributor to global REE markets.

Conclusion

Indonesia's REE resources, while currently small on the global stage, represent a significant future opportunity. With strategic exploration and responsible development, Indonesia has the potential to support global efforts toward securing sustainable and diversified supplies of critical materials necessary for the clean energy transition and technological innovation.

Rare Earth Element (REE) Resources in Indonesia, 2023: A Snapshot

Indonesia's potential in the Rare Earth Element (REE) sector continues to attract attention, particularly as the global demand for critical minerals rises sharply. As of 2023, the Geological Agency of Indonesia has compiled data showing the classification of

REE resources within the country, highlighting significant opportunities — and challenges — in their development.

The resource classification is divided into three categories: Inferred, Indicated, and Measured. Each classification reflects the level of geological confidence and the potential for future economic extraction.

The Inferred Resources category dominates Indonesia's REE inventory. Approximately 128.89 million tons of ore have been identified under this classification, containing about 114,236 tons of REE metals. Inferred resources indicate a high level of potential, although further detailed exploration is required to better define these deposits and confirm their economic viability.

Moving to a higher level of certainty, the Indicated Resources amount to about 5.5 million tons of ore, with an estimated 3,317 tons of REE metals. These resources are based on more substantial geological evidence compared to inferred resources, providing a stronger foundation for future exploration and project development.

The Measured Resources, the highest confidence category, are relatively modest. Approximately 1.82 million tons of ore have been classified as measured, containing about 1,097 tons of REE metals. Measured resources provide the most reliable estimates and form the basis for detailed mine planning and investment decisions.

The overwhelming dominance of inferred resources underscores Indonesia's early stage in REE exploration compared to more mature REE-producing countries like China, Australia, or the United States. However, it also reflects tremendous growth potential, provided that sustained exploration, drilling, and feasibility studies are undertaken to upgrade the resource classifications.

Figure 10.5 below presents a visual summary of Indonesia's REE resources by classification. The chart shows the distribution of ore (in thousand tons) and metal content (in tons) across Inferred, Indicated, and Measured categories.

This distribution emphasizes the need for accelerated investment in exploration activities and supporting infrastructure to develop these critical mineral resources into economically viable projects. Strengthening Indonesia's REE industry could not only contribute to the global supply of critical minerals but also position the country as a strategic player in the global energy transition.

In conclusion, while Indonesia's measured and indicated REE resources remain relatively small, the vast inferred resources represent a strategic opportunity. With appropriate policies, technology transfer, and sustainable mining practices, Indonesia could unlock its REE potential and become a significant contributor to the global rare earth supply chain in the coming decades.

The Growing Demand for Rare Earth Elements and Indonesia's Emerging Potential

The global demand for rare earth elements (REEs) has shown a steady and significant increase over the past two decades. As illustrated in Figure 10.6, world consumption of REEs has grown consistently, with an estimated annual growth rate of 8% projected from 2021 to 2025. Despite challenges such as the Chinese embargo around 2010 and the COVID-19 crisis in 2020, global consumption continues to climb, reflecting the critical role of REEs in high-tech industries, renewable energy, and defense sectors.

Historically, China has dominated REE production, accounting for approximately 70% of global output as of 2023. However, the widening gap between global consumption and China's production, coupled with geopolitical tensions, has pushed many countries to seek alternative sources. This dynamic presents an exciting opportunity for emerging REE producers, including Indonesia.

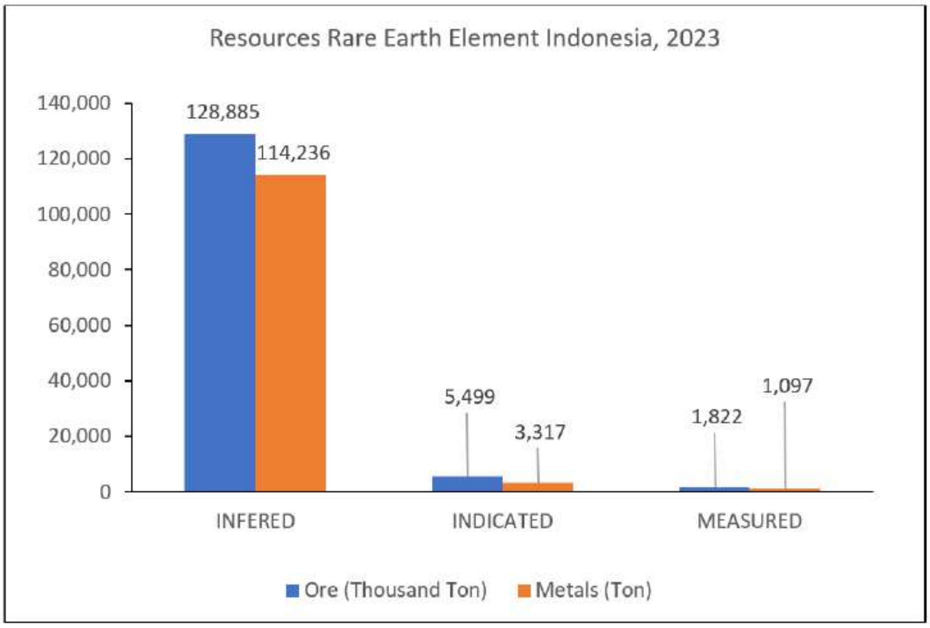

Figure 10.5 Rare Earth Element (REE) Resources in Indonesia by Classification, 2023 (Nursahan et al., 2024)

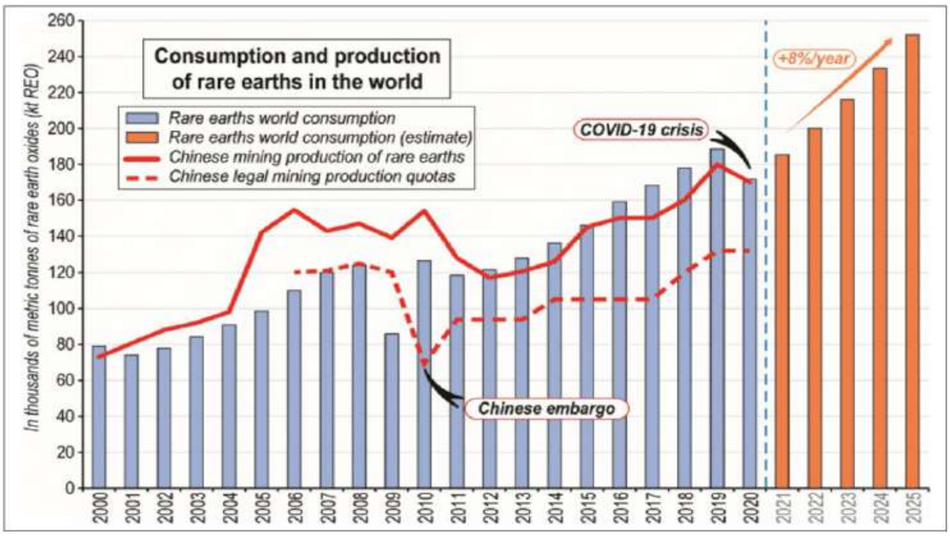

Figure 10.6 Global Consumption and Production of Rare Earth Elements (2000–2025) (Charles et al., 2023)

According to recent data, Indonesia's estimated REE resources in 2023 totaled 136.2 million tons of ore containing 118,650 tons of REE metals, predominantly classified as inferred resources. Major REE prospects have been identified across the islands of Sumatra, Kalimantan, Sulawesi, and Bangka Belitung, with some deposits—such as those in Mamuju, West Sulawesi—showing exceptionally high grades reaching up to 6,012 ppm in soil samples.

The breakdown of Indonesia's REE resource classification shows that:

- 94.6% are Inferred Resources,
- 4% are Indicated Resources, and
- 1.3% are Measured Resources.

While Indonesia's share of global REE reserves is currently modest compared to giants like China, Vietnam, and Russia, its potential is increasingly strategic. With continued exploration, improved resource classification, and investment in REE processing capabilities, Indonesia could soon become a key player in the global rare earth market, helping to diversify supply chains and meet the surging global demand.

In a world racing toward electrification, clean energy, and advanced technologies, Indonesia's rare earth resources could be the nation's next critical mineral frontier.

Rising Global Demand for Rare Earth Elements: 2010–2035

Introduction

Rare Earth Elements (REEs) are critical components in many modern technologies, and their global demand is projected to rise significantly over the coming decades. The graph illustrates the projected demand growth across various sectors between 2010 and 2035 (Figure 10.7), showing an upward trend driven by technological advancements and energy transition initiatives.

Demand Trends Across Applications

Since 2010, the global demand for REEs has steadily increased, with projections indicating a surge to nearly 375,000 tonnes by 2035. This growth is largely fueled by several key industries. The magnets sector, which is vital for electric vehicles, wind turbines, and electronics, shows the largest and fastest expansion.

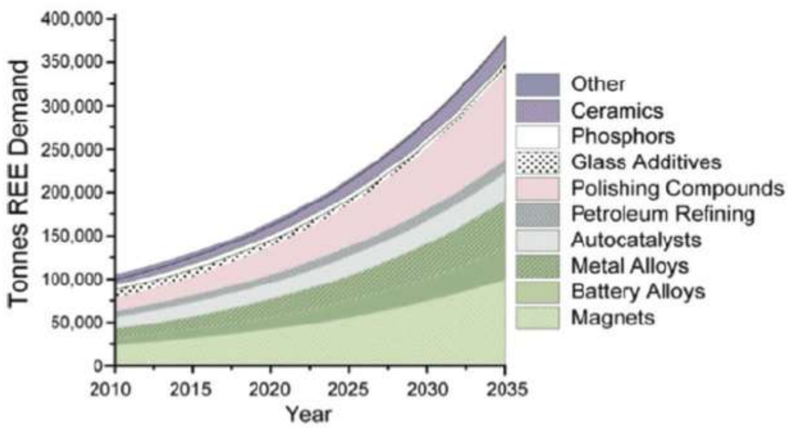

Figure 10.7 Projected Global Demand for Rare Earth Elements (REEs) by Application, 2010–2035 (Alonso et al., 2012)

Following magnets, battery alloys—important for rechargeable batteries in electric vehicles and portable electronics—are also witnessing strong demand growth. Metal alloys, used extensively in aerospace and defense industries, contribute significantly as well.

Other sectors such as autocatalysts (for vehicle emission controls), petroleum refining, and polishing compounds maintain steady but moderate increases in REE consumption. Applications like glass additives, phosphors (for lighting and displays), and ceramics also continue to require REEs but at a relatively smaller scale compared to magnets and batteries.

Drivers of Growth

The demand trajectory is closely tied to the global shift toward cleaner energy and the electrification of transportation. Governments worldwide are pushing for low-carbon technologies, boosting the need for high-performance magnets and batteries that rely heavily on REEs. Furthermore, the rise of smart devices, renewable energy installations, and environmental regulations reinforce the growing consumption patterns.

Conclusion

Global demand for rare earth elements (REEs) is projected to grow significantly through 2035, driven by magnet and battery alloy applications amid the shift to an electrified, sustainable economy. Ensuring sustainable supply will require supply chain management, recycling, and alternative technologies.

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Radioactive Minerals

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Image: Uraninite
Courtesy of: https://i0.wp.com/geologyscience.com/wp-content/uploads/2023/05/uraninite.jpg?w=380&ssl=1

According to Government Regulation Number 96 of 2021 on the Implementation of Mineral and Coal Mining Business Activities, Article 2, Paragraph (a), radioactive minerals are defined to include uranium, thorium, and other naturally occurring radioactive materials. This discussion aims to provide a detailed examination of the definition of radioactive minerals, focusing specifically on uranium and thorium resources, which are often associated with rare earth elements.

In 2023, a collaborative research effort between the Nuclear Mineral Materials Technology Research Center of the Nuclear Energy Research Organization (PRTBGN-ORTN-BRIN) and the PSDMBP led to an updated assessment of the national balance of radioactive mineral resources, specifically uranium and thorium. The data presented on these resources is drawn from the inventory and evaluation reports compiled by the Nuclear Mineral Materials Development Center (PPBGN-BATAN) under the National Nuclear Energy Agency (BATAN), and was further published in the 'Report on Nuclear Mineral Resources in Indonesia 2021,' issued by the Nuclear Mineral Materials Technology Research Center under the National Research and Innovation Agency.

Radioactive Minerals: Overview

Radioactive minerals are naturally occurring minerals that contain significant quantities of radioactive elements, such as uranium (U) and thorium (Th). These minerals are categorized into various groups based on their chemical composition, including silicates, phosphates, and oxides. Common examples of radioactive silicate minerals include zircon, allanite, titanite, and thorite/huttonite. Phosphate minerals, such as monazite, apatite, and xenotime, are also known to be radioactive, as well as oxide minerals like urano-thorianite and niobium-tantalum (Nb-Ta) oxides.

Uraninite (UO_2), a prominent radioactive mineral, contains a high concentration of uranium and thorium, typically comprising 60% to 80% UO_2 and 1% to 5% thorium. Another notable mineral, urano-thorianite ($(U, Th)O_2$), contains between 20% and 40% uranium in the form of UO_2, along with 30% to 50% thorium as ThO_2. These minerals are crucial sources of radioactive elements used in various industrial and energy applications.

In accordance with the classification established by the International Atomic Energy Agency (IAEA) in 2016, uranium deposits are considered highly strategic because uranium serves as the primary raw material for the production of nuclear fuel. Uranium can be found in various types of deposits, which are classified into fifteen distinct categories based on their formation processes and geological contexts. These deposit types include:

Intrusive-related: Uranium deposits associated with intrusive geological processes.
Granite-related: Deposits found in or around granite formations.
Polymetallic Iron-Oxide Breccia Complex: Complex deposits consisting of iron oxides and other metals.
Volcanic-related: Uranium deposits formed in volcanic environments.
Metasomatite: Deposits resulting from chemical alteration of pre-existing rocks.
Metamorphite: Uranium deposits found in metamorphic rock formations.
Proterozoic Unconformity: Uranium deposits found at geological unconformities in Proterozoic rocks.
Collapse Breccia Pipe: Deposits formed in breccia pipes due to collapse events.
Sandstone-hosted: Uranium deposits found within sandstone formations.
Palaeo Quartz-Pebble Conglomerate: Deposits within ancient quartz-pebble conglomerates.
Surficial: Uranium deposits found at or near the Earth's surface.
Coal-Lignite: Deposits associated with coal and lignite formations.
Carbonate: Uranium deposits located in carbonate rock formations.
Phosphate: Uranium deposits found within phosphate rock deposits.
Black Shales: Uranium found in black shale formations, typically associated with organic-rich sediments.

These deposit types are important in understanding uranium resource distribution and are integral to assessing the potential for future uranium mining, which plays a crucial role in the global energy transition toward nuclear power.

Radioactive Minerals Occurrence in Indonesia

In Indonesia, conventional uranium resources are primarily found in metamorphic, volcanic, and black shale deposits. Notably, in North Sumatra, the Aloban sector hosts uranium deposits located within localized intra-basin formations, bounded by normal faults and surrounded by granite rocks. Uranium in this region is predominantly adsorbed by organic material in fine-grained sediments, forming a type of black shale deposit. Additionally, uranium anomalies are present in intercalated sandstones and conglomerates. The primary uranium minerals in this area include uraninite, carnotite, and coffinite (Ciputra et al., 2019; Sukadana & Syaeful, 2016).

In the Kalan area of West Kalimantan, uranium mineralization is associated with the Pinoh Metamorphic Group (PMG) rocks, which are intruded by granitic bodies, such as the Sepauk Tonalite and Sukadana Granite in certain sections. The protolith of the Pinoh Metamorphics is believed to be volcanogenic sediment, which formed during subduction at the Paleo-Pacific margin after the collision of Southwest Kalimantan with Sundaland in the Early Cretaceous (approximately 130 million years ago) (Hennig, et al., 2017). Exploration in the Kalan area reached its peak in 1981 with the development of the Eko-Remaja tunnel, which intersected the ore body and the Eko Hill. By 1986, the main tunnel reached another slope of Eko Hill, extending for a length of 618 meters. Mining and processing research continued until 1996, resulting in the production of 740 kg of yellowcake. Although exploration efforts decreased after the closure of the Eko-Remaja site, the Kalan area and its surroundings, including Mentawa in Central Kalimantan, remain areas of interest for ongoing research (Syaeful et al., 2021).

In East Kalimantan, the Nyaan volcanic rocks, found in Paluq, Kawat, and Nyaan along the upper Mahakam River, serve as the host rocks for uranium deposits. The uranium is dispersed within layers predominantly shaped by lava flows, with subsequent tectonic activity contributing to the migration of uranium into open fractures. Uranium minerals in this area include pitchblende and autunite (Ngadenin et al., 2011; Sukadana, 2012).

In Central Kalimantan, the Darab area also possesses uranium resources within both metamorphic and granitic rocks. Mineralization is confined to the contact zones, often filling tectonic breccias and veins. Uranium-bearing minerals in this region include uraninite, monazite, and possibly thorianite-uraninite. In the Mentawai area, uranium is found in quartzite rocks (Retno, et al., 1991). Mineralization is associated with tourmaline, quartz, and sulfides, typically occurring as lenses aligned parallel to the schistosity (Ngadenin, et al., 1997).

In the Batubulan area of West Kalimantan, uranium mineralization occurs within metapelite and metasiltstone rocks. This mineralization is primarily found in boudinage veins, with uraninite being the key radioactive mineral, often associated with quartz-tourmaline, feldspar, pyrite, iron oxides, and hematite.

The Adang Volcanic Formation in Mamuju, West Sulawesi, is geologically associated with regions exhibiting high radiation dose rates (Figure 11.1). Composed of alkaline volcanic rocks with a basic to intermediate composition, this formation resulted from several volcanic events. Since 2013, extensive exploration has been conducted to identify uranium, thorium, and other elements with potential by-products (Sukadana et al., 2016; Khairani, 2018). The uranium-bearing minerals found here include uraninite, branerite, and secondary minerals such as uranophane and autunite, as shown in Figure 11.2 . The primary U-Th-REE bearing minerals in this region are davidite, britholite, monazite, and apatite (Sukadana et al., 2022).

Figure 11.1 Outcrop: U-Th-REE Mineralization in Britholite Formation at Mamuju Area, exhibiting a dose rate of 1.1 mSv/h (Sukadana et al., 2022)

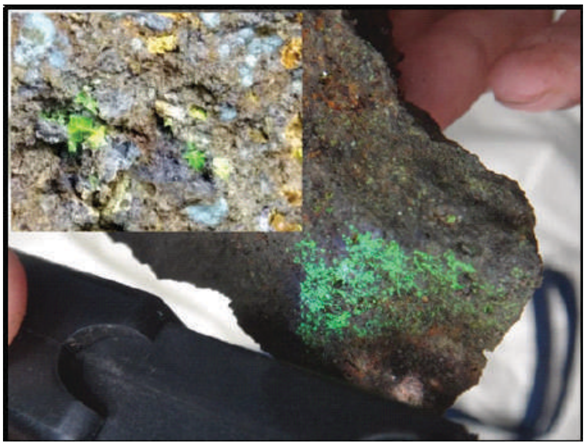

Figure 11.2 Secondary Uranium Minerals (Autunite and Uranophane) in Mamuju, West Sulawesi (Sukadana et al., 2022)

In the Bangka Belitung Province, prospection has identified radioactive minerals as by-products of tin mining. The primary minerals found in these deposits are monazite and the rare xenotime. The simple geological setting, basic mining techniques, and the high economic value of placer deposits have led to significant interest in tin mining activities (Syaeful et al., 2021).

Indonesia's Uranium Resources in 2023: Strategic Potential for Future Energy Development

As the global energy transition accelerates, Indonesia is turning a sharper focus toward the potential of its untapped strategic mineral resources, including uranium. Recognized for its critical role in the nuclear fuel cycle, uranium offers a clean, low-carbon energy alternative that aligns with national goals for energy security and sustainability.

According to the 2023 uranium resource evaluation, a collaborative effort between the Nuclear Mineral Materials Technology Research Center (PRTBGN-BRIN) and the Center for Geological Resources (PSDMBP) (Figure 11.3), Indonesia’s uranium inventory has been comprehensively categorized based on geological confidence: inferred, indicated, and measured. These categories follow international classification systems, including those set by the International Atomic Energy Agency (IAEA), ensuring alignment with global reporting standards.

The inferred uranium resources comprise the largest volume, with an estimated 24.28 million tons of ore, yielding 4,796 tons of concentrated U_3O_8 and 4,065 tons of uranium metal. Despite the significant size, this category carries the lowest geological certainty, necessitating further exploration to refine the estimates. Much of this inferred resource is associated with black shale formations, volcanic-hosted systems, and placer deposits, primarily located in regions such as West Kalimantan, East Kalimantan, and parts of North Sumatra.

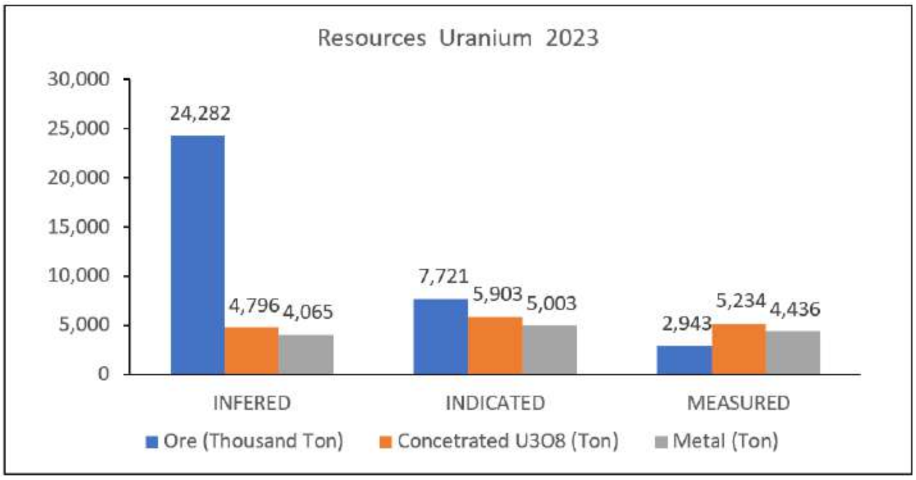

Figure 11.3 Uranium Resource Classification in Indonesia (2023) (Nursahan et al., 2024)

The indicated resources represent a more defined portion of the uranium inventory. This category includes 7.72 million tons of ore, from which 5,903 tons of U_3O_8 and 5,003 tons of uranium metal are projected. These figures reflect a medium confidence level, supported by systematic sampling, geochemical analysis, and preliminary drilling, especially in well-documented mineralized zones such as Kalan (West Kalimantan) and Mamuju (West Sulawesi).

At the highest confidence level are the measured resources, which have undergone the most intensive evaluation through detailed geological mapping, core drilling, and pilot-scale testing. This category records 2.94 million tons of ore, containing 5,234 tons of U_3O_8 and 4,436 tons of uranium metal. Notably, these resources stem from the historic Eko-Remaja uranium prospect in Kalan, where underground development, including a 618-meter exploration tunnel and a pilot processing plant, was initiated in the 1980s. Although operations were suspended in the late 1990s, the site remains one of Indonesia's most promising and technically evaluated uranium deposits.

Beyond conventional uranium, Indonesia's uranium and thorium occurrences are often genetically linked to rare earth element (REE)-bearing minerals, such as monazite, xenotime, and britholite. In Mamuju, West Sulawesi, the Adang Volcanic Formation, composed of alkaline volcanics, hosts uranium-thorium-REE mineralization with high natural radiation levels — in some cases exceeding 1.1 mSv/h, as recorded in outcrops. Uranium is present in both primary minerals like uraninite and brannerite, and secondary minerals such as autunite and uranophane. These polymetallic associations open new prospects for co-extraction strategies, especially for critical elements vital to renewable technologies.

Additionally, Bangka Belitung Province has shown potential for uranium recovery as a by-product of tin mining, where monazite and xenotime concentrate in placer deposits. This aligns with a growing international trend of recovering strategic elements from secondary or waste streams — an economically viable and environmentally favorable practice.

With these updated resource figures and emerging exploration fronts, Indonesia holds substantial potential to contribute to regional nuclear fuel supply chains. However, the realization of this potential will depend on sustained investment in geological surveys, refinement of regulatory frameworks, environmental risk management, and alignment with global non-proliferation commitments.

In light of the national commitment to develop a nuclear power roadmap as part of the Net Zero Emissions 2060 agenda, the 2023 uranium resource update marks a pivotal step. It not only reflects the growing scientific and technical capacity of Indonesian institutions but also lays a foundation for informed decision-making and strategic planning toward energy diversification.

Thorium Resources in Indonesia: Unlocking a Strategic Nuclear Future

Indonesia's abundant natural resources include not only traditional minerals but also strategic radioactive elements such as thorium, a promising alternative to uranium for next-generation nuclear energy. As the global conversation increasingly turns toward sustainable and safer energy sources, thorium's potential is drawing more attention. In this context, the 2023 national assessment of thorium resources—jointly conducted by PRTBGN and PSDMBP—positions Indonesia as a nation with significant, yet still untapped, nuclear mineral wealth (Figure 11.4).

According to the latest figures, Indonesia holds approximately 9.9 million tons of inferred ore containing 3,424 tons of thorium metal, and about 653 thousand tons of measured ore with a notably higher thorium content of 4,729 tons. This data suggests that even where the ore volume is smaller, the concentration of thorium is richer—making these deposits especially promising for future extraction and application.

Thorium mineralization in Indonesia typically occurs within phosphate and silicate minerals, especially monazite and britholite, often as by-products of tin mining operations in Bangka Belitung. However, some of the country's richest thorium-bearing formations lie in West Sulawesi, particularly the Adang Volcanic Formation in Mamuju. These alkaline volcanic rocks, formed through multiple volcanic episodes, have demonstrated high levels of radioactivity and host not only thorium but also uranium and rare earth elements (REEs). Exploration activities in this region have been intensifying since 2013, aiming to assess the full economic potential of these multi-element deposits.

Thorium's strategic value lies in its suitability for use in advanced nuclear reactor designs such as molten salt reactors (MSRs). These reactors promise enhanced safety, reduced nuclear waste, and resistance to nuclear proliferation. Unlike uranium, thorium does not require enrichment and produces less long-lived radioactive waste, positioning it as a cleaner, safer alternative for nuclear power. Several countries, including India and China, are already advancing thorium reactor technologies, and Indonesia could eventually benefit both as a supplier of raw materials and as an end-user of thorium-based nuclear energy systems.

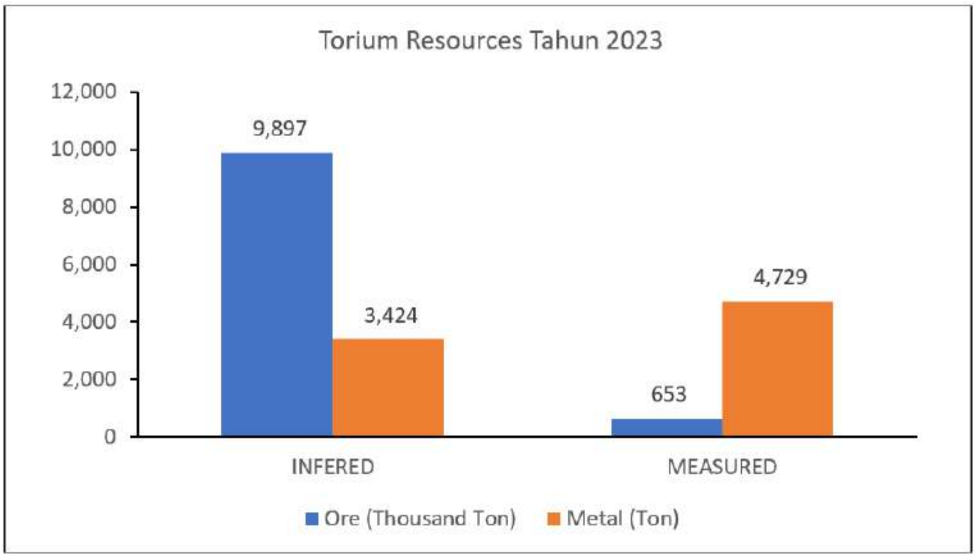

Figure 11.4 Thorium Resources in Indonesia, 2023 (Nursahan et al., 2024)

Despite this promising potential, Indonesia still faces challenges in realizing its thorium ambitions. The regulatory framework remains under development, and current laws, such as Government Regulation No. 96 of 2021, categorize thorium as a radioactive mineral without detailing commercial use pathways. Furthermore, thorium extraction and processing require technological investment and environmental safeguards to ensure safety and sustainability.

Nevertheless, Indonesia's strategic position—combined with its significant thorium and uranium deposits—offers a compelling opportunity. With global momentum shifting toward cleaner energy, the country is well-placed to play a leading role in the development of thorium-fueled nuclear power. Moving forward, collaboration between government agencies, research institutions, and international partners will be essential to transform these geological assets into a foundation for energy security and technological leadership in the region.

Radioactive Mineral Commodities

Uranium

Over the past six decades, uranium has emerged as one of the world's most critical energy minerals (World Nuclear Association, 2024). It is primarily found in minerals such as uraninite (Figure 11.5), pitchblende, brannerite, uranophane, and gummite. As the essential fuel for nuclear fission reactors, uranium underpins efforts to generate low-carbon electricity, supply industrial heat, and produce hydrogen—core components of global strategies to reduce greenhouse gas emissions and ensure energy security (Fautngiljanan, 2023).

Figure 11.5 Uraninite bearing minerals (https://media.sciencephoto.com/image/c0124877/800wm/C0124877-Uraninite_bearing_minerals.jpg)

According to the World Nuclear Association (2024), more than 20 countries—including Indonesia—have committed to doubling their nuclear energy capacity by 2050. The development of advanced technologies such as Small Modular Reactors (SMRs) and High-Temperature Gas-Cooled Reactors (HTGRs) is accelerating this transition. Indonesia itself is conducting feasibility studies and regulatory preparations for adopting SMRs by the early 2030s (Rahmanta et al., 2023; Amatullah et al., 2024).

Global demand for uranium in 2024 stands at approximately 67,000 tonnes of uranium (tU) per year, with the vast majority consumed by the electricity generation sector. The remainder supports medical isotopes, research, and defense applications. The world's known recoverable uranium resources are estimated at 5.7 million tonnes, sufficient to fuel current-generation reactors for over 90 years at existing consumption rates.

Uranium production is divided into three main methods: 1) 50% from in-situ leaching (ISL), 2) 46% from conventional underground and open-pit mining, and 3) 4% as a by-product of other mineral operations.

Top producers include Kazakhstan, Canada, and Australia, which together account for over 70% of global supply. These countries maintain stringent nuclear non-proliferation safeguards. For instance, Australia's uranium exports are governed by bilateral agreements and International Atomic Energy Agency (IAEA) protocols to ensure peaceful usage.

Indonesia, while not yet a uranium producer, possesses significant radioactive mineral potential. The Mamuju area in West Sulawesi has shown promise with uraninite and secondary uranium minerals such as autunite and uranophane, with surface dose rates reaching 1.1 mSv/h, indicating near-surface radioactive mineralization (Geological Agency, 2024). Indonesia's uranium resources in 2023 are estimated at:

- Ore: 34.946 thousand tonnes
- U_3O_8 concentrate: 15.934 tonnes
- Metal uranium: 13.503 tonnes

Despite this potential, regulatory frameworks remain incomplete. Government Regulation No. 52/2022 addresses safety and security in nuclear mineral mining, yet detailed implementing policies for resource management and utilization are still pending.

Thorium

Thorium is a naturally occurring radioactive metal present in rocks, soils, and waters, often found alongside or formed from the decay of uranium. Major global thorium reserves are hosted in placer deposits, carbonatites, and hydrothermal veins, with key thorium-bearing minerals including monazite, thorite, and thorianite (USGS, 2024) (Figure 11.6).

Figure 11.6 Thorianite mineral (https://www.dakotamatrix.com/images/products/thorianite33748c.jpg)

According to the World Nuclear Association (2024), global thorium resources are estimated at 6.4 million tonnes, distributed primarily across India, Brazil, Australia, and the United States. India leads in thorium reserves and has an extensive thorium reactor development program, reflecting its strategic long-term energy vision.

Thorium presents several advantages over uranium:

- It is three times more abundant in the Earth's crust (average 10.5 ppm versus 3 ppm for uranium) (Vlasov, 2023),
- It produces less long-lived radioactive waste (Jyothi, et al., 2023),
- It can generate energy more efficiently when converted into fissile uranium-233 in breeder reactors or molten salt reactors (MSRs).

Unlike uranium, thorium is not fissile on its own. It is considered a fertile material, requiring a neutron source—typically from uranium or plutonium—to initiate a nuclear chain reaction. Once activated, thorium-232 transmutes into uranium-233, a fissile isotope suitable for sustained energy production (Alexander et al., 2020; Garcia et al., 2013).

A coordinated four-year study by the IAEA, titled "Near term and promising long term options for the deployment of thorium-based nuclear energy (IAEA-TECDOC-2019)", evaluated the viability of thorium-based fuels across various reactor technologies. The study underscored thorium's potential as a sustainable and safer nuclear option for the future.

In Indonesia, thorium is found as a by-product of tin mining, especially in Bangka Belitung and West Kalimantan. Indonesia's thorium resources as of 2023 are:

- Inferred ore resources: 9,897 thousand tonnes with 3,424 tonnes of thorium metal
- Measured ore resources: 653 thousand tonnes with 4,729 tonnes of thorium metal

Despite these reserves, Indonesia lacks a comprehensive regulatory and technological framework for thorium utilization. However, research initiatives and bilateral collaborations are underway to explore thorium fuel cycles as part of the national energy mix post-2040.

The global nuclear energy map continues to expand, with more than 410 operational nuclear power reactors and 60+ under construction. Countries in Asia, particularly China and India, are leading new reactor builds, while nations in Europe and North America are focusing on life-extension and SMR deployment (Figure 11.7).

Conclusion and Outlook

Indonesia's potential in radioactive mineral resources—particularly uranium and thorium—positions it strategically in the global clean energy transition. However, unlocking this potential requires:

- Robust and coherent regulations on exploration, extraction, and utilization,
- Strengthening of research infrastructure and human capital,
- Continued international cooperation, especially with countries experienced in thorium and uranium fuel cycles.

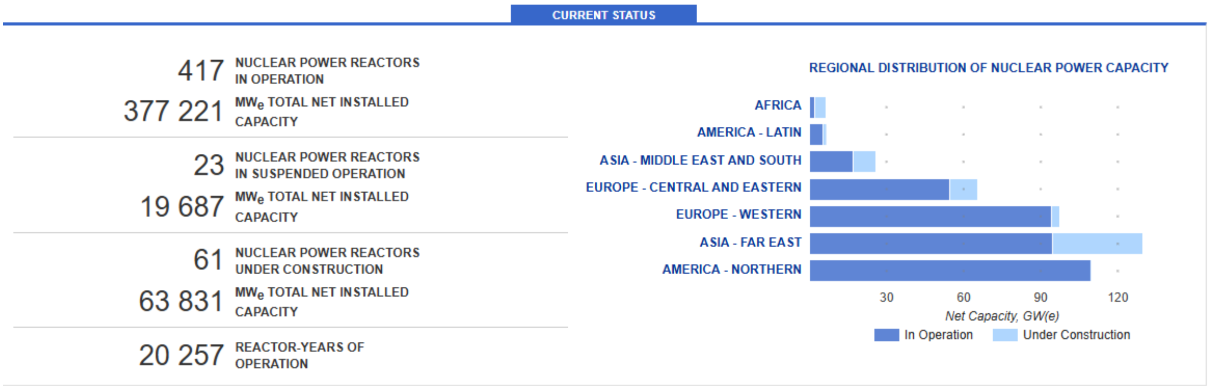

Figure 11.7 Global Status and Regional Distribution of Nuclear Power Reactors (https://pris.iaea.org/pris/)

With the global push toward Net-Zero Emissions (NZE) and rising demand for low-carbon energy, the time is opportune for Indonesia to prepare a clear roadmap for responsible and strategic use of its radioactive mineral wealth.

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Lithium

Image: Lithium Ore
Courtesy of: https://mineralseducationcoalition.org/wp-content/uploads/Lithium2_lepidolite_334916054.jpg

As the global push for clean energy intensifies, lithium has become a critical element in the transition. Widely used in batteries for electric vehicles and energy storage systems, lithium is in increasing demand worldwide. While Indonesia is not yet recognized as a lithium-producing nation, recent investigations reveal promising occurrences across various geological environments. This article explores the distribution, characteristics, and development potential of lithium in Indonesia.

Introduction

Lithium is the lightest of the alkali metals and among the most electropositive and reactive elements. Due to its high affinity for water and oxygen, it rarely occurs in its elemental form and is instead found in mineral compounds. While it was once primarily known for its role in thermonuclear devices, lithium today is more widely valued for its essential function in rechargeable batteries, especially those used in electric vehicles (EVs) and portable electronics.

Indonesia, known for its rich mineral endowment, has recently begun to explore its potential as a source of lithium. Investigations have identified occurrences in pegmatite-granite formations, geothermal and saline brines, and even in mud volcano systems—pointing to a varied and potentially significant lithium resource base.

Global Lithium Usage Trends: Dominance of Battery Applications and Emerging Uses

Lithium has become a linchpin in the global push toward clean energy, thanks to its unique electrochemical properties—light weight, high energy density, and rechargeability. Once mainly known for niche industrial uses and even military applications, lithium's relevance has skyrocketed with the growth of electric vehicles (EVs) and renewable energy storage. The global lithium market, valued at more than USD 8 billion in 2023, is expected to more than double by 2028, reaching nearly USD 19 billion. This surge is driven by a compound annual growth rate (CAGR) of over 19 percent, according to recent projections by MarketsandMarkets (2024).

Current Consumption Patterns

An analysis of lithium end-use sectors based on 2021 data from the U.S. Geological Survey highlights the dominance of battery-related applications. As shown in the accompanying chart (Figure 12.1), batteries account for 74% of total global lithium consumption. This includes lithium-ion batteries for EVs, smartphones, laptops, and large-scale energy storage systems. The next largest segment—ceramics and glass—represents 14%, where lithium improves thermal shock resistance and mechanical strength. Smaller but still relevant sectors include lubricating greases (3%), polymer production and continuous casting flux powders (2% each), and air treatment systems (1%). The remaining 4% covers diverse uses ranging from pharmaceuticals to aluminum alloys and specialty chemicals.

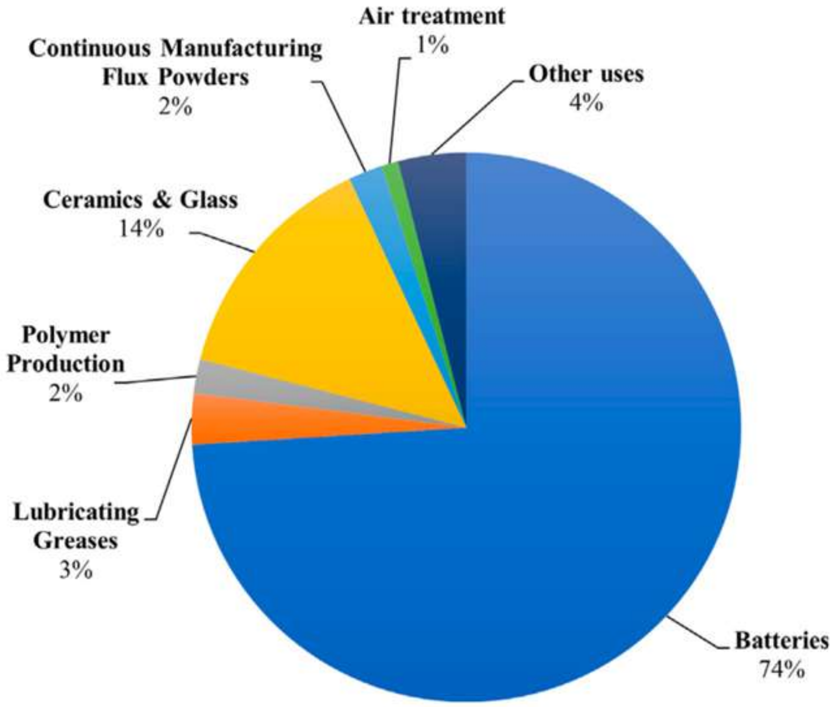

Figure 12.1 Global Lithium End-Use Distribution (2021) (U.S. Geological Survey, 2022)

Why Batteries Dominate

The steep rise in battery demand is closely tied to the global EV boom. In 2023 alone, EV sales exceeded 14 million units globally, led by China, followed by Europe and the United States. The International Energy Agency (2024) reports this as a 35% increase from the previous year. At the same time, lithium-based batteries are becoming integral to renewable energy storage solutions, particularly to balance intermittent sources such as wind and solar. BloombergNEF (2024) projects that by 2030, more than 90% of lithium demand will be battery-related.

Emerging Producer Opportunities: A Focus on Indonesia

This shifting demand landscape opens significant opportunities for countries rich in critical mineral resources. Indonesia, for example, has already established itself as a global player in nickel and cobalt—two other battery metals. While commercial lithium production has yet to begin, early studies show promising occurrences of lithium in several geological settings across the archipelago. Pegmatite-granite bodies in Sumatra, Kalimantan, Sulawesi, and Papua have recorded lithium anomalies. Meanwhile, geothermal brines in Central Java (Dieng) and saltwater-rich mud volcanoes in Bledug Kuwu show lithium concentrations ranging from 100 to over 1,000 ppm. Sidoarjo Mud in East Java, a mudstone system, has also returned positive lithium values in recent exploration by CMCGR, suggesting clay-hosted lithium potential.

Environmental and Technical Challenges

Despite the market optimism, lithium extraction is not without significant environmental and technical hurdles. Traditional brine operations, such as those in the Lithium Triangle (Chile, Bolivia, Argentina), consume large quantities of water and often conflict with local communities over land and resources. Additionally, only about 5% of lithium-ion batteries are currently recycled, creating pressure for more circular economy practices. Emerging technologies like Direct Lithium Extraction (DLE) and lithium-from-clay processing offer potential solutions but are still in development and face scalability issues.

Conclusion

The data speaks clearly: lithium's role in the energy transition is pivotal and growing. With nearly three-quarters of current lithium use tied to battery production—and this share projected to grow—countries, industries, and investors are increasingly aligning their strategies with this new energy reality. For countries like Indonesia, lithium is not just a geological curiosity; it is a strategic asset with the potential to enhance national energy security, industrial competitiveness, and climate goals. Realizing this potential, however, will depend on environmentally responsible exploration, technological innovation, and integration into the global supply chain.

Understanding Lithium Deposit Types in Magmatic and Brine Systems

As global demand for lithium continues to surge—driven primarily by its critical role in rechargeable batteries for electric vehicles (EVs), energy storage systems, and consumer electronics—understanding the various geological settings where lithium is concentrated becomes increasingly important. Lithium occurs in nature in a variety of forms, but commercially viable deposits are generally classified into two broad categories: magmatic (hard rock) and brine systems (Figure 12.2). Each of these systems originates through different geological processes, leading to distinct mining and processing approaches.

Lithium in Magmatic Systems

In magmatic systems, lithium is primarily found within pegmatites, which are coarse-grained igneous rocks formed during the final stages of magma crystallization. Pegmatites, particularly those derived from granitic magmas, can be enriched with lithium-bearing minerals such as spodumene, lepidolite, and petalite. These hard-rock deposits are most commonly mined in countries like Australia, which dominates global production from pegmatite sources.

Additionally, lithium can also be mobilized by geothermal fluids within granite-hosted systems. These geothermal brines circulate through fractures in the earth's crust, leaching lithium from surrounding rocks. Magmatic geothermal brines may be even more lithium-enriched, directly influenced by recent volcanic or sub-volcanic activity. In some cases, volcanic ash deposits known as ignimbrites also contain disseminated lithium, although these are less frequently exploited due to lower grades and more complex metallurgy.

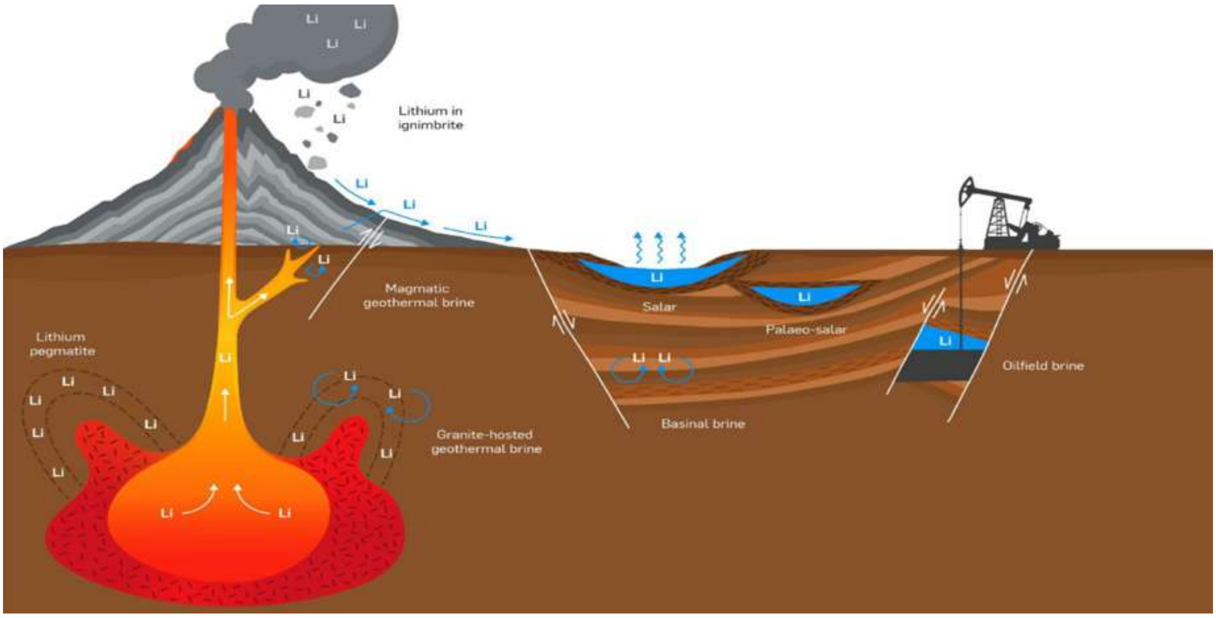

Figure 12.2 Conceptual illustration of lithium deposit types associated with magmatic and brine systems, including lithium pegmatites, geothermal brines, salars, palaeo-salars, basinal brines, and oilfield brines. (Bunker et al,, 2022)

Lithium in Brine Systems

Brine systems account for a significant portion of the world's lithium resources, particularly in South America's "Lithium Triangle" comprising Bolivia, Chile, and Argentina. These deposits form in salars, or salt flats, where lithium is concentrated in brine through the evaporation of saline groundwater in arid environments.

Beyond modern salars, palaeo-salars—ancient evaporite basins—can also contain lithium-bearing brines preserved in sedimentary layers. In deeper geological settings, basinal brines within sedimentary basins and oilfield brines associated with hydrocarbon reservoirs also present viable lithium sources. Although not yet widely exploited, these brines are gaining attention due to advancements in direct lithium extraction (DLE) technologies, which may allow economic recovery from lower-grade resources.

Strategic Importance and Exploration Potential

The global shift toward sustainable energy has intensified lithium exploration across diverse geological environments. In addition to traditional regions, countries like Indonesia are investigating their own lithium potential in pegmatite-granites, geothermal brines, and mud volcanic systems such as Bledug Kuwu and Sidoarjo.

Understanding the genesis and geological context of each lithium deposit type is critical for efficient exploration and extraction. For instance, magmatic pegmatites are generally high-grade but costly to mine and process, while brines offer lower costs but are dependent on climate and surface conditions. Each deposit type also presents unique challenges in environmental management, water use, and resource sustainability.

Conclusion

As the world transitions to a low-carbon future, lithium will remain a cornerstone of energy technology. Unlocking new resources across different geological settings—from high-grade hard rocks to unconventional brines—requires multidisciplinary collaboration, innovation in extraction techniques, and an in-depth understanding of earth systems. This integrated model of lithium deposit types provides a valuable framework for guiding future exploration and sustainable resource development.

Geological Settings of Lithium in Indonesia

Pegmatite-Granite Potential

Hard-rock lithium sources are typically associated with pegmatite or granite intrusions, which form during the final stages of magma crystallization. In Indonesia, such formations are widespread, with known occurrences in Sumatra, Kalimantan, Sulawesi, and Papua.

Exploratory studies have highlighted lithium anomalies in several locations. In North Sumatra, for instance, Hatapang Granite hosts lithium concentrations reaching 350 parts per million (Johari, 1984). Other significant findings include pegmatitic rocks in Riau and Belitung Island, with values ranging from 19 to 53 ppm and 1 to 49 ppm respectively (Table 12.1). Although these concentrations are modest by global standards, they represent the early stages of what could become a more detailed exploration and resource assessment.

Brine Water Systems

Another promising lithium source comes from brine—either geothermal or saline. Indonesia, being volcanically active, possesses extensive geothermal resources. In Central Java's Dieng geothermal field, lithium content in geothermal fluids has been recorded at up to 68 ppm (Herdianita et al., 2019). However, the most notable lithium concentrations come from saline mud volcanoes in Central Java, particularly the Bledug Kuwu area (Figure 12.3).

At Bledug Kuwu, lithium-rich brine emerges through mud vents, with initial concentrations of 103–111 ppm. Post-crystallization analysis reveals enrichment exceeding 1,000 ppm, indicating significant evaporative concentration. High boron content further underscores the site's economic potential. (Figure 12.4).

Figure 12.4 The traditional processing of brine water through evaporation to obtain lithium-rich salt at Bledug Kuwu (CMCGR, 2023)

Table 12.1 Lithium (Li) Content in Selected Granite Formations in Indonesia

Rock Formation	Location	Li Content (ppm)	Source
Hatapang Granite	North Sumatra	350	Johari, 1984
Akar Granite	Pegunungan Tiga Puluh, Riau	19 - 53	Sulaeman et al, 2018
Tanjung Pandan	Belitung Island	1 - 49	CMCGR, 2018

Figure 12.3 Bledug Kuwu Area. (CMCGR, 2023)

Similar characteristics are observed at nearby Bledug Cangkring (Figure 12.5), where lithium levels in brine range from 12 to over 600 ppm, with corresponding increases in boron. These findings suggest that brine systems in Indonesia, particularly in Central Java, may hold lithium concentrations comparable to international brine deposits under the right conditions.

Lithium in Mudstone: The Sidoarjo Mudflow

In East Java, the infamous Sidoarjo Mud Volcano—commonly known as "Lusi"—has also drawn attention for its lithium-bearing potential (Figure 12,6). The mud, originating from subsurface clay-rich formations, contains lithium associated with minerals like illite, kaolinite, and montmorillonite (Mazzini et al., 2007).

Initial sampling in 2020 revealed lithium content between 99 and 280 ppm. Continued exploration in 2023, supported by more precise ICP-MS analysis, reported values between 54 and 110 ppm. Though not exceptionally high, the consistency of lithium within the mud matrix, coupled with the large volume of material and accessibility, suggests a novel resource opportunity. The lithium here appears to correlate with the clay content, although the low lithium concentration in the accompanying water limits potential for direct lithium extraction from fluid phases.

Development Potential and Challenges

Indonesia's lithium potential spans a broad spectrum of geological settings. The pegmatite-granite zones may offer hard-rock mining prospects, while the brine systems—especially in Central Java—present high-grade lithium concentrations that could be viable for extraction through evaporation and precipitation methods. The mudstone systems, though lower in grade, offer unconventional opportunities aligned with emerging technologies for lithium extraction from clays.

Figure 12.5 Bledug Cangkring Area. (CMCGR, 2023)

Figure 12.6 Lithium exploration in the Sidoarjo mud using a hand auger (Muksin, 2022)

Despite this promise, several challenges remain. Key among them are the economic feasibility of extraction, environmental management of saline and geothermal waste, and the development of domestic processing capacity. Moreover, lithium extraction from clays and certain types of brine requires advanced technology that is still under development or controlled by a few global players.

Nevertheless, the integration of lithium exploration with existing geothermal and salt production infrastructure could reduce costs and environmental impact. Partnerships with foreign technology holders and pilot-scale testing are essential next steps in transforming Indonesia's lithium potential into a viable industry.

Conclusion

Indonesia is at the threshold of unlocking a new strategic mineral. Lithium occurrences in pegmatite-granite, brine water systems, and mudstone deposits represent a diversified and nationally distributed opportunity. While still in its early stages, Indonesia's lithium exploration signals the country's intent to become more involved in the global battery supply chain.

As the energy transition accelerates, the strategic importance of lithium cannot be overstated. Continued research, investment in pilot projects, and supportive government policies will be key to advancing Indonesia's role in the global lithium market—alongside its already dominant position in nickel and cobalt

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13

Silica

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Image: Quartz Mineral
Courtesy of: https://www.chm.bris.ac.uk/motm/silica/quartz1.jpg

Quartz Sand: Formation, Characteristics, and Industrial Relevance

Quartz sand, often referred to as white sand, is a sedimentary deposit primarily composed of silica (SiO_2) in the form of quartz crystals. It commonly contains varying levels of impurities such as iron oxides, calcium oxides, alkali oxides, magnesium oxides, clay minerals, and organic material. These impurities are typically introduced during the sedimentation process and originate from the weathering of rocks and organic remains. The presence and concentration of these materials not only affect the chemical composition of the sand but also influence its color—an attribute often used as an indicator of purity (Prayogo & Budiman, 2009).

The formation of quartz sand begins with the weathering of parent rocks rich in quartz, such as granite, sandstone, and metamorphic rocks like quartzite. Both mechanical and chemical weathering processes play a role in breaking down these rocks into smaller particles. Over time, natural agents like water, wind, and glacial movement transport the resulting quartz grains across varied landscapes. During this transport, the grains undergo sorting by size and density, leading to distinct patterns of sediment deposition.

When the energy of the transporting medium decreases—for instance, when a river slows as it approaches a delta or when wind speed drops—quartz sand settles and accumulates. In riverbeds, lakes, coastal zones, and desert environments, these grains gradually build up into deposits that may range in composition, grain size, and purity. In certain conditions, quartz can also form through chemical precipitation. Silica-rich solutions, when cooled or depressurized, can precipitate quartz crystals that contribute to the growth of existing deposits.

Environmental setting plays a major role in shaping the properties of quartz sand. Coastal deposits, for example, tend to have well-rounded, uniform grains due to the constant tumbling action of waves. Desert sands, shaped by wind activity, often have frosted surfaces and exhibit high degrees of sorting. In contrast, inland river sands may show a broader mix of grain sizes and mineral impurities, reflecting a more complex transport history.

Over long geological periods—spanning thousands to millions of years—quartz sand undergoes further changes through a process known as diagenesis. During this stage, the sand can become compacted and cemented, potentially forming sedimentary rocks such as quartz-rich sandstone. These rocks can later be uplifted and weathered again, continuing the cycle of quartz sand formation.

Quartz sand holds substantial industrial significance. Its high silica content and chemical stability make it a key raw material in the production of glass, ceramics, and silicon for electronics and solar panels. It is also essential in metal casting, water filtration, and hydraulic fracturing. The increasing demand for high-purity silica sand in global industries underscores the importance of understanding its genesis, as well as implementing sustainable practices in its extraction and processing.

In essence, quartz sand is the product of prolonged geological processes influenced by rock composition, environmental dynamics, and time. Its formation reflects the intricate interactions between earth systems, and its utilization illustrates the bridge between natural resources and human innovation.

Occurrence of Quartz Sand in Indonesia

Quartz sand is widely distributed across Indonesia, underpinned by the country's diverse geological formations and dynamic sedimentary environments. Notable deposits have been identified in the provinces of Bangka Belitung Islands, Aceh, North Sumatra, Riau, Riau Islands, South Sumatra, Lampung, West Kalimantan, South Kalimantan, Central Kalimantan, Banten, West Java, Central Java, East Java, West Nusa Tenggara, East Nusa Tenggara, South Sulawesi, Southeast Sulawesi, Central Sulawesi, and West Papua (Nursahan et al., 2024)) (Figure 13.1).

In the **Bangka Belitung Islands**, quartz sand is associated with weathered granitic intrusions and tin-bearing lithologies. These deposits frequently contain high-purity silica, with SiO_2 content typically exceeding 95%, making them suitable for applications in the glass and ceramics industries. Similarly, in **West Kalimantan**, quartz-rich sands derived from granitoid terrains have shown promising purity levels and are considered to have potential as export-grade material.

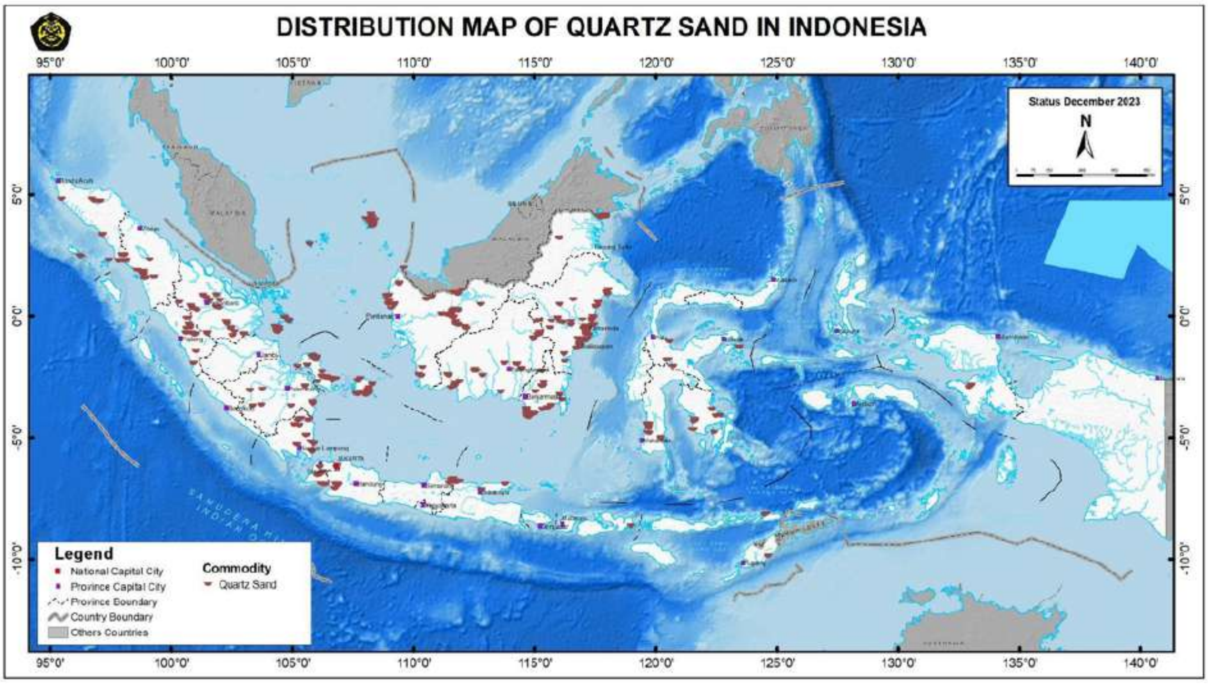

Figure 13.1 Geographical Occurrence of Quartz Sand Across Indonesian Provinces (Nursahan et al., 2024)

In **South Kalimantan**, extensive fluvial and deltaic quartz sand deposits occur within the Barito Basin. These sands are generally well-sorted, and selected areas yield silica contents over 98% with minimal iron oxide impurities—an essential criterion for float glass and photovoltaic glass manufacturing. Comparable alluvial deposits in **Central Kalimantan** and **Lampung** are also being evaluated for their suitability in high-tech industrial applications, including semiconductors and solar panels.

On the island of Java, particularly in **East and Central Java**, quartz sand is found in riverine and coastal zones. These deposits often require beneficiation to remove clay and iron impurities but can still meet the quality standards for industrial uses. In the **Riau Islands** and **Aceh**, coastal dune and beach sands support regional glass production and construction needs, though they are generally of moderate silica content.

Globally, Indonesia's quartz sand resources are comparable in quality to major producers such as Australia (notably the Murray Basin), Vietnam (Binh Thuan region), and the United States, where the Ottawa Formation in Illinois and Wisconsin supplies some of the world's highest-purity silica sands (U.S. Geological Survey, 2023). While Indonesia's quartz sand potential remains largely underexploited, certain deposits in Sumatra, Kalimantan, and Bangka Belitung Islands exhibit chemical characteristics on par with these established sources.

The rising demand for ultra-pure silica for renewable energy and electronics applications—especially in solar photovoltaic (PV) panel and semiconductor manufacturing—presents a strategic opportunity for Indonesia to become a significant global supplier. Achieving this potential will require enhanced geological exploration, processing infrastructure, and environmental safeguards to ensure sustainable resource development.

Trends in Quartz Sand Resources and Data Collection (2019–2023)

The development of quartz sand resource data in Indonesia from 2019 to 2023 demonstrates a significant upward trend in both total resources and reserves, alongside a steady increase in the number of data records. These trends are visualized in Figure 13.2.

Total Resources and Reserves

Between 2019 and 2023, the total identified resources of quartz sand increased from 1,442.96 million tons to a peak of 13,477.56 million tons. The most substantial growth occurred between 2022 and 2023, with a nearly fourfold increase in reported resources. This sharp rise suggests an intensification of exploration activities, improved geological mapping, and possibly reclassification of known deposits based on new data or updated methodologies.

Similarly, the total reserves of quartz sand—representing the economically viable portion of resources—rose from 183.19 million tons in 2019 to 3,402.35 million tons in 2023. A marked increase was observed in 2022, when reserves reached 1,122.52 million tons, indicating enhanced confidence in the extractability and quality of the material.

Data Coverage and Reporting

The number of recorded data entries, represented by the green line in Figure 13.2, rose steadily from 318 entries in 2019 to 478 entries in 2023. This increase reflects the ongoing efforts by geological survey institutions and related agencies to expand data coverage, verify field reports, and digitize mineral occurrence records. The improved data infrastructure not only contributes to national mineral inventory accuracy but also enhances investment transparency in the mining sector.

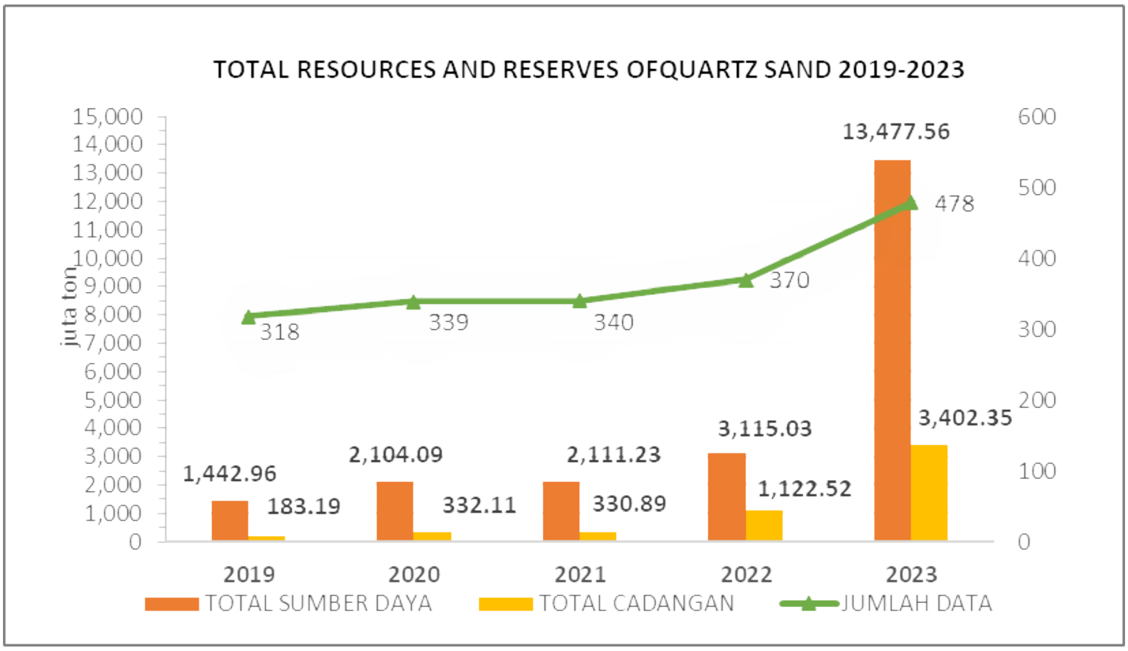

Figure 13.2 Trends in Quartz Sand Resources, Reserves, and Data Records in Indonesia (2019–2023) (Nursahan et al., 2024)

Implications

The upward trend in both quantity and quality of quartz sand data points to growing national interest in the strategic development of industrial minerals. Given quartz sand's increasing role in high-tech industries—including glassmaking, solar photovoltaics, and electronics—Indonesia's strengthened resource base positions the country to become a key regional supplier of high-purity silica materials. However, this opportunity must be balanced with responsible resource management, including environmental monitoring, sustainable extraction practices, and infrastructure readiness.

Indonesia's Quartz Sand Resources: A 2023 Provincial Analysis

Indonesia, an archipelago endowed with vast mineral wealth, holds significant deposits of quartz sand—a vital commodity for industries such as glass production, construction, and electronics. As of 2023, the distribution of these resources reveals striking disparities across provinces, shaped by geological formations, historical mining activities, and coastal dynamics. This analysis delves into the regional distribution of quartz sand reserves and resources, underscoring economic opportunities, challenges, and pathways for sustainable management (Figure 13.3).

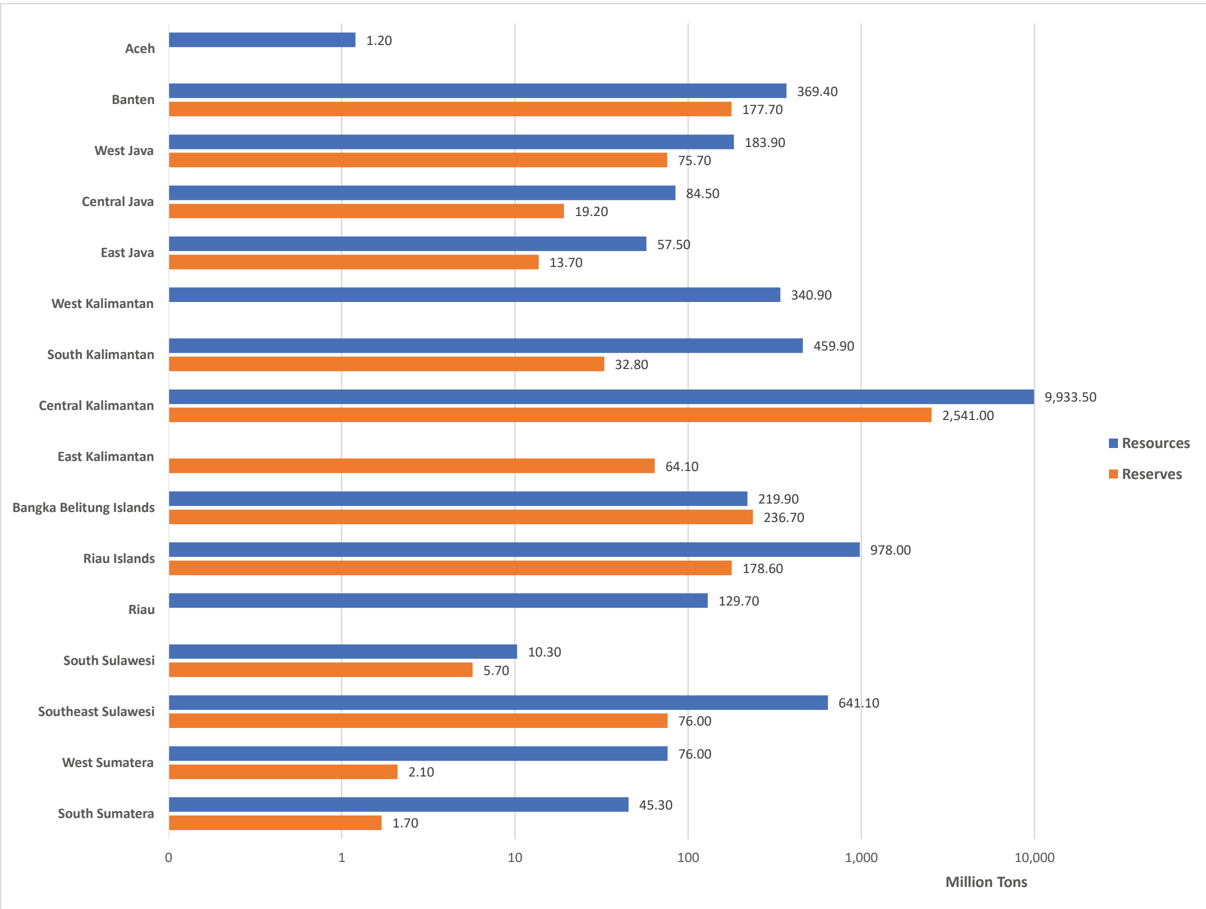

Figure 13.3 Mineral-resource distribution of quartz sand by Indonesian province (resources = orange bars; reserves = green bars), plotted on a logarithmic scale to illustrate the wide range of deposit sizes (Nursahan et al., 2024)

Central Kalimantan: The Uncontested Leader

Central Kalimantan emerges as the cornerstone of Indonesia's quartz sand industry, accounting for over 50% of the nation's total inventory. The province boasts 9,933.5 million tons of resources and 2,541 million tons of economically recoverable reserves, figures unparalleled in scale. This dominance stems from its extensive alluvial systems, which have accumulated vast quantities of sand over millennia. The Barito Basin, a geological hotspot, facilitates large-scale extraction, positioning Central Kalimantan as a linchpin for both domestic supply and potential global exports.

Coastal Provinces: Marine and Riverine Deposits

The Riau Islands rank second nationally, with 978 million tons of resources and 178.6 million tons of reserves, primarily derived from coastal and nearshore deposits. The province's proximity to marine sand sources underscores the critical role of coastal geomorphology in resource accumulation. Similarly, Banten, on the northwestern tip of Java, leverages its coastal geography to contribute 369 million tons of resources and 177.7 million tons of reserves, sourced from well-sorted sands along its shores.

In contrast, Bangka Belitung Islands—historically known for tin mining—harbor 219.9 million tons of resources and 236.7 million tons of reserves. These deposits originate from granitic and tin-bearing lithologies, remnants of ancient geological processes. The province exemplifies how legacy mining activities can create secondary opportunities for resource extraction, though environmental rehabilitation remains a pressing concern.

Sulawesi and Kalimantan: Contrasts in Potential

Southeast Sulawesi presents a paradox: while it holds 641.1 million tons of resources, only 76 million tons are classified as reserves. Complex sediment origins, including volcanic and metamorphic sources, complicate extraction and reduce economic viability. This gap highlights the need for advanced technologies to enhance recoverability.

In Kalimantan, South Kalimantan contributes 459.9 million tons of resources, concentrated in the alluvial plains of the Barito Basin. However, its reserves stand at a modest 32.8 million tons, reflecting challenges in upgrading resources to commercially viable reserves. Neighboring West Kalimantan reports 340.9 million tons of resources but lags in reserve quantification, signaling untapped potential awaiting further exploration.

Java's Riverine Systems: Moderate but Strategic Contributions

Java's provinces—West, Central, and East Java—collectively contribute between 57 and 369 million tons of resources, primarily from riverine deposits. These sands, transported by Java's extensive river networks, are critical for local construction industries. Banten leads with 177.7 million tons of reserves, underscoring the economic importance of its coastal sands. However, East Java's reserves dwindle to 13.7 million tons, illustrating the variability even within geographically proximate regions.

Provinces with Limited Deposits: Challenges and Opportunities

Several provinces face constraints due to localized or fragmented sand bodies. South Sumatra, West Sumatra, South Sulawesi, and Aceh each report resources below 100 million tons and reserves under 5 million tons, reflecting either sparse distributions or under-exploration. Riau, with 129.7 million tons of resources, and East Kalimantan, with 64.1 million tons, fall into a marginally higher tier but still lag behind national leaders. These regions underscore the necessity of targeted geological surveys to assess untapped potential and address technical barriers.

Economic and Environmental Imperatives

The disparity between resources and reserves—exemplified by provinces like Southeast Sulawesi—reveals systemic challenges in converting geological potential into economically viable projects. Technological innovation, particularly in sediment processing and recovery methods, could bridge this gap. Coastal provinces such as the Riau Islands and Banten must also prioritize sustainable extraction practices to mitigate shoreline erosion and habitat disruption, balancing industrial demand with ecological preservation.

Historical mining regions like Bangka Belitung demonstrate the dual legacy of resource wealth and environmental degradation. While quartz sand extraction offers a secondary revenue stream, comprehensive rehabilitation of former tin-mining areas remains essential to restore ecosystems and community livelihoods.

Strategic Pathways Forward

To harness Indonesia's quartz sand potential sustainably, policymakers and industry stakeholders must focus on three key areas:

Investment in Technology: Advanced exploration and extraction techniques are critical for provinces like West Kalimantan and Southeast Sulawesi to upgrade resources into reserves.

Sustainability Frameworks: Coastal provinces should adopt regulated extraction zones, environmental impact assessments, and rehabilitation mandates to protect fragile ecosystems.

Regional Collaboration: Knowledge-sharing between resource-rich and resource-limited provinces could optimize extraction practices and foster equitable economic growth.

Conclusion

Indonesia's quartz sand wealth is a tale of geological fortune and regional disparity. Central Kalimantan's unparalleled reserves anchor the nation's mining sector, while coastal and riverine provinces like Banten and the Riau Islands play strategic roles in meeting regional demand. Yet, challenges persist in converting resources into reserves and balancing extraction with environmental stewardship. By prioritizing innovation, sustainability, and collaboration, Indonesia can transform its quartz sand wealth into a pillar of long-term economic resilience—one that respects both the land and its people.

This nuanced approach will not only secure Indonesia's position as a global resource leader but also set a benchmark for responsible mineral governance in the 21st century.

Indonesia’s Silica Sand Production: Global Standing and Domestic Trends

Indonesia, endowed with extensive silica sand reserves, remains a minor contributor to global production, ranking 18th worldwide with a 0.8% share (3.5 million tons) of the 402.6 million tons produced globally in 2023. This section examines Indonesia’s production trends from 2017 to 2022, analyzes challenges constraining its output, and identifies strategic opportunities to enhance its role in the global silica sand market.

Introduction

Silica sand, a critical raw material for industries such as construction, electronics, and renewable energy, has seen global demand surge at an annual growth rate of 4.92% between 2019 and 2023. Despite Indonesia’s geological wealth in quartz sand resources, its contribution to global production remains marginal. This section explores the dichotomy between Indonesia’s resource potential and its current production performance, contextualizing its position within broader economic and regulatory frameworks.

Global Quartz Sand Production and Indonesia’s Role in the Market

Quartz sand, also known as silica sand, is a critical industrial mineral used extensively in glassmaking, ceramics, foundry molds, electronics, and hydraulic fracturing. As global demand for high-purity silica increases—driven by technological and renewable energy sectors—production trends reflect both geological endowment and industrial capacity.

The United States leads global quartz sand production by a significant margin, recording an output of 130 million tons per year. This dominance is supported by vast reserves of high-purity silica and mature downstream industries such as glass, semiconductor fabrication, and oil and gas fracking. China follows as the second-largest producer, generating approximately 88 million tons annually. China's demand is fueled by its expansive construction sector, solar panel manufacturing, and electronics industries (Figure 13.4).

In Europe, Italy contributes 33 million tons per year, benefiting from a strong industrial base, especially in ceramics and glass. Turkey (15 million tons), France (14 million tons), and Germany (11 million tons) also maintain notable production volumes, reflecting their developed processing capabilities and robust demand in the construction and automotive sectors. India and the Netherlands both report 12 million tons annually, showing increasing domestic demand as well as involvement in the export market for silica-based products.

Countries like Bulgaria, Russia, Malaysia, and Spain produce between 7 to 8.5 million tons each, indicating growing regional markets for silica sand. These countries may not dominate the global stage but play important roles in their respective continental economies, supplying raw materials for infrastructure and consumer goods.

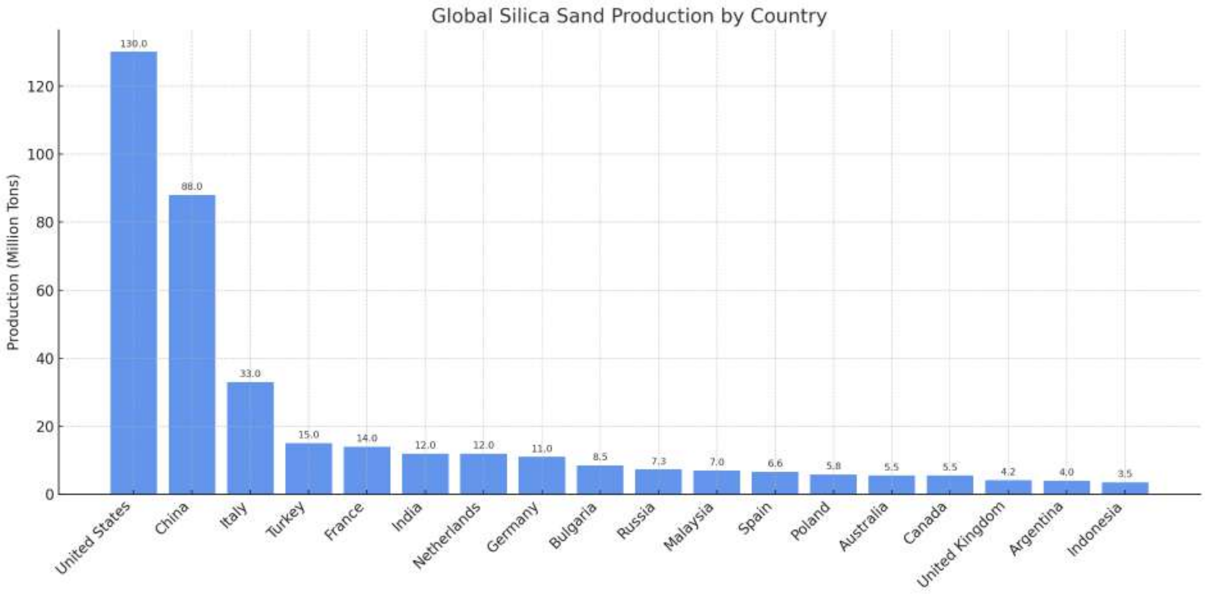

Figure 13.4 Global Quartz Sand Production by Country (in million tons per year) (USGS, 2023)

Poland, Australia, and Canada have moderate production capacities ranging from 5.5 to 5.8 million tons, contributing to both domestic consumption and limited exports. Meanwhile, the United Kingdom, Argentina, and Indonesia round out the lower end of the global top producers list, with Indonesia producing 3.5 million tons annually.

Indonesia's relatively modest output contrasts with its vast geological potential. The country has identified extensive quartz sand resources, particularly in Kalimantan, Sumatra, and the Bangka Belitung Islands. However, current production levels remain limited, largely due to underdeveloped industrial processing capacity and a lack of downstream infrastructure for high-purity silica refinement. This presents a strategic opportunity for investment in beneficiation technologies and value-added industries such as solar-grade silicon and electronics manufacturing.

Overall, global quartz sand production is unevenly distributed, heavily influenced by each country's geological wealth, technological advancement, and industrial development. With the global push toward green energy and digitization, demand for high-quality silica is set to rise, offering countries like Indonesia a pathway to strengthen their role in the international market through strategic development and industrialization.

Indonesia's Quartz Sand Production: Trends, Challenges, and Strategic Outlook (2017–2022)

Quartz sand—commonly referred to as silica sand—is a critical industrial mineral with widespread applications in glassmaking, ceramics, foundries, construction, and increasingly in high-tech industries such as solar photovoltaics and semiconductors. Indonesia, endowed with substantial quartz sand deposits, has shown variable yet promising production trends over the past decade, reflecting both the sector's latent potential and structural constraints.

Production Trends (2017–2022)

Data from the Indonesian Central Statistics Agency (BPS, 2023) (Figure 13.5) reveal fluctuating silica sand production between 2017 and 2022, shaped by both domestic and global dynamics. In 2017, Indonesia recorded quartz sand output at approximately 2.2 million tons, a robust figure reflecting continued extraction in key producing provinces such as Bangka Belitung Islands, West Kalimantan, and South Kalimantan. However, by 2018, production declined sharply to 1.6 million tons, attributable to shifting environmental regulations, logistical inefficiencies in remote mining zones, and regulatory uncertainties involving mining license reforms.

A partial recovery in 2019 saw production climb back to 2.2 million tons, supported by revived demand in the domestic construction and glass industries. Yet, the onset of the COVID-19 pandemic in 2020 once again suppressed output, bringing it down to 1.8 million tons. Despite these setbacks, the post-pandemic period witnessed a notable resurgence. Output rose to 2.0 million tons in 2021 and then surged to 3.1 million tons in 2022—the highest level in the six-year period. This growth coincides with renewed investment, increased infrastructure development, and expanded export opportunities, particularly to neighboring Southeast Asian countries.

Challenges Constraining Production

Indonesia's silica sand sector, while rich in resources, is constrained by several systemic challenges. Foremost among these is the underdeveloped processing infrastructure. A large portion of silica sand exports remains unprocessed, thereby missing out on higher-value markets that demand high-purity silica (over 99.5% SiO_2), particularly in electronics and solar cell manufacturing.

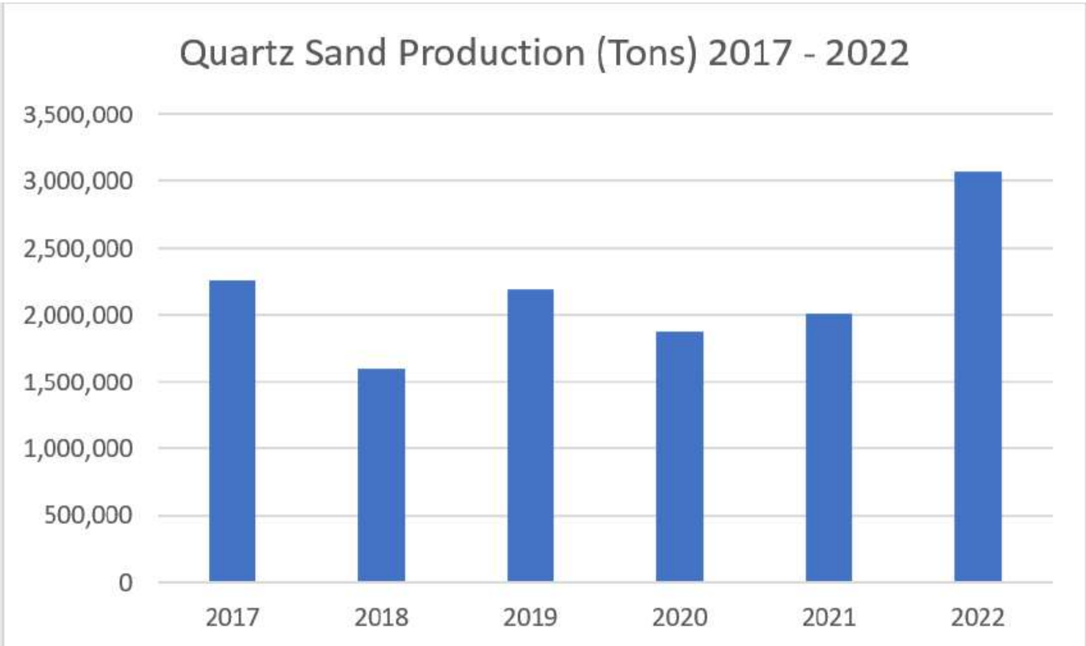

Figure 13.5 Quartz Sand Production in Indonesia, 2017–2022 (in tons) (BPS, 2023)

Additionally, environmental regulations pose critical barriers. Mining moratoriums in coastal zones—intended to prevent erosion and marine degradation—limit access to high-grade coastal deposits. This is compounded by bureaucratic delays in permit issuance, often due to overlapping national and regional regulatory frameworks. Furthermore, policy prioritization of other strategic minerals, such as nickel for electric vehicle battery manufacturing, has diverted attention and capital from the silica sand sector.

Logistical and geographic constraints also hamper production efficiency. Remote locations such as parts of Kalimantan, Sumatra, and Nusa Tenggara suffer from inadequate transportation infrastructure, including poor road connectivity and limited port facilities. These factors inflate production costs and extend project timelines, making Indonesian silica sand less competitive internationally.

Opportunities for Strategic Growth

Despite current limitations, Indonesia's quartz sand industry holds considerable potential for strategic growth. Upgrading processing capabilities to produce refined, high-purity silica is a crucial first step. Establishing domestic beneficiation and purification hubs through public-private partnerships would reduce export dependency on raw sand and enable entry into premium global markets.

Moreover, investments in transportation and logistics infrastructure, particularly in Central Kalimantan and Bangka Belitung, could unlock access to vast, underutilized reserves. Port upgrades and integrated road networks would reduce bottlenecks in the supply chain, lower shipping costs, and improve market accessibility.

Adopting sustainable mining practices is equally essential. Implementing coastal zone management, post-mining land rehabilitation, and alignment with global environmental, social, and governance (ESG) standards would enhance the sector's long-term viability and appeal to responsible investors.

Indonesia could also benefit from diversifying its export markets, reducing overreliance on traditional buyers like China and Singapore. Tapping into emerging economies in the Middle East, Africa, and other parts of Southeast Asia would strengthen resilience and open new commercial avenues.

Conclusion

Indonesia's silica sand industry stands at a pivotal juncture. While the country's current global production ranking reflects a degree of underperformance given its rich geological endowment, recent trends—especially the sharp uptick in 2022—indicate strong latent potential. To realize this potential, a coordinated approach is required: modernizing processing infrastructure, streamlining regulation, investing in transport and logistics, and adopting sustainable practices.

By leveraging its vast resources, improving governance, and fostering innovation, Indonesia is well-positioned to emerge as a leading player in the global silica sand market—supporting not only industrial growth but also environmental stewardship and regional economic development.

Genesis of Quartz and the Formation of Quartz Stone

Quartz, one of the most abundant minerals in the Earth's crust, forms through complex geological processes involving weathering, transportation, crystallization, and metamorphism over geological timescales. These natural processes not only produce loose quartz grains but also lead to the development of quartz stone (Figure 13.6), a solid and compact material increasingly valued in construction, architecture, and industrial applications.

Figure 13.6 Appearance of Natural Quartz Stone (https://kidsloverocks.com/wp-content/uploads/2021/12/MG_2410-copy.jpg)

The genesis of quartz begins with the breakdown of silicate-rich rocks such as granite, sandstone, and metamorphic rocks like quartzite and schist. Through prolonged exposure to physical weathering and chemical alteration, quartz crystals are released from these parent rocks. These liberated quartz grains—owing to their extreme hardness (7 on the Mohs scale) and chemical resistance—survive long transportation by rivers, wind, glaciers, or marine currents.

During transport, quartz grains are deposited in various environments like riverbeds, beaches, desert dunes, or oceanic basins. Over time, layers of these sediments may become compacted and cemented, forming sedimentary rocks rich in quartz. In some settings, particularly in hydrothermal veins and silica-saturated caves, quartz crystallizes directly from aqueous solutions. These processes can yield clear or milky quartz crystals and microcrystalline quartz such as chalcedony or agate.

Additionally, under conditions of high temperature and pressure—common in mountain-building episodes—quartz can recrystallize during metamorphism, forming dense, interlocking mosaics typical of rocks like quartzite. These naturally occurring quartz-rich rocks are the geological precursors of what is now commercially known as quartz stone.

Quartz stone, in the industrial sense, often refers to engineered or reconstituted stone made by combining natural quartz crystals with resin and pigments under heat and pressure. However, it also encompasses natural quartzite and high-purity quartz used as dimension stone or in decorative applications. The fine grain structure, aesthetic appeal, and durability of quartz stone make it ideal for countertops, flooring, wall cladding, and even precision instruments.

Ultimately, whether in its raw, crystalline form or as refined quartz stone, the mineral reflects a long and dynamic geological history. The conditions under which quartz forms—ranging from sedimentary to metamorphic environments—play a direct role in defining the properties of the final material, linking the natural history of quartz directly to its modern use in both decorative and high-tech contexts.

Status of Quartz Stone Resources in Indonesia: 2023 Overview

Indonesia's quartz stone potential, a critical material for the glass, ceramics, and engineered stone industries, displays stark regional variation as reflected in the 2023 data. The chart highlights three provinces—Jambi, West Sumatra, and West Kalimantan—revealing differing stages of resource identification, ranging from measured reserves to hypothetical estimations (Figure 13.7 and Figure 13.8).

Jambi stands out as Indonesia's most quartz-rich province, with 28.3 million tons of identified resources and 20.5 million tons of confirmed reserves—highlighting both geological maturity and intensive exploration. This substantial resource base positions Jambi as a strategic center for future quartz mining and industrial development, particularly for high-purity silica and engineered quartz, in response to growing global demand from the solar and electronics sectors.

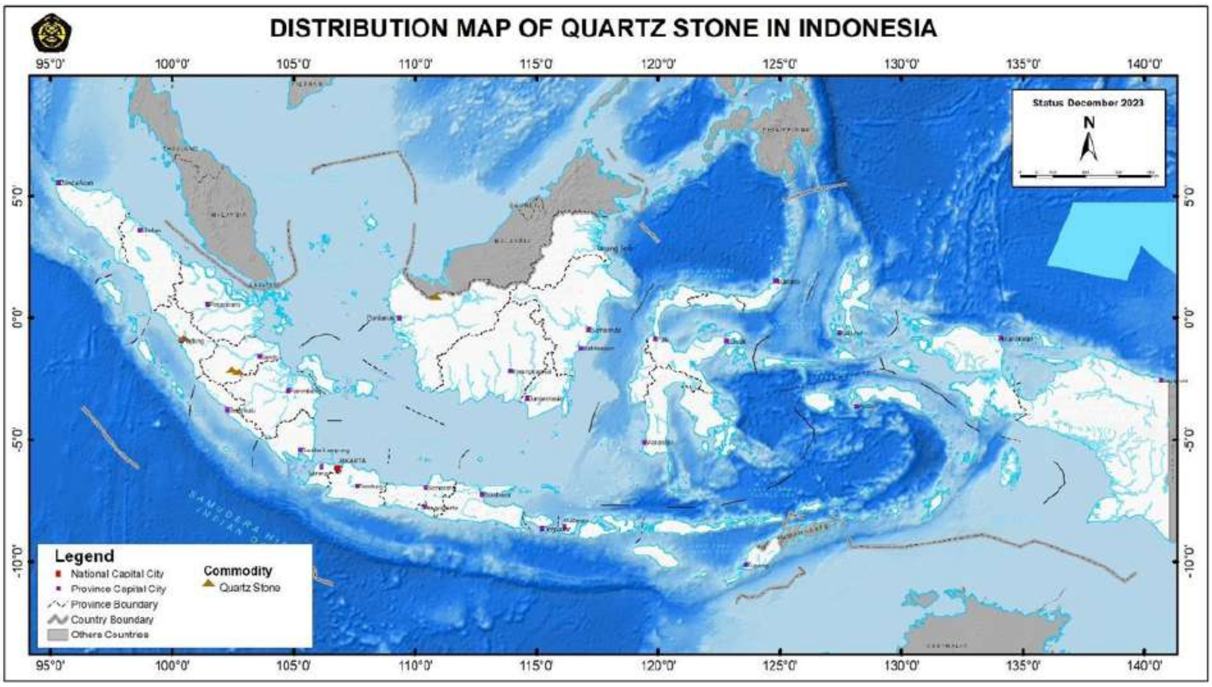

Figure 13.7 Map illustrating the spatial distribution of quartz stone resources across Indonesia (Nursahan et al., 2024)

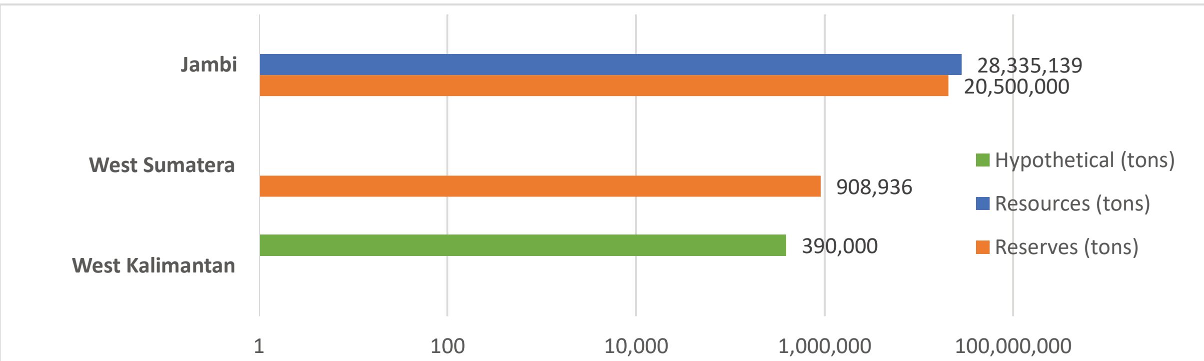

Figure 13.8 Total Quartz Stone Resources and Reserves by Province in Indonesia, 2023 (Nursahan et al., 2024)

West Sumatra, while significantly trailing Jambi, still reports nearly 909 thousand tons of reserves, suggesting limited but viable quartz stone occurrences. The absence of categorized resources or hypothetical estimates, however, may point to early-stage exploration or insufficient geological survey coverage in the region. With additional investigation and mapping, the potential for growth in quartz identification remains open.

West Kalimantan presents a contrasting case. While no proven reserves or measured resources have yet been confirmed, the province holds an estimated 390 thousand tons in hypothetical resources. This figure reflects geological indications based on regional analogs or early reconnaissance, yet awaits validation through detailed exploration. As such, West Kalimantan represents a frontier opportunity—ripe for geoscientific study and investment in exploration drilling.

The overall distribution reveals Indonesia's uneven development in quartz resource evaluation. While Jambi is poised for industrial exploitation, other provinces are either emerging or speculative in nature. Bridging this gap requires targeted geological surveys, investment in exploration technology, and integration with downstream processing industries.

Amid growing global demand for high-quality silica in green technology and construction, Indonesia's varied quartz resources offer significant potential. With targeted investment and strategic management, the country is well-positioned to become a leading regional supplier.

Quartzite: Formation, Characteristics, and Genesis

Quartzite is a non-foliated metamorphic rock composed almost entirely of quartz minerals, typically ranging from over 90% to as high as 99% quartz content. It originates from quartz-rich sedimentary rocks—most commonly sandstone—that undergo metamorphism. Through the intense heat, pressure, and chemical activity associated with metamorphic environments, the original sand grains and their silica-based cement recrystallize. This transformation results in an interlocking crystalline structure that binds the quartz grains tightly, producing a rock that is significantly harder, denser, and more resistant to weathering and erosion than its protolith, sandstone.

One of the key distinguishing features of quartzite is its exceptional hardness and durability, a result of this crystalline bonding. On the Mohs hardness scale, quartzite typically ranks around 7, the same as pure quartz, making it one of the toughest natural building stones available. This makes quartzite ideal for applications in construction, flooring, and even decorative stonework where strength and resistance to abrasion are crucial.

In terms of appearance, quartzite is commonly gray to white due to its high purity of quartz (Figure 13.9). However, the presence of trace impurities such as iron oxide can result in a range of other colors, including pink, red, or purple. Additional mineral inclusions may impart hues of yellow, orange, brown, green, or even blue, giving quartzite a diverse and often visually striking appearance. Despite these variations, its texture remains generally fine to medium-grained and homogenous.

Figure 13.9 Appearance of Quartzite (https://cdn.shopify.com/s/files/1/1027/4949/products/vemkxa3y7e9fqbj76v9x_6edc5dbd-0c37-461c-b17e-5e41ccc6cf4c_3712x2800.jpg?v=1589577561)

The genesis of quartzite is rooted in metamorphic processes that alter quartz-bearing sedimentary rocks under elevated pressure and temperature conditions. This transformation typically occurs during regional metamorphism, often associated with mountain-building events or tectonic plate collisions. The original source rock—commonly quartz sandstone or quartzose sandstone—undergoes recrystallization where any additional minerals such as feldspar or clay are either expelled or transformed, resulting in a purer quartz composition.

As pressure increases, the grains compact, and at high temperatures, silica begins to recrystallize, fusing the grains together without the presence of pores or cement. The result is a dense, interlocking quartz fabric that gives quartzite its characteristic strength and non-foliated texture. Unlike foliated metamorphic rocks like schist or slate, quartzite lacks visible layers or banding, emphasizing its uniformity and mineralogical purity.

Quartzite is not only a testament to the transformative power of geological processes but also a valuable resource in both industrial and aesthetic applications. As global demand grows for durable and visually appealing natural stone, quartzite stands out for its strength, beauty, and deep geologic origins.

Distribution and Potential of Quartzite Resources in Indonesia by Province

The graph (Figure 13.10) presents a comparative overview of quartzite resources and geological potential (hypothetical resources) across several Indonesian provinces as of 2023. This data is crucial for understanding the regional potential of quartzite (Figure 13.11), a high-strength metamorphic rock widely used in the construction and materials industry.

West Sumatra emerges as the province with the most significant quartzite potential, reporting 39 million tons of identified resources and an impressive 2.9 billion tons of hypothetical resources. This indicates that while a substantial amount of quartzite has already been geologically assessed, the province may hold much larger untapped reserves pending further exploration and confirmation. West Sumatra's geological setting, dominated by ancient sedimentary and metamorphic formations, supports this extensive mineral presence.

Aceh ranks second in terms of both confirmed and speculative quartzite potential. The province possesses 50 million tons of identified quartzite resources and a large volume of approximately 484 million tons categorized as hypothetical. This dual strength in resources and geological potential highlights Aceh's growing importance in the future of Indonesia's industrial mineral supply chain, particularly given its tectonically active terrain, which favors the formation of high-grade metamorphic rocks.

West Papua shows significant promise, with 5.3 million tons of quartzite resources identified. Although hypothetical resources are not shown in the graph for this region, the existing data suggests a valuable opportunity for targeted geological surveys to uncover additional deposits.

East Nusa Tenggara, with 1.03 million tons of identified quartzite, reflects moderate but notable potential. The region's archipelagic and volcanic-geological background could suggest the presence of localized metamorphic zones, warranting further geoscientific study to evaluate continuity and quality.

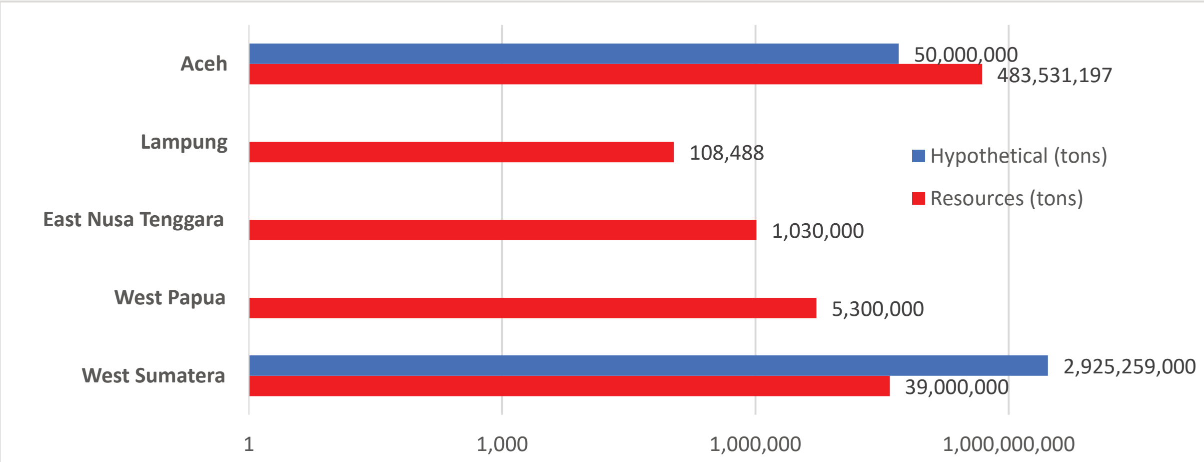

Figure 13.10 Total Quartzite Resources and Hypothetical Resources by Province in Indonesia, 2023 (Nursahan et al., 2024)

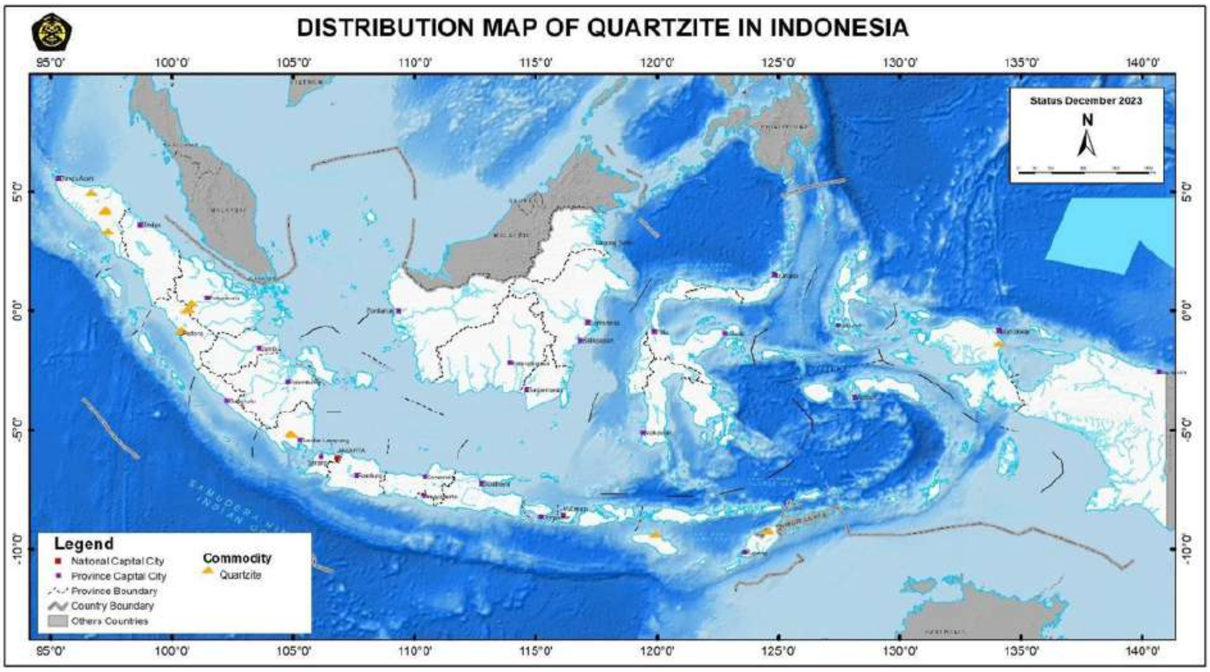

Figure 13.11 Map illustrating the spatial distribution of quartzite occurrences across Indonesia (Nursahan et al., 2024)

Lampung represents the smallest contributor among the provinces displayed, with only 108,488 tons of quartzite resources recorded. The limited figures may be attributed to either genuinely small deposit volumes or a lack of detailed exploration in the region.

The graph underscores the significant disparity between identified resources and hypothetical resources in several regions, especially West Sumatra and Aceh. This gap reveals an urgent need for enhanced exploration efforts, particularly through drilling and laboratory analysis, to convert geological potential or hypothetical resources into measurable and mineable reserves.

From a national policy perspective, the strategic development of quartzite reserves aligns with Indonesia's ambition to reduce dependency on imported raw materials for construction and manufacturing. Given its hardness, durability, and aesthetic potential, quartzite can serve various industrial purposes, including countertops, flooring, railway ballast, and even decorative architecture.

The data also highlights the untapped geological wealth in eastern and peripheral provinces such as West Papua and East Nusa Tenggara, suggesting a more balanced, regionally inclusive resource development strategy could be pursued.

Industrial Utilization of Silica Sand in Indonesia: Current Status and Sectoral Demands

The industrial utilization of silica sand in Indonesia plays a vital role in supporting various downstream sectors, ranging from glass manufacturing to refractory materials. Based on the latest data from the Ministry of Industry (September 2023), the utilization rate of silica sand in upstream industries has reached 65.32%, with a processing capacity of approximately 738,536 tons per year. This figure reflects operations by 21 industrial companies, excluding integrated mining facilities, underscoring the material's importance in non-metallic mineral processing (Table 13.1).

Product Outputs and Sectoral Demand

Silica sand processed in Indonesia contributes to three primary product categories: silica sand, silica flour, and resin-coated sand. These outputs serve a wide spectrum of industrial applications:

Glass Industry: The largest consumer of high-purity silica sand, which is tailored to specific glass types—sheet, container, household, and optical glass. Table 13.2 (SNI 15-0346-1989) outlines the varying purity requirements, with optical glass requiring over 99.5% SiO_2 and minimal iron content (Fe_2O_3 < 0.001%).

Metal Casting Industry: Silica sand is employed as a molding and core material. The specifications (SNI 19-1066-1989, Table 13.3) call for a minimum 90% SiO_2 content, specific grain size distribution, and sub-angular grain shape to withstand thermal shock and ensure cast quality.

Refractory Industry: Used in the production of firebricks and linings for high-temperature industrial equipment, this sector requires sand with ≥95% SiO_2 and precise granulometry. According to SNI 13-666-2002 (Table 13.4), silica sand must also contain low levels of impurities such as TiO_2 and Na_2O_3.

Ceramics: In the glaze and advanced ceramics industry, silica sand provides a critical raw material with a required SiO_2 content above 95%. It also serves as a base for non-oxide ceramics like silicon carbide and silicon nitride.

Building Materials: Serving as a replacement for natural sand, quartz sand is integral in concrete mixes, mortars, and plasters. Standards dictate angularity, low organic content, and specific sieve residue distributions to ensure strength and consistency in final construction products.

Strategic Potential: Solar-Grade Silicon

Beyond traditional uses, ongoing research highlights the potential of ultra-pure silicon derived from quartz and quartzite as a raw material in photovoltaic (PV) solar panels. According to Syafrizal et. al (2022), high-purity silicon offers superior energy conversion efficiency and economic feasibility, positioning Indonesia as a potential player in the global renewable energy supply chain.

Provincial-Level Utilization Patterns

Utilization of silica sand varies widely by province, reflecting regional industrial priorities and resource availability. Data from 23 provinces show that (Table 13.5):

Aceh, Riau Islands, Bangka Belitung, Central and East Kalimantan, and Southeast Sulawesi are leading hubs with diversified use across all five major industries: glass, casting, refractory, ceramics, and construction.

Provinces such as **West Java, Central Java, East Java, and South Sulawesi** primarily utilize quartz sand for building materials, reflecting infrastructure-driven demand.

West Papua and East Nusa Tenggara are emerging regions with niche usage in casting and refractory sectors, hinting at untapped resource potential.

Outlook and Policy Implications

As Indonesia seeks to expand its mineral downstreaming strategy, silica sand stands out not only for its industrial versatility but also for its strategic role in clean energy materials. Enhancing upstream integration, upgrading processing technologies, and strengthening national standards (SNI) will be crucial to maximize domestic value addition.

In conclusion, silica sand utilization in Indonesia is evolving, driven by industrial demand and green technologies. With adequate investment and policy support, it holds strong potential to advance industrial growth and energy transition efforts.

Issue and Strategic Significance of Silica in Indonesia

Non-metallic mineral and rock commodities in Indonesia are regulated under Government Regulation Number 96 of 2021 on the implementation of mineral and coal mining business activities. Subsequently, Decree of the Minister of Energy and Mineral Resources (MEMR) Number 147.K/MB.01/MEM.B/2022 was issued, revising the classification of several mineral commodities including dolomite, feldspar, phosphate, graphite, quartzite, and zircon.

Table 13.1 Silica Sand Demand by Industrial Sector in Indonesia (2022)
(SIINas – National Industrial Information System, Associations, and Partner Companies under Directorate of Cement, Ceramics, and Non-Metallic Mineral Processing Industries, Directorate General of Chemical, Pharmaceutical, and Textile Industries, Ministry of Industry, 2023)

No.	Type of Industry	Installed Capacity per Year (2022)	Silica Sand Demand (Tons)	SiO_2 (% min.)	Fe_2O_3 (% max.)	Al_2O_3 (% max.)
1	Glass Industry	- Flat and Safety Glass: 1.3 million TPY - Glassware: 348 thousand TPY - Glass Containers: 414 thousand TPY - Glass Block: 96 thousand TPY	803,746	98.5	0.05	-
2	Cement Industry	- Cement: 116 million TPY - Clinker: 81 million TPY	1,639,410	90	1	-
3	Ceramic Industry	- Floor Tiles: 540 million m^2 - Sanitary Ceramics: 6.1 million pcs - Tableware: 85.1 million pcs	380,867	-	-	-
4	Metal Smelting Industry *(Estimation)*	—	500,000	90	-	-
5	Cement-Based Products Industry (Mortar, Fiber Cement, Lightweight Concrete, Silica Board)	Combined: 86 million TPY	556,752	-	-	-
6	Silica Processing Industry (Silica Flour, etc.)	—	493,062	-	-	-
7	Other Industries (Chemicals, Paint, Water Treatment, Sandblasting, Refractory, etc.)	—	150,000	97	0.3	-
	Total		**4,523,837**			

Table 13.2 Specifications of Quartz Sand for the Glass Industry (SNI 15-0346-1989)

Parameter	Sheet Glass	Packaging & Household Glass	Optical Glass
Chemical Composition			
SiO_2 (min, %)	99	98.5	99.5
Fe_2O_3 (max, %)	0.5	0.03	0.001
Al_2O_3 (max, %)	0.1	0.3	0.002
CaO + MgO (max, %)	0.5	0.2	0.1
Cr_2O_3 (max, %)	0.5	0.006	0.0002
Grain Size Distribution			
+14 mesh	Not specified	Not specified	Not specified
+25 mesh	Max. 1.0%	Max. 0.5%	-
+36 mesh	Max. 5.0%	Max. 1.5%	-
-120 mesh	Max. 5.0%	-	Max. 95.0%
Dimmed light at 1000°C	Max. 0.5%	Max. 0.5%	Max. 0.5%
Humidity	Max. 5.0%	Max. 5.0%	Max. 0.5%

Table 13.3 Quartz Sand Specifications for Metal Casting Industry (SNI 19-1066-1989)

Parameter	Specification
Chemical Composition	
SiO_2 (min, %)	90
Fe_2O_3 (max, %)	1.5
$Na_2O + K_2O$ (max, %)	2
Grain Size Distribution	
Coarse (-30 +70 mesh)	35%
Medium (70 mesh)	30%
Fine (-70 +200 mesh)	35%
Grain Shape	Sub-angular

Table 13.4 Specifications of Quartz Sand for Refractory Bricks (SNI 13-6668-2002)

Parameter	Specification
Chemical Composition	
SiO_2 (min, %)	95
Al_2O_3 (min, %)	1
Na_2O_3 (max, %)	0.3
TiO_2 (max, %)	0.3
K_2O (max, %)	0.3
Grain Size Distribution	
Coarse	3.35 – 0.50 mm
Medium	0.50 – 0.18 mm
Fine	< 0.18 mm
Grain Shape	Slightly angular

Table 13.5 Quartz Sand Utilization by Province (2023) (SIINas – National Industrial Information System, Ministry of Industry, 2023)

No.	Province	Utilization Sectors
1	Aceh	Glass, Casting, Refractory, Ceramic, Building Materials
2	North Sumatra	Building Materials
3	Riau	Refractory and Building Materials
4	West Sumatra	Building Materials
5	South Sumatra	Building Materials
6	Riau Islands	Glass, Casting, Refractory, Ceramic, Building Materials
7	Bangka Belitung Islands	Glass, Casting, Refractory, Ceramic, Building Materials
8	Lampung	Refractory and Building Materials
9	Banten	Casting, Ceramic, Building Materials
10	West Java	Building Materials
11	Central Java	Building Materials
12	East Java	Building Materials
13	West Kalimantan	Refractory and Building Materials
14	Central Kalimantan	Glass, Casting, Refractory, Ceramic, Building Materials
15	North Kalimantan	Building Materials
16	East Kalimantan	Glass, Casting, Refractory, Ceramic, Building Materials
17	South Kalimantan	Glass, Casting, Refractory, Ceramic, Building Materials
18	West Nusa Tenggara	Building Materials
19	East Nusa Tenggara	Casting, Refractory, and Building Materials
20	Central Sulawesi	Casting, Building Materials
21	Southeast Sulawesi	Glass, Casting, Refractory, Ceramic, Building Materials
22	South Sulawesi	Building Materials
23	West Papua	Building Materials

Silica has emerged as a mineral of national and strategic importance. It is now classified as a Critical Mineral under MEMR Decree No. 296.K/MB.01/MEM.B/2023, and also designated as a Strategic Mineral Commodity under MEMR Decree No. 69.K/MB.01/MEM.B/2024. This classification underscores silica's significant potential to dominate the global market through its abundant resources and/or reserves.

In alignment with the national downstreaming agenda, the Minister of Trade Regulation No. 23 of 2023 governs silica export policies, aiming to support domestic value-added processing.

Furthermore, under the Government's Industrial Development Roadmap (2015–2035), priority sectors for 2020–2024 include the Solar Cell Power Generation Industry and the Non-Metallic Mineral Industry—particularly the ceramics, glass, and refractory industries, where silica is a vital raw material.

Investment and Industrial Developments

Indonesia's vast silica sand potential has attracted global industrial giants. One notable example is the Xinyi Group, a leading Chinese firm in the glass and solar panel sector. As announced by Bahlil Lahadalia, Minister of Investment and Head of the Investment Coordinating Board (BKPM), Xinyi plans to invest in Rempang, Batam (Riau Islands), where it intends to build the world's second-largest glass factory. This facility will position Indonesia as a major solar panel supplier.

In parallel, the KCC Glass Indonesia plant in Batang, Central Java, is expected to begin production in August 2024. Upon completion, KCC Glass Indonesia will become Southeast Asia's largest glass manufacturer, reinforcing Indonesia's role in regional glass and solar material production.

Challenges and Opportunities in the Solar Energy Industry

Despite its natural resource wealth, Indonesia remains highly dependent on imported components for its solar energy industry. The key barriers include limited investment capital and a scarcity of skilled human resources. As a result, the domestic solar cell manufacturing sector is still underdeveloped.

According to preliminary data from the Ministry of Energy and Mineral Resources, Indonesia possesses an estimated 17 billion tons of silica raw materials, widely distributed across the archipelago. Notable high-quality deposits include quartzite in Lampung and silica sand in Tuban.

To illustrate silica's industrial value, producing 1 MW of solar cells requires approximately 50 tons of silica sand. Cleaned and sieved silica sand can be sold for Rp 100 per kilogram, meaning a truckload of 40 tons (~Rp 200,000) could support 1 MW of solar cell production. This highlights silica's strategic role in supporting renewable energy transitions (Directorate General of Mineral and Coal, Ministry of Energy and Mineral Resources, 2024).

Given the high costs associated with solar panel production, innovation in silica purification is crucial. Emphasis should be placed on developing upstream processing technologies—particularly converting silica sand into solar-grade silicon wafers, which are the foundation for photovoltaic (PV) modules. Automation has already advanced downstream, so upstream innovation offers the most strategic leverage.

Case Study: High-Purity Silica Fabrication from Kendawangan, West Kalimantan

Quartz sand from Kendawangan, West Kalimantan, was effectively processed into high-purity silica precipitates, as demonstrated by Prasetyo et al. (2023). The process included:

- Roasting quartz sand with sodium carbonate in a 55:45 ratio at 1,200°C for 2 hours, forming sodium silicate crystals.
- Dissolving sodium silicate in boiling water, followed by leaching, precipitation, and multiple acid washes using hydrochloric acid (HCl).

Results of atomic absorption spectroscopy (AAS) showed the original quartz sand had a SiO_2 content of 99.2%, with trace impurities. After processing, silica precipitates with 99.99% purity were successfully obtained—meeting the requirements for solar-grade silicon.

This breakthrough offers a promising domestic alternative for producing materials used in photovoltaic (PV) solar devices, reducing reliance on imports and contributing to Indonesia's green energy transition.

Conclusion

Silica's elevation to critical and strategic mineral status reflects its growing role in supporting Indonesia's industrial downstreaming, energy transition, and technological independence. Through supportive regulations, strategic investments, and innovation in purification technologies, Indonesia can unlock the full potential of its silica resources—positioning itself as a regional hub for glass, ceramics, and solar cell production.

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Limestone

Image: Limestone Rock
Courtesy of:https://www.nordkalk.com/wp-content/uploads/2023/04/HighKeyRocks-2-1.jpg

Limestone is a sedimentary rock predominantly composed of calcium carbonate ($CaCO_3$), which occurs mainly in the forms of calcite, dolomite ($CaMg(CO_3)_2$), and aragonite. These minerals form through various geological processes—organic, mechanical, and chemical in nature (Warren, 2000; Dollimore et al., 1998).

The most common type of limestone is organically formed, resulting from the accumulation of biological material such as shells, snails, foraminifera, algae, and other marine organisms. Over time, these biological remains become compacted and lithified, creating fossil-rich limestone deposits that serve as important indicators of past marine environments.

In contrast, mechanically formed limestone originates from the physical breakdown of organic limestone. This detrital material is transported by currents and then deposited, often not far from its source. Although its composition is similar to that of organic limestone, its texture and structure are more granular or layered due to its sedimentary nature.

Chemically formed limestone develops through the precipitation of calcium carbonate from mineral-rich waters under specific environmental conditions, either in marine or freshwater settings. For example, calcareous sinter or travertine is deposited from mineral springs, especially those associated with geothermal activity. In such cases, hot groundwater dissolves carbonate rocks underground and redeposits calcium carbonate at the surface as the water cools.

Terminology, Composition, and Characteristics

Limestone is also known as calcareous rock or kalsteine. In Indonesia, the term "gamping" is commonly used, believed to originate from Gamping Village in Sleman Regency, Yogyakarta, where limestone has been mined since the 18th century.

Typically, limestone is composed of approximately 90% calcite, with around 3% dolomite, and smaller amounts of clay minerals and other impurities (Park et al., 2008). Aragonite, another form of calcium carbonate, is also present. Although aragonite is chemically identical to calcite, it is a metastable polymorph that gradually transforms into calcite over geological time (Noviyanti et al., 2015).

Limestone comes in a wide range of colors, including milky white, gray, brown, red, and black. These color variations are mainly due to the presence of impurities: iron and manganese oxides give limestone a reddish hue, while organic matter tends to darken it. For instance, limestone from Ujung Batu Village in Pasie Raja District, South Aceh Regency, is dark gray to black, hard in texture, and features joints and fractures filled with calcite veins, reflecting secondary mineralization processes in the rock (Figure 14.1).

Occurrence of Limestone in Indonesia

Limestone deposits are widely distributed across the Indonesian archipelago (Figure 14.2), reflecting the country's complex geological history and extensive carbonate sedimentation environments. These deposits occur in both coastal and inland areas, spanning multiple geological formations and ages—from Paleozoic to recent.

Figure 14.1 Blackish limestone in the Ujung Batu Village area, Pasie Raja District, South Aceh Regency. (Muksin, 2020)

Significant limestone occurrences have been documented in nearly every province, including Aceh, North Sumatra, South Sumatra, West Sumatra, Riau, Bengkulu, Jambi, Lampung, Banten, West Java, Central Java, East Java, and the Yogyakarta Special Region in western Indonesia. In Kalimantan, deposits are found in South, Central, East, and North Kalimantan, often associated with Tertiary formations and shallow marine environments.

In Sulawesi, limestone is present in West, South, Central, Southeast, and North Sulawesi, as well as in Gorontalo, typically forming in uplifted reef complexes and karst landscapes. The Maluku and North Maluku islands also host limestone deposits, often linked to island arc tectonics and localized carbonate platforms.

Further east, limestone is found in West Nusa Tenggara (NTB) and East Nusa Tenggara (NTT), where it forms prominent karst landscapes such as those in East Sumba and

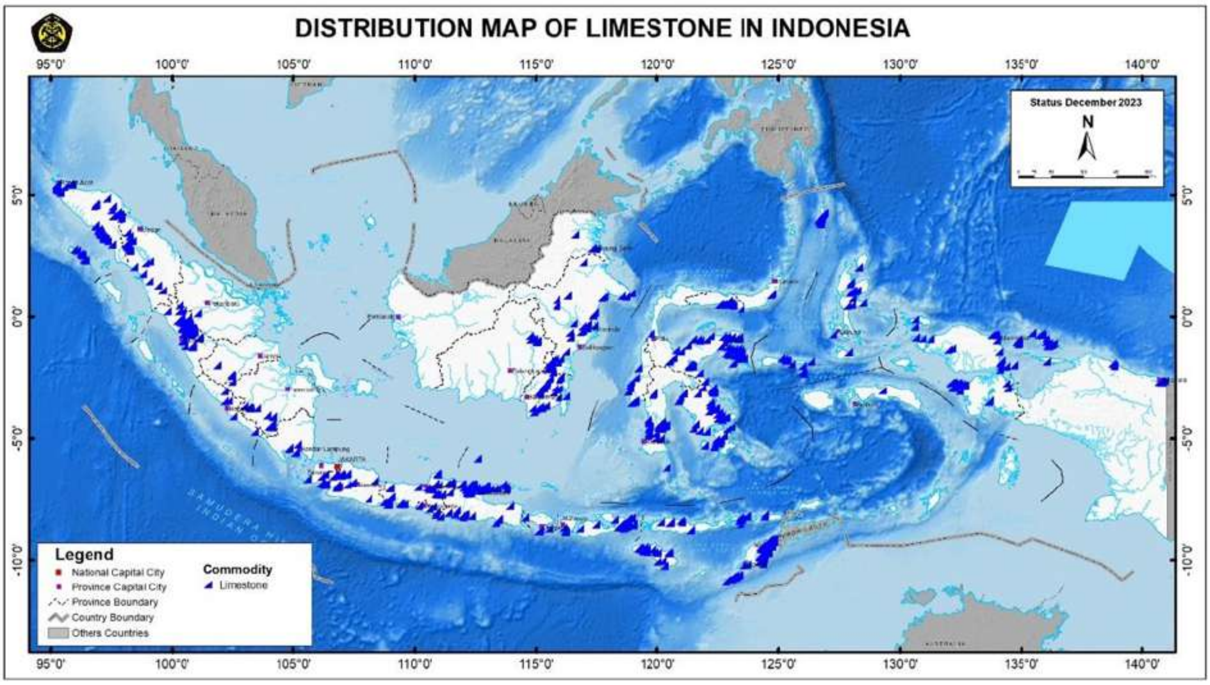

Figure 14.2 Distribution Map of Limestone in Indonesia (Nursahan et al., 2024)

Flores. In the Papua region, limestone formations are widely distributed in Papua and West Papua, particularly in the Bird's Head Peninsula and the Central Range, forming part of uplifted marine sequences and extensive karst terrains.

These widespread occurrences make limestone one of the most accessible and economically important industrial minerals in Indonesia, supporting sectors such as cement production, construction, agriculture, and environmental remediation.

Regulatory and Industrial Issues in Limestone Utilization

Protected Areas and Karst Regulation

The development and utilization of limestone in Indonesia are closely tied to environmental regulations, particularly those concerning protected Karst Landscape Areas (*Kawasan Bentang Alam Karst* or KBAK). These areas are designated for conservation due to their distinctive geological characteristics, their role in regulating natural groundwater systems, and their value for scientific study and education. According to Ministry of Energy and Mineral Resources Regulation No. 17 of 2012, areas identified as part of KBAK cannot be exploited for mining or commercial development. Instead, they must be preserved to ensure ecological balance and long-term sustainability.

Limestone as a Critical Mineral

To secure domestic raw material supply chains, especially for strategic industries, the Indonesian government has formally classified limestone (calcium) as a critical mineral through Ministry of Energy and Mineral Resources Regulation No. 296.K/MB.01/MEM.B/2023. This regulation is part of a broader effort to strengthen self-sufficiency and reduce dependency on imports. The inclusion of limestone in the list reflects its importance to national industries such as cement production and metal smelting, where continuous, high-quality supply is essential.

Industrial Use in Cement Manufacturing

Limestone, primarily composed of calcium carbonate ($CaCO_3$), is the main raw material in Portland cement production, which is the most widely used type of cement worldwide. Typically, each ton of Portland cement requires at least one ton of limestone. The raw material blend generally consists of approximately 75% limestone, 20% clay, and about 5% additional components, such as iron sand, silica sand, and gypsum.

For industrial purposes, the quality of limestone is assessed based on its chemical composition and processing characteristics. The ideal limestone for cement should contain around 50–55% calcium oxide (CaO), with magnesium oxide (MgO) kept below 2%. The content of iron oxide (Fe_2O_3) and aluminum oxide (Al_2O_3) should be below 2.47% and 0.95%, respectively, while the slurry formed during processing must maintain a viscosity of approximately 3200 centipoise with 40% water. Numerous limestone deposits in Indonesia meet these criteria. For example, the Tonasa Formation in Maros and Pangkep Regencies, South Sulawesi, supplies raw material to the Tonasa Cement Plant, one of the country's leading cement producers.

Importance in the Metallurgical Industry

Limestone also serves an essential role in the metal smelting industry, where it is used as a fluxing agent to remove impurities and facilitate metal purification. In steelmaking, either raw limestone or its calcined form, quicklime (CaO), is added to bind with unwanted substances like silica (SiO_2), alumina, and gases such as sulfur dioxide (SO_2) and hydrogen sulfide (H_2S). The resulting compounds are then separated as slag.

For optimal performance in metallurgy, limestone must be dense, hard, and rich in CaO, ideally with a minimum content of 52%. Silica levels should range between 1.5 and 4%, and the combined content of alumina and iron oxide should not exceed 3%. Additionally, low phosphorus and sulfur content are crucial for high-quality output, though the magnesium content (MgO) is less critical and, in some cases, dolomitic limestone is acceptable. In Indonesia, high-quality limestone suitable for smelting is found in the Laonti Formation, located in Konawe Selatan Regency, Southeast Sulawesi.

Global Limestone Production: Trends and Strategic Implications

Limestone continues to be one of the world's most essential industrial minerals, with its widespread use in construction, cement manufacturing, metallurgy, and environmental applications. As of 2023, global limestone production reached approximately 430 billion metric tons, according to the U.S. Geological Survey Mineral Commodity Summaries (2024). The dataset represented in the chart reflects individual country contributions, highlighting both consistency and subtle growth patterns across the two years (Figure 14.3).

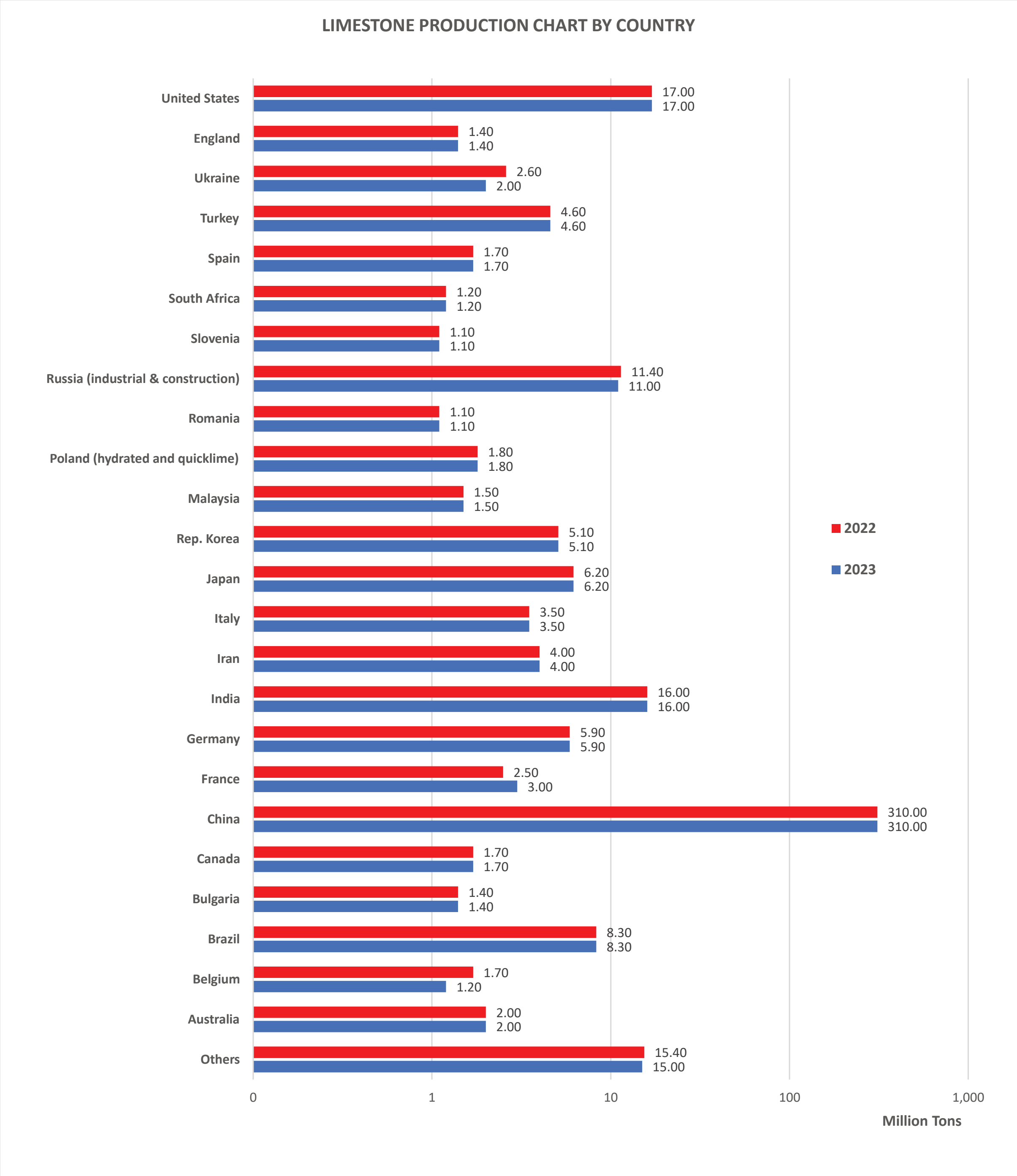

Figure 14.3 Global Limestone Production by Country (2022–2023) (U.S. Geological Survey [USGS], 2024)

Global Leaders in Production

China remains the undisputed global leader in limestone production, reporting a staggering 310 million tons in both 2022 and 2023. This dominance is driven by China's massive domestic demand for cement, steel, and infrastructure development. Following China are the United States and India, producing 17 million tons and 16 million tons, respectively, each year. These figures underscore the heavy industrialization and large-scale construction activities taking place in these nations.

Other notable producers include Russia (11 million tons in 2023), Japan (6.2 million tons), Germany (5.9 million tons), and Brazil (3.3 million tons). These countries maintain consistent output levels, indicating stable limestone demand for cement production and steel smelting industries.

Steady but Concentrated Growth

From the graph, it is evident that most countries have maintained steady production levels from 2022 to 2023, with only marginal fluctuations observed in places like Russia, where a slight decrease occurred from 11.4 million to 11.0 million tons. Similarly, the “Others” category—representing smaller or aggregated producers—saw a slight drop from 15.4 million tons in 2022 to 15.0 million tons in 2023.

The lack of dramatic year-on-year changes signals a mature industry with predictable demand cycles. Most increases are relatively modest and likely tied to national infrastructure investments or shifts in export demand. For instance, countries like Turkey (4.6 million tons), South Korea (5.1 million tons), and Iran (4.0 million tons) also reflect steady output, indicative of balanced domestic-industrial utilization.

Industrial Relevance and Policy Considerations

The global limestone market remains essential for two of the world's most resource-intensive industries: cement manufacturing and steel production. As noted by the U.S. Geological Survey (2024), for every ton of cement produced, at least one ton of limestone is required, with quality specifications varying depending on its end use. In the metallurgy sector, high-calcium limestone and quicklime are critical for removing impurities from molten metals.

With limestone now being classified as a critical mineral in several countries—including Indonesia through Regulation No. 296.K/MB.01/MEM.B/2023—its strategic importance has increased, particularly in contexts of self-sufficiency and resource security. Countries with large reserves are beginning to view limestone not merely as a construction material but as a strategic asset tied to national industrial policy.

Toward Sustainable Extraction and Regulation

Environmental concerns are also shaping the future of limestone exploitation. In Indonesia, the designation of Karst Landscape Areas (KBAK) under Ministerial Regulation No. 17/2012 prevents extraction from sensitive ecological zones, emphasizing the balance between economic utilization and conservation. Similar initiatives in other parts of the world aim to regulate quarrying activities to mitigate habitat destruction and groundwater contamination.

Conclusion

Global limestone production is dominated by a few industrial giants but supported by numerous consistent contributors worldwide. As limestone continues to underpin infrastructure, energy, and industrial development, policy frameworks that promote sustainable extraction and ensure equitable supply chains are becoming increasingly important. With no signs of declining demand, particularly from emerging economies, limestone will remain a cornerstone of global development well into the next decade.

Growth Trends in Limestone Resources, Reserves, and Data Coverage in Indonesia (2019–2023)

The limestone mining sector in Indonesia has demonstrated steady and significant development over the five-year period from 2019 to 2023, as illustrated in the Figure 14.4. This progress reflects the results of ongoing geological surveys, data integration, and national policy support.

Over the reporting period, total limestone resources increased from 159.35 billion tons in 2019 to 227.60 billion tons in 2023, representing a growth of more than 42%. This expansion is indicative of enhanced exploration activities and the identification of new deposits across various provinces. The increase may also result from the improved quality and coverage of geological data.

In parallel, limestone reserves—which represent the portion of resources that are economically and legally feasible to exploit—showed a threefold increase, rising from 7.63 billion tons in 2019 to 21.07 billion tons in 2023. This suggests not only better confidence in the data collected but also reflects a growing emphasis on converting potential resources into extractable reserves, a critical step in ensuring material availability for national industries.

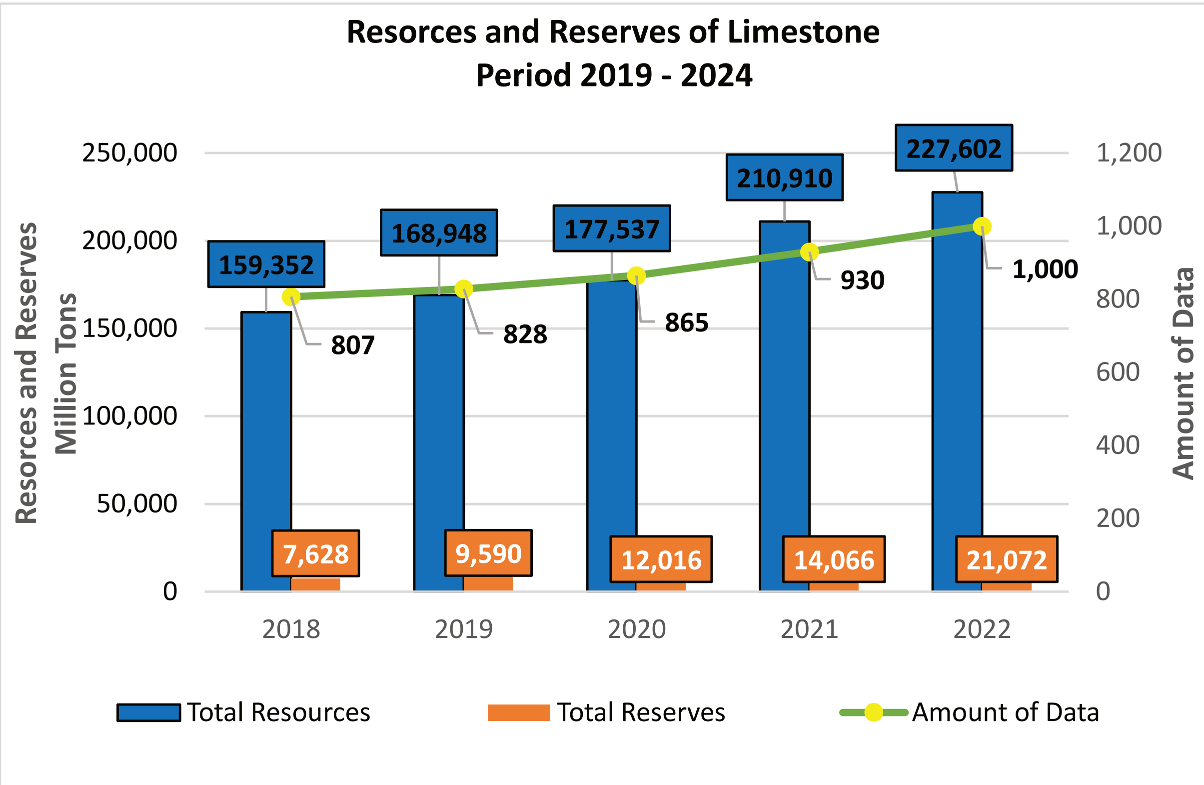

Figure 14.4 Growth Trends in Limestone Resources, Reserves, and Data Coverage in Indonesia (2019–2023) (Nursahan et al., 2024)

Another noteworthy trend is the increase in the number of data points or surveyed locations, from 607 sites in 2019 to 1,000 in 2023. The steady growth in data coverage demonstrates significant advancements in mapping and geoinformation systems, supported by both governmental and private sector initiatives. These efforts help ensure that development of limestone resources aligns with sustainable practices and national spatial planning.

The alignment of increased resources, reserves, and data points indicates a strong correlation between policy implementation, data-driven decision-making, and the growing strategic role of limestone as a critical mineral—especially considering its importance in cement manufacturing and metallurgical applications.

Provincial Overview of Limestone Resources and Reserves in Indonesia

The distribution of limestone resources and reserves across Indonesian provinces reveals significant regional variation in both the quantity and development status of this key industrial mineral. The bar chart presents figures in million tons using a logarithmic scale, effectively highlighting disparities between provinces while ensuring visual clarity (Figure 14.5).

Southeast Sulawesi leads with the most substantial limestone resource base, totaling 42,981.11 million tons, and reserves of 7,853.91 million tons. This province illustrates a strong correlation between resource potential and development activity, indicating effective exploration, evaluation, and readiness for industrial use. **East Nusa Tenggara** follows with 31,982.13 million tons in resources but reports only 0.60 million tons in reserves. Despite its abundant geological potential, the province has yet to convert its findings into economically or legally mineable reserves, likely due to regulatory, economic, or infrastructural limitations.

Gorontalo, West Sumatra, and North Maluku are also noteworthy for their vast resource quantities, standing at 25,533.35, 21,998.46, and 17,016.14 million tons respectively. However, in these cases, reserves remain minimal or unreported. This suggests early-stage exploration or challenges in progressing from geological identification to extractive feasibility.

Banten stands out for having 2,670.30 million tons in reserves and 4,106.49 million tons in resources. This high reserve-to-resource ratio indicates that Banten has not only assessed its deposits thoroughly but also made substantial progress in advancing them to the production-ready stage. Likewise, **East Java** has 6,182.22 million tons of limestone resources, with 762.47 million tons already classified as reserves—highlighting its mature development and importance to national industrial supply chains.

Several provinces in the eastern part of the country, such as **Papua** and **West Papua**, report significant resources—5,559.08 and 315.97 million tons, respectively—but minimal reserves, with West Papua listing only 0.58 million tons. These figures point to untapped potential that could support future regional development if proper investment and infrastructure are put in place.

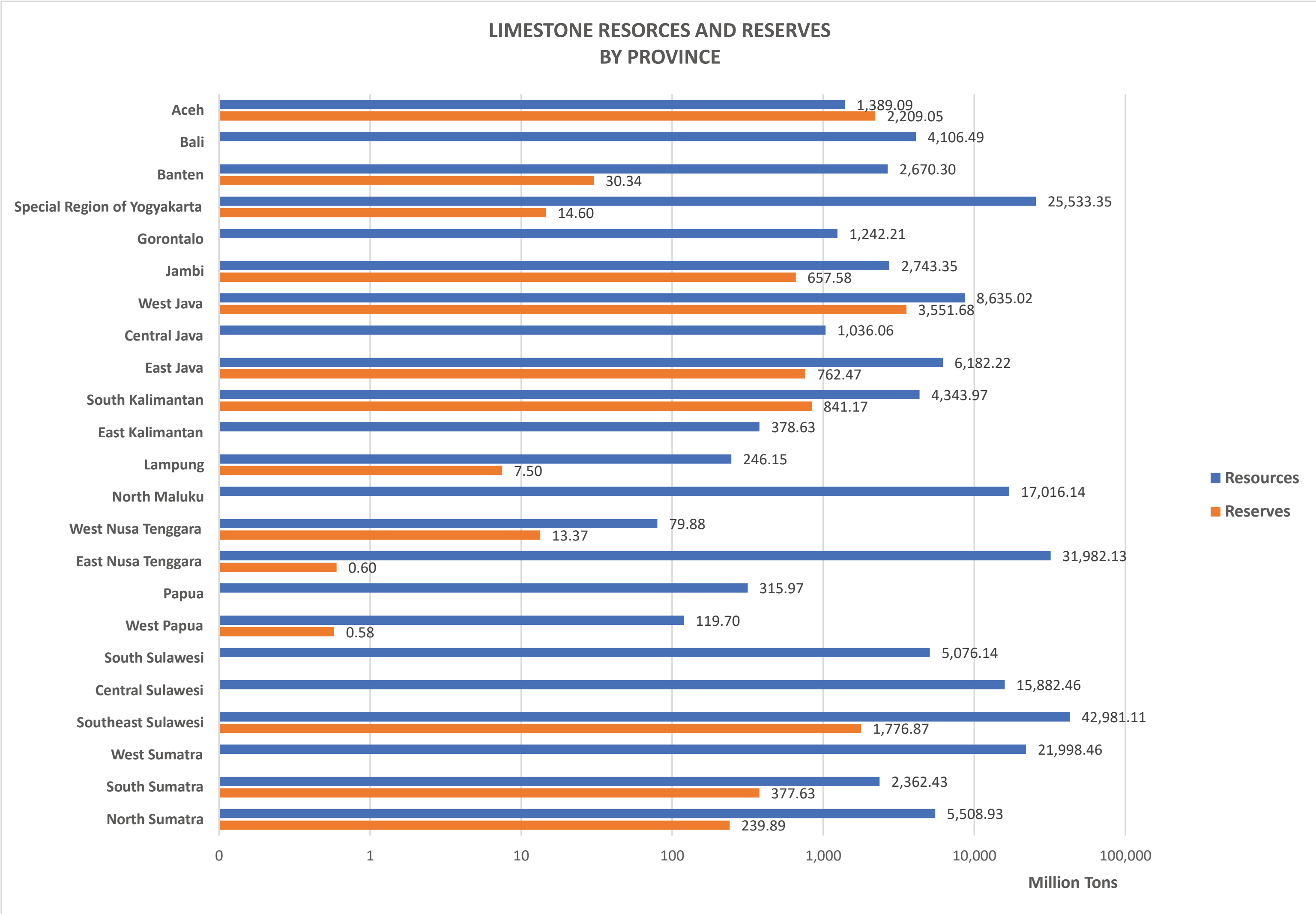

Figure 14.5 Provincial Distribution of Limestone Resources and Reserves in Indonesia (in Million Tons) (Nursahan et al., 2024)

Lampung, East Kalimantan, and Central Java show balanced resource and reserve values, reflecting active mining sectors supported by reliable geological data. In contrast, **Gorontalo**, despite having one of the largest resource volumes nationwide (25,533.35 million tons), lacks any documented reserves, underlining the urgency for development programs or feasibility assessments.

Overall, while Indonesia is richly endowed with limestone deposits across multiple regions, the degree of reserve development varies widely. This pattern underscores the need for enhanced investment in exploration-to-exploitation workflows, better spatial planning, and more comprehensive data integration to transform geological potential into sustainable industrial supply.

Utilization of Processed Limestone in Industry

Processed limestone serves as a critical raw material across a broad spectrum of industries, functioning either as a primary input or a complementary component depending on the application. Its industrial usability is highly dependent on specific chemical and physical requirements, including a high calcium oxide (CaO) content, low concentrations of impurities such as magnesium, aluminum, iron, phosphorus, sulfur, sodium, potassium, and fluorine, as well as minimal mineral contaminants like quartz, pyrite, and marcasite. Additionally, physical parameters—such as brightness, particle size, surface area, and moisture content—must meet stringent industry-specific specifications to ensure performance and compatibility.

Limestone is processed into a variety of industrial products, including quicklime (CaO) and slaked lime ($Ca(OH)_2$), which are essential in steel manufacturing for smelting and refining. The cement industry remains the largest consumer of limestone globally, where it is calcined with clay to produce clinker. Beyond heavy industry, limestone is used in the production of glass, ceramics, silica bricks, paper, rubber, soda ash, and in water purification processes. Additionally, it supports processes like non-ferrous metal ore flotation, sugar refining, and soil conditioning in agriculture.

Among recent innovations is ground calcium carbonate (GCC), produced by mechanically crushing and grinding limestone into fine powders. GCC is now widely used as a filler in paints, plastics, rubber, and especially paper manufacturing. It has become a preferred material for paper coating, meeting stringent brightness and particle size distribution standards. More advanced applications are realized through the production of precipitated calcium carbonate (PCC), which involves a chemical process that yields a purer and finer material than GCC. PCC is increasingly replacing traditional fillers like kaolin in the paper industry, offering better opacity and printability.

Further innovation has led to the development of food-grade PCC, used as a calcium fortifier in food and beverages, and nano-PCC, which enhances paper coating performance while reducing wood pulp consumption. These applications not only demonstrate the adaptability of limestone-derived products but also reflect broader trends in sustainable material use and value-added mineral processing.

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Graphite

Image: Graphite-Bearing Rocks (Schist), Kolaka, Southeast Sulawesi
Courtesy of: Dwiantara, 2022

Graphite is an opaque, gray-black mineral known for its softness (rated 1–2 on the Mohs hardness scale) and metallic luster. It has a greasy feel to the touch, low density (ranging from 2.09 to 2.23 g/cm³), excellent resistance to thermal shock, and high electrical conductivity (Anthony et al., 2003, as cited in Simandl et al., 2015).

Graphite occurs in several distinct forms, classified based on their mode of occurrence and deposit morphology (Yarangga et al,, 2017). The three primary types of graphite deposits are:

Vein Graphite

Vein graphite, also known as lump graphite, contains exceptionally high graphitic carbon content (typically 75–100%). It appears as flaky to flattened crystals with an interlocking texture. Common associated minerals include quartz, pyroxene, feldspar, pyrite, and calcite. Veins can range from a few millimeters to several meters in thickness, with strike lengths extending thousands of feet and dip lengths reaching up to 1,500 feet. The genesis of vein graphite is debated; it is thought to form either from hydrothermal fluids or through pneumatolytic processes associated with magmatic activity.

Amorphous Graphite

Amorphous graphite, formed through coal seam metamorphism, occurs as dense cryptocrystalline aggregates with ~85% carbon content. Its characteristics—carbon purity, texture, and impurities like silicates, carbonates, and sulfides—depend on the original coal quality.

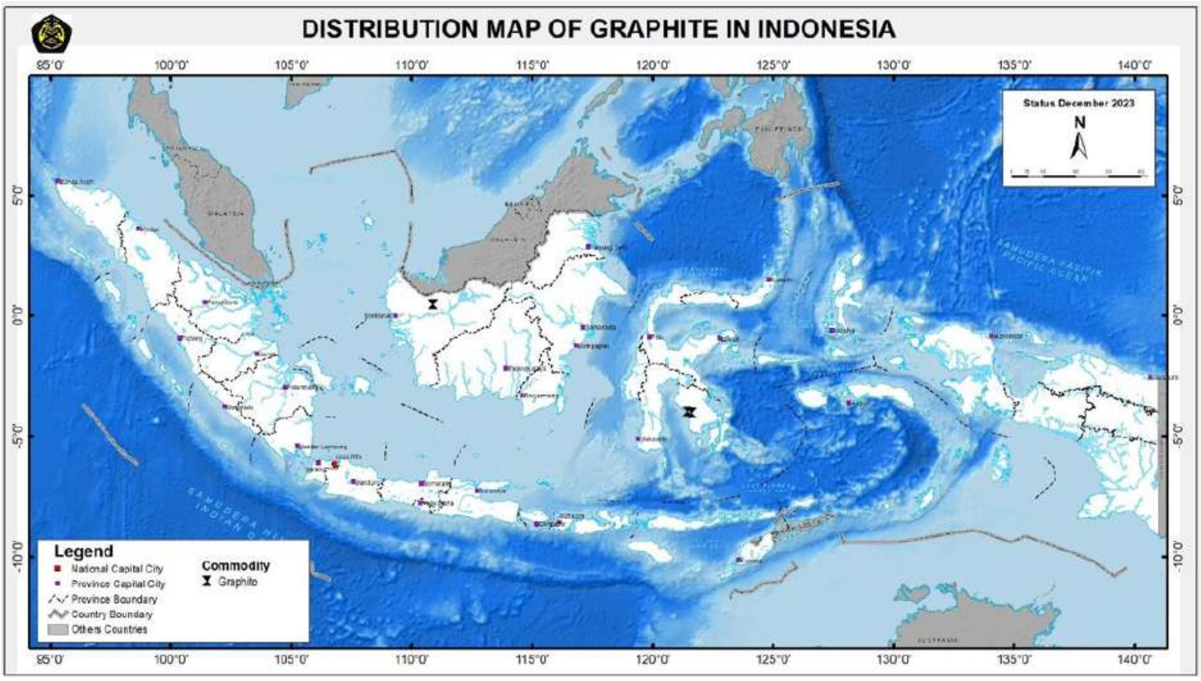

Figure 15.1 Graphite Potential Zones in Indonesia (Nursahan et al., 2024)

Flake Graphite

Flake graphite is formed under high-grade metamorphic conditions, typically during regional metamorphism involving temperatures sufficient for garnet formation. It is found in graphitic metasedimentary rocks such as gneiss and schist. Flake graphite is highly valued for its purity and crystallinity. Carbon content in these deposits is generally high, often exceeding 90%. Impurities include quartz, feldspar, mica, amphibole, and garnet—minerals commonly present in high-grade metamorphic environments. The original sedimentary carbon concentration plays a key role in determining the final graphite content.

Graphite Occurrence in Indonesia

CMCGR has carried out several initiatives to assess the graphite potential in Indonesia. Mapping efforts have been focused on regions with metamorphic rock distribution, particularly in Sanggau Regency, West Kalimantan, and Kolaka Regency, Southeast Sulawesi (Figure 15.1). These areas were identified based on a 2017 CMCGR study that targeted graphite deposits within metasedimentary formations.

In Sanggau Regency, graphite occurs within slate and phyllite units (Dwiantara & Rosdiana, 2021) (Figure 15.2). These rocks are typically black in color, greasy to the touch, weakly foliated, and have a massive yet loose structure. They are soft (with a hardness below 2.5) and electrically conductive. Regionally, these phyllite rocks are part of the Balaisebut Complex (CTrb), which dates back to the Carboniferous–Permian period. The graphite here is likely flake-type, formed through regional metamorphism of carbon-rich sediments.

In contrast, graphite-bearing rocks in Kolaka Regency are dominated by schist (Dwiantara, et al) (Figure 15.3). This schist is characterized by a grayish-black appearance, moderate to strong foliation, micaceous and sheet-like texture, and a layered, easily breakable structure. Like in Sanggau, the hardness is low, and the rock is conductive. Geologically, these schists belong to the Mekongga Complex (Pzm), also assigned to the Carboniferous–Permian age.

Figure 15.2 Metamorphic Rock Outcrop – Phyllite, Sanggau Area. (Dwiantara & Rosdiana, 2021)

Figure 15.3 Exposure of Metamorphic Schist, Kolaka Area. (Dwiantara et al., 2022)

Graphite identification in these areas has been confirmed through petrographic analysis (Figure 15.4), Raman spectroscopy (Figure 15.5), and X-ray diffraction (Figure 15.6). Petrography reveals the presence of carbonaceous material, while Raman spectroscopy detects graphite's characteristic G-band spectra. XRD further confirms the mineral composition and degree of crystallinity, helping distinguish between amorphous and crystalline forms.

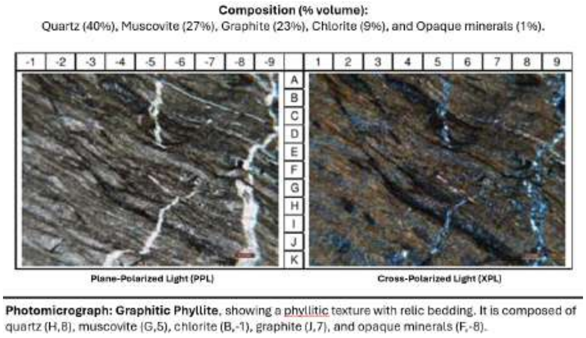

Figure 15.4 Petrographic Characterization of Graphitic Phyllite Samples. (Dwiantara et al., 2022)

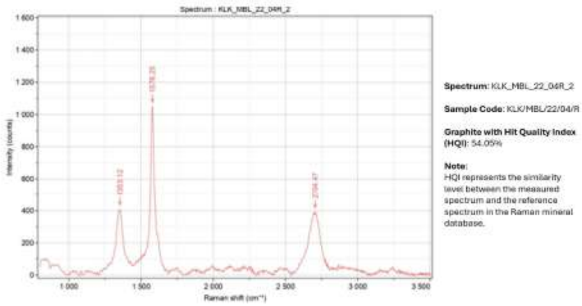

Figure 15.5 Raman Spectroscopic Identification of Graphite in Schist Samples. (Dwiantara et al., 2022)

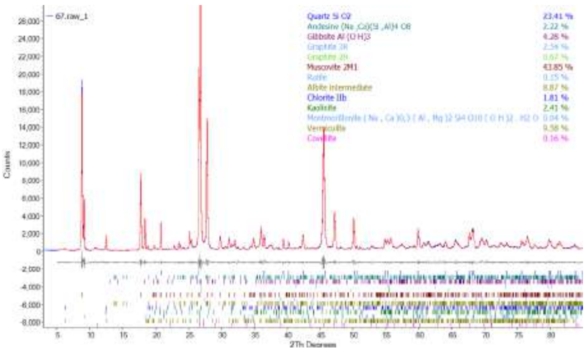

Figure 15.6 X-Ray Diffraction Analysis of Graphite-Hosting Schist Rocks. (Dwiantara et al., 2022)

These investigations form the foundation for evaluating the quality and commercial potential of Indonesia's graphite resources. Further exploration and resource estimation will be essential for advancing these prospects to development stages.

Graphite Resources and Reserves in Indonesia

According to the 2023 Non-Metallic Mineral Resource Inventory published by the CMCGR (Nursahan, 2023), graphite resources in Indonesia have been identified in two primary regions: Sanggau Regency in West Kalimantan Province and Kolaka Regency in Southeast Sulawesi Province. In Sanggau Regency, graphite occurs within metamorphic rocks and is currently classified into two resource categories. The inferred graphite resources are estimated at approximately 17 million tons, while the indicated resources are estimated at around 14.3 million tons. These figures reflect substantial potential for further development, especially in light of the increasing global demand for graphite in industrial applications such as battery production, refractories, and lubricants.

In Kolaka Regency, graphite is also associated with metamorphic formations. The estimated hypothetical graphite resources in this area amount to approximately 23.46 million tons. These resources are still in the early stages of exploration, and further geological and drilling work is necessary to confirm their extent and upgrade them to higher resource categories. Overall, these findings position Indonesia as a country with promising graphite potential, particularly relevant as graphite becomes a critical raw material for the clean energy transition and the growing electric vehicle battery supply chain.

Graphite-Bearing Formations in Sulawesi and Kalimantan: Geological Insights

According to the Decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 296.K/MB.01/MEM.B/2023 on the Determination of Critical Mineral Commodities, graphite is officially classified as a critical mineral. This designation is based on its strategic importance for the national economy, defense, and security, its vulnerability to supply disruptions, and the lack of adequate substitutes.

In response, CMCGR has conducted preliminary evaluations of graphite prospectivity to identify potential graphite-bearing zones across Indonesia. Indonesia's potential for graphite mineralization is primarily concentrated on the islands of **Sulawesi** and **Kalimantan**. Several geological formations on these islands show significant potential based on their lithology, metamorphic history, and structural features (Figure 15.7).

In Sulawesi, graphite is commonly associated with formations that have undergone significant metamorphism. **The Meluhu and Laonti Formations**, dating from the Triassic-Jurassic periods, consist predominantly of sedimentary rocks such as shale and sandstone that may have transformed into graphite-bearing units through regional metamorphism. **The Mekongga Complex**, composed of Paleozoic schist and gneiss, exhibits higher-grade metamorphic characteristics, making it one of the most favorable units for graphite occurrence in the region.

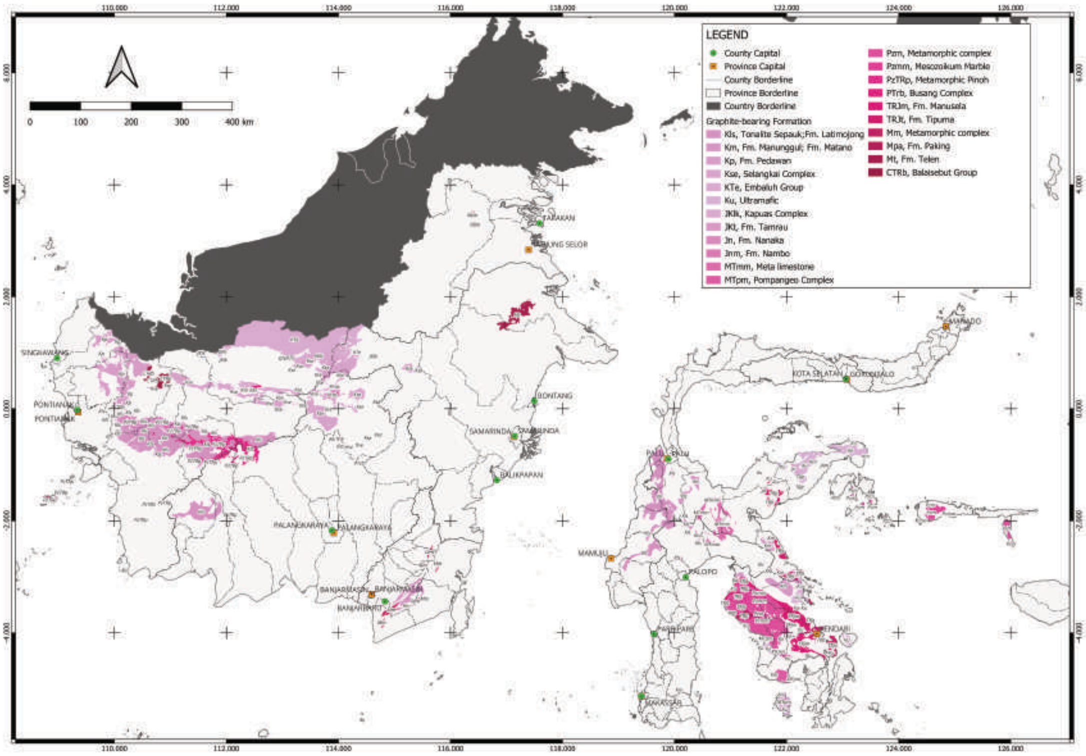

Figure 15.7 Graphite-bearing Formation in Kalimantan and Sulawesi Island Map. (Modified from Dwiantara et al., 2021, 2022)

The Ultramafic Complex and the Matano Complex, while not traditionally graphite-bearing due to their ultrabasic nature, are part of tectonically active belts that may structurally influence the deposition of graphite in adjacent formations. **The Pompangeo Complex**, another Paleozoic metamorphic assemblage, and **the Nanaka and Nambo Formations**, both Jurassic in age, contain fine-grained clastic rocks that have undergone low- to medium-grade metamorphism, potentially resulting in graphite development.

Further evidence of graphite presence is found in **the Metamorphic Limestone unit and the Paleozoic Marble**, where the carbon-rich content of original limestones, when subjected to sufficient metamorphism, may crystallize into graphite. **The Latimojong Formation**, a Cretaceous clastic unit, also shows signs of low-grade metamorphic alteration favorable to graphite formation.

In Kalimantan, a similar geological context is observed. **The Paking, Seminis, and Telen Formations** include Mesozoic and Paleozoic sedimentary sequences, predominantly composed of shale and sandstone. These units, when exposed to regional metamorphism, may develop into phyllite or schist, both of which are commonly graphite-bearing. **The Kapuas, Busang, and Pinoh Complexes** consist of higher-grade metamorphic rocks such as schist and gneiss, suggesting good potential for hosting graphite.

The Balaisebut Group, identified as the host of graphite-bearing phyllite in Sanggau, West Kalimantan, is composed of Carboniferous to Triassic-aged metasedimentary rocks and is one of the key formations under active study. Additional promising formations include the **Pendawan, Semitau, and Selangkai Groups**, as well as the **Embaluh Group**, each consisting of sedimentary units that show metamorphic overprints conducive to graphite formation.

Lastly, **the Garnet-Amphibolite Schist** represents high-grade metamorphic conditions where graphite may form alongside minerals like garnet and amphibole, especially in structurally complex zones.

Understanding the geological framework of these formations is vital for graphite exploration in Indonesia. With the strategic importance of graphite recognized by the Indonesian government—as classified under critical minerals—detailed geological mapping and exploration using geophysical techniques are essential for delineating graphite potential and supporting future mineral development.

Utilization of Graphite

Graphite is a highly versatile industrial mineral known for its excellent thermal stability, electrical conductivity, and chemical inertness. These properties make it essential for a wide range of applications, particularly those involving high temperatures or corrosive environments. One of its most traditional uses is in the manufacture of crucibles and refractory materials for the steel and metallurgical industries, where it withstands extreme heat without melting or degrading.

In the consumer and industrial sectors, graphite is widely used as the core material in pencils, as a dry lubricant in machinery, and as an additive in brake linings and foundry facings. Its role in energy storage has become increasingly important, especially in the production of battery anodes for lithium-ion batteries, which power electric vehicles (EVs), portable electronics, and energy storage systems.

Graphite is also a critical raw material for the production of graphene, a one-atom-thick sheet of carbon known for its extraordinary strength, conductivity, and flexibility, used in cutting-edge applications including electronics, sensors, and composites. In the medical field, pyrolytic carbon, a graphite-like material, is used in the manufacture of artificial heart valves and other biomedical implants due to its biocompatibility.

In nuclear technology, nuclear-grade graphite serves as a moderator and reflector in certain types of reactors, particularly high-temperature gas-cooled reactors (HTGRs). Additionally, due to its thermal resistance and structural integrity, graphite is used in aerospace and defense applications, such as coating the nose cones of missiles, thermal shields, and solid rocket motor nozzles.

The growing importance of graphite in the clean energy transition, advanced materials, and national defense sectors underscores its strategic value and the need for a secure and sustainable supply chain.

Evolving Applications of Graphite in 2024

As the global transition to cleaner technologies accelerates, the demand landscape for both natural and synthetic graphite has shifted significantly in 2024. The pie chart comparison provides insight into the diverse industrial uses of each graphite type, with batteries and electrodes emerging as dominant segments, though with notable differences in application focus (Figure 15.8).

Natural graphite is primarily consumed by the battery industry, commanding 52% of its application share, driven by the booming lithium-ion battery sector. This rise reflects growing demand from electric vehicles and renewable energy storage. Refractories hold the second-largest share at 24%, continuing to be essential in high-temperature industrial processes such as steelmaking. Castings, other industrial uses, friction materials, and lubricants follow with more modest shares, each ranging between 3% to 8%. Recarburising and graphite shapes round out the remainder.

In contrast, synthetic graphite is dominated by electrode production, which takes up 47% of its total use, reflecting its established role in electric arc furnace steelmaking. Batteries also hold a substantial share at 31%, showcasing synthetic graphite's competitive presence in the battery materials market, particularly for its consistency and purity. Other uses include recarburising (8%), graphite shapes (4%), lubricants (3%), and smaller proportions for friction materials, refractories, and castings.

The comparison underscores that while both forms of graphite are integral to battery production, synthetic graphite continues to be indispensable in traditional high-temperature metallurgical processes, especially for electrodes. On the other hand, natural graphite's growing market share in batteries reflects supply chain shifts and resource availability.

As Indonesia enters the graphite value chain with prospects in Kalimantan and Sulawesi, understanding these application trends becomes critical. The country’s development strategy must align with the growing dominance of battery-related uses while exploring the potential to serve traditional graphite markets.

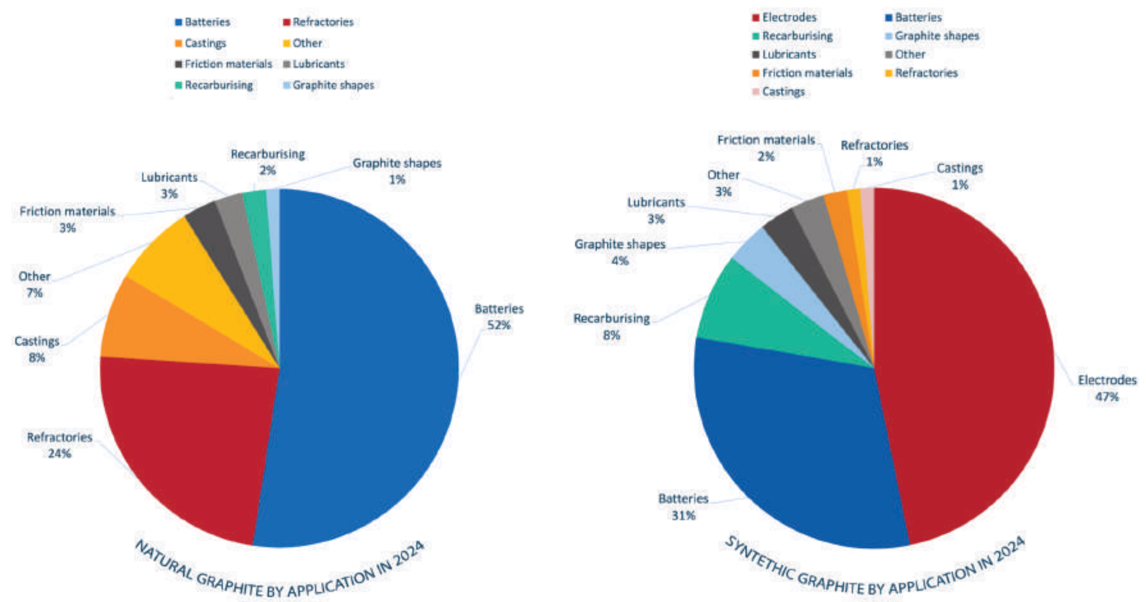

Figure 15.8 Global Applications of Natural vs Synthetic Graphite in 2024 (European Carbon and Graphite Association, 2024)

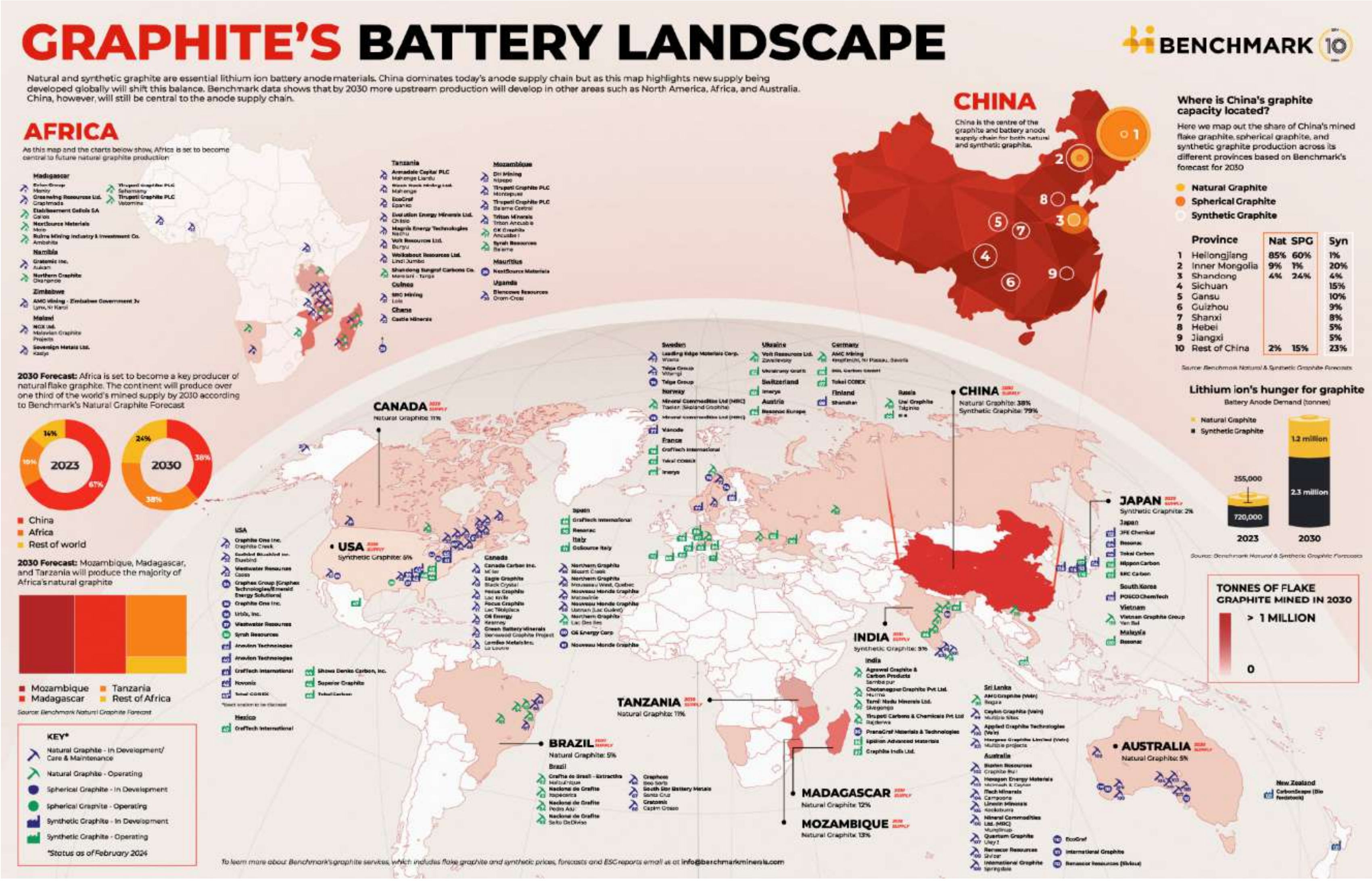

Figure 15.9 Global Graphite Supply Chain Shift Map (2030 Outlook) (Benchmark Mineral Intelligence, 2024)

Graphite's Global Supply Shift: From Chinese Dominance to Global Diversification

Graphite, a key component of lithium-ion battery anodes, plays a critical role in the rapidly expanding electric vehicle (EV) and energy storage industries. While China currently dominates both natural and synthetic graphite production, the global supply chain is undergoing a significant transformation. By 2030, new sources of graphite are expected to emerge in Africa, North America, and Australia, reshaping the geopolitical and economic landscape of this essential mineral (Figure 15.9).

As of 2023, China accounts for the overwhelming majority of the world's mined graphite and nearly all of its spherical and synthetic graphite production. The provinces of Heilongjiang, Shandong, and Inner Mongolia are at the forefront of China's graphite industry. Heilongjiang alone contributes more than half of China's mined graphite. However, concerns over supply security have been amplified by recent Chinese export restrictions, pushing global stakeholders to seek alternative sources.

Africa is fast becoming the most promising region for graphite diversification. The continent's graphite production is forecast to rise from 19% of the global total in 2023 to 38% by 2030. This surge is largely driven by Mozambique, Madagascar, and Tanzania. Mozambique is already an established player, with multiple operational and upcoming graphite projects. Madagascar offers high-purity graphite and is scaling up its production capacity that shown impressive growth with an 18% CAGR in graphite production from 2017 to 2022 (Mining Technology, 2024), while Tanzania is advancing several major graphite developments that will soon come online.

In North America and Europe, efforts are intensifying to build resilient graphite supply chains. The United States is expanding its synthetic graphite capabilities and investing in new processing facilities, Novonix is establishing a major synthetic graphite plant in Tennessee with federal backing. The facility is projected to generate sufficient graphite by 2028 to meet the annual needs of approximately 325,000 electric vehicles once it reaches full operational capacity (Financial Times, 2024). Canada, rich in mineral resources, is developing both natural and synthetic graphite projects with government and private sector backing, Vianode, for instance, plans to produce approximately 80,000 tonnes of synthetic graphite annually, sufficient to supply around 1.5 million electric vehicles per year. Production is expected to commence in 2027, following a multi-year agreement with General Motors to supply synthetic graphite for EV batteries produced by Ultium Cells, a joint venture between GM and LG Energy Solution (Reuters, 2025). In Europe, countries like Germany, Sweden, Norway, and Ukraine, are pursuing domestic graphite production as part of broader strategies to ensure secure access to critical raw materials.

The growing urgency for diversified graphite supply is driven by surging demand. Benchmark Mineral Intelligence projects that synthetic graphite demand for batteries will exceed 2.3 million tonnes by 2030, up from 720,000 tonnes in 2023. Natural graphite demand is expected to grow in parallel, reaching 1.2 million tonnes. This sharp increase is primarily fueled by the global shift toward electric mobility and the rise of stationary battery systems.

As countries race to secure graphite for their energy transitions, the global supply network is evolving. China will remain an essential player, but by 2030, its share of supply is expected to decline as new production hubs emerge. Africa, with its rapidly expanding graphite sector, will become a cornerstone of the global battery materials market. Meanwhile, North America and Europe are laying the groundwork for more self-sufficient and secure supply systems.

This transformation is not merely a reaction to market forces but a proactive reshaping of industrial strategies in the face of geopolitical uncertainty and environmental responsibility. With graphite set to become one of the most strategically important minerals of the decade, countries that adapt early and invest in resilient, diversified supply chains will gain a crucial edge in the clean energy future.

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