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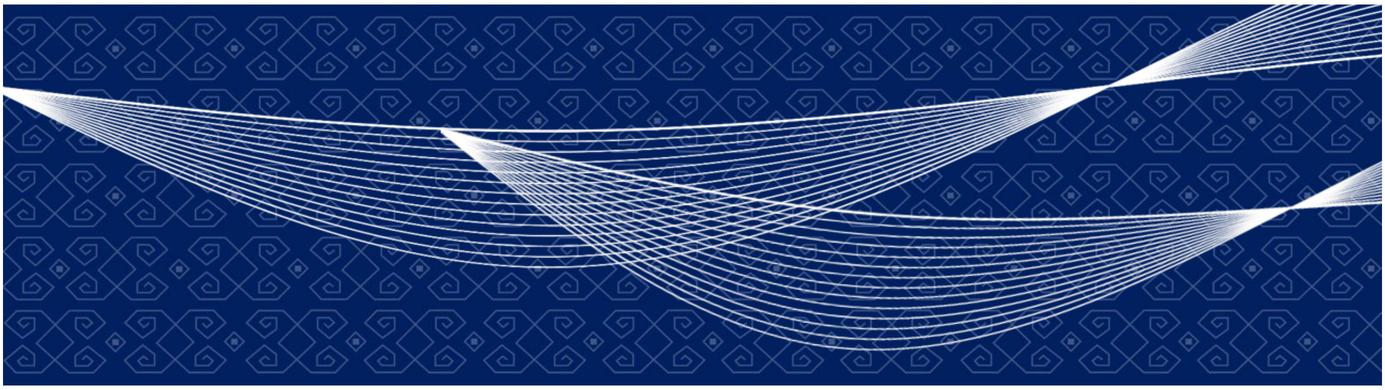

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WORKING PAPER

CRITICAL MINERALS INDUSTRIES IN INDONESIA: A FIRM-LEVEL PERSPECTIVE

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Abstract

This research provides a new perspective on developing Indonesia's critical mineral industry ecosystem from the standpoint of business practitioners and experts. Despite Indonesia's significant potential in critical mineral resources, the success of downstream development is determined by how well the upstream and downstream ecosystems can be strengthened. This includes improving raw material and material efficiency, building a strategic position in the global value chain, ensuring long-term supply sustainability, stimulating local demand, prioritizing the use of green energy, enhancing effective hazardous waste management, and addressing social issues in mining and processing areas. The analysis of Net Present Value (NPV) and Internal Rate of Return (IRR) in nickel downstream development indicates that, although substantial investment is required, a quicker return on investment can be achieved through technological changes, such as adopting pyrometallurgy. The NPV and IRR evaluation in copper downstream development demonstrates the economic feasibility of processing copper concentrate, showing significant profitability. The copper industry continues to grow with added value in the value chain, highlighting the economic benefits of copper downstream development. The prospects for downstream development of bauxite and aluminum are also promising. Based on NPV results, brownfield projects appear more economically viable than greenfield projects. Thus, the downstream development of critical minerals in Indonesia necessitates collaboration between the private sector (national and global) and the government to balance economic, social, and environmental objectives.

Keywords: critical minerals, downstream, firm-level, value-added

JEL Classifications: L72, O13, Q32

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1. Introduction

1.1. Background

In line with the development of the green economy concept in various parts of the world, multiple breakthroughs have been made to use environmentally friendly energy sources. One of the ways to develop energy sources is by using critical minerals. Critical minerals are a group of future minerals that can be utilized for technological innovation based on clean and renewable energy (IEA, 2022). These minerals are said to be critical because their availability is increasingly limited. However, society's demand for mineral resources increases yearly (Qurbani et al., 2021). The Paris Climate Agreement (2015) has provided a legal basis for countries. To develop a low-carbon economy. Although the amount of critical minerals is limited, the function of critical minerals is limited and necessary to promote world development (US Geological Survey, 2020).

Indonesia is one of the countries with very high potential reserves of critical minerals. It holds the top position in nickel production, contributing 36% to global nickel production in 2022 (OECD, 2023). Additionally, Indonesia actively contributes about 39% to global gold production, ranking second after China (World Bank, 2021). This makes Indonesia one of the top 10 mineral producers in the world. However, the utilization of these resources in Indonesia is not yet optimal (ESDM, 2021). This is attributed to the mining sector's role, often viewed as a commodity for national income, resulting in suboptimal, inclusive, and sustainable use of critical minerals. Most mining companies still focus on extracting and exporting low-value raw ore or minerals (Yasin et al., 2021), with a significant portion designated for export. Consequently, the government has taken policy renewal steps through Law Number 3 of 2020 regarding Minerals and Coal to regulate mineral management in Indonesia (Government of Indonesia, 2020). However, implementing the Minerba Law faces various challenges, including legal demands from the European Union concerning the ongoing ban on nickel ore exports at the World Trade Organization (WTO) (European Commission, 2022).

Downstream development strategies have yielded positive results, with increased exports of high-value-added products supporting a larger role in Renewable Energy (RE) (ESDM, 2021). Downstream efforts have also positively impacted Indonesia's export profile toward the medium-high tech manufacturers category. Furthermore, the downstream development of critical minerals, such as nickel, has progressed rapidly. Implementing the nickel ore export ban has successfully driven the export of high-value-added nickel ore derivative products (BPS, 2022). Therefore, the development of the critical mineral industry in Indonesia needs to be maximized for the benefit of the Indonesian people and to escape the middle-income trap.

On the other hand, the mining industry presents several issues that need attention, including significant environmental impacts and sustainability challenges (Rajaeifar et al., 2022). Hence, research focusing on the perspectives of business practitioners and experts is needed to provide deeper insights into how these companies manage operations, create economic, environmental, and social impacts, and address the complexity of sustainability aspects (Amoah and Eweje, 2023). Substantial research on downstream development has been conducted in several countries globally, such as the United States, Japan, the European Union, the United Kingdom, India, and Brazil (Giese, 2022).

The above studies show limited literature on critical minerals from the perspective of companies in developing countries. It highlights how companies complete the entire value chain of critical mineral industries and their impact on company operations and social and environmental responsibilities. Similarly, research exploring downstream development focusing on critical minerals, especially nickel, copper, and aluminum, is not extensive. Therefore, starting from the viewpoint that resource-rich countries may experience low growth and lag countries with limited natural resources (resource-poor), it is crucial for Indonesia not to fall into the resource curse trap.

Based on this, Coxhead (2007) identified four key elements that must be strengthened to prevent the resource curse trap. First, natural resource expansion should not disrupt the growth of manufacturing industries. Competition related to labor, capital, and non-trade sectors can disrupt the dynamics of potential economic growth. Second, natural resource exploitation can reduce the return on human resource investments and erode incentives related to educational achievements. Low-quality education can interfere with the ability to enter the manufacturing phase with higher diversity and quality. Third, dependence on natural resources will disrupt the "developmental state" mentality and, conversely, promote the growth of the "predatory state." This will worsen policy and administrative efficiency. Fourth, commodity booms will suppress the non-resource tradable sector. On the other hand, significant dependence on resource exports will cause greater vulnerability through commodity price volatility. Thus, if simplified, these four arguments suggest four key factors that must be strengthened for a resource-rich country to enhance its competitiveness and make its natural resources provide justice and prosperity: manufacturing, human capital, regulatory, and non-resource sectors. These key factors will deepen understanding and contribute to exploring the impact of the downstream development of critical minerals in Indonesia.

This research also analyzes value addition to identify where value creation occurs along the value chain. The urgency of this value-addition analysis is related to the projection of incremental value for various parts of the value chain, requiring market prices for semi-finished and finished goods (Besanko et al., 2013). Value addition analysis techniques provide a better understanding of the stages of downstream development and the value that can be created from each value chain (Buchholz, 2022). With a deeper understanding of the costs involved in processing critical minerals, companies, and governments can make more informed and effective decisions in designing policies, business strategies, and investments that support the downstream development of critical minerals (Hine et al., 2022).

1.2. Research Objectives

This research has several objectives, including analyzing the economic impact of downstreaming minerals in Indonesia, both from the perspective of domestic stakeholders' readiness for downstreaming (producers) and absorption (consumers). Additionally, the study aims to analyze the mapping of pathways for the downstream development of various minerals in Indonesia. Furthermore, the research assesses the potential reinforcement of downstreaming in Indonesia by examining four dimensions: manufacturing, human capital, regulatory, and non-resource sectors.

2. Literature Review

In order to become a developed country, Indonesia needs a strong manufacturing industry structure with high added value. This will also help to achieve a healthy and stable current account balance. Developing high-value-added industries will help Indonesia enter a better global value chain structure. The ideal condition is if the industries developed fall into the category of green industries or industries with controlled and minor environmental impacts and risks.

Table 1. List of raw materials for green technology

Material	Li-ion battery	Fuels cells	Wind energy	Electric traction motors	Photo-voltaic	Number of technologies
Aluminum	x	x	x	x	x	5
Copper	x	x	x	x	x	5
Iron ore	x	x	x	x	x	5
Borates		x	x	x	x	4
Germanium and other	x	x	x		x	4
Cobalt	x	x	x			3
Rare earth elements	x	x	x	x		3
Lead	x		x		x	3
Manganese	x	x	x			3
Molybdenum		x	x		x	3
Nickel	x	x			x	3
Chromium		x	x			2
Lithium	x	x				2
Natural graphite	x	x				2
Selenium	x	x				2
Silver		x			x	2
Tin	x				x	2
Titanium	x	x				2
Arsenic		x				1
Cadmium					x	1
Gold		x				1
Magnesium		x				1
Palladium and platinum		x				1
Phosphorus	x					1
Zinc					x	1
Zirconium		x				1
Iron ore and steel products**			x		x	

Source: Kowalski and Legendre (2023)

Dallas et al. (2021) define critical minerals as essential and subject to high-risk conditions (in secure supply). This high risk is related to supply chain risks that threaten production due to various economic, social, geopolitical, and geological factors. Similarly, Dou et al. (2023) provide a similar definition of the risks that characterize critical minerals due to geopolitical threats, development inequalities, growing nationalism over natural resources, and the impacts of mining on ecology, the environment, and human rights.

In the context of the three largest mineral producers and owners of mineral reserves in 2019, according to Kowalski and Legendre (2023), for nickel production, Indonesia ranks first in the world with a share of 31.6%, followed by the Philippines 12%, and Russia 8.3%. Meanwhile, in terms of nickel reserves, Indonesia's position is 23.6%, Australia’s 21.3%, and Brazil's 12.4%. Furthermore, Indonesia has an essential position in tin production and reserves. In terms of production, China ranks first (27.8%), followed by Indonesia (25.1%) and Myanmar (16.2). Meanwhile, in terms of tin reserves, China (23.4%), Indonesia (17%), and Australia (7.9%) are ranked first to third.

Dou et al. (2023) state that the sustainable availability of critical minerals urgently requires a global governance system to secure various interest groups' interests. A sustainable and equitable supply of minerals is essential in achieving the Sustainable Development Goals (SDGs). Meanwhile, the global economy lacks consensus on many issues, and mutual trust and cooperation are declining. A global agreement for the supply of critical minerals based on the SDGs is essential to support the stability of the critical minerals needed to decarbonize economies and transition to net zero emissions. Developing and utilizing critical minerals will involve many countries, and they need these materials to achieve SDG targets, especially those related to climate change. Similarly, McNulty and Jowitt (2021) note the importance of the knowledge base to ensure a safer supply of critical minerals, most of which will experience increased demand driven by efforts to mitigate anthropogenic climate change and CO2 emissions.

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Developing and utilizing critical minerals will involve many countries, and they need these materials to achieve SDG targets, especially those related to climate change. This is in line with McNulty and Jowitt (2021), who noted the importance of a knowledge base to ensure a safer supply of critical minerals, most of which will experience increased demand driven by efforts to mitigate anthropogenic climate change and CO2 emissions.

For Indonesia, the development and utilization of upstream natural resources through the critical minerals pathway offer two major advantages. First, it creates opportunities for the growth of new industries (green technology) based on high-tech products and processes, such as battery technology, solar panels, fuel cells, wind turbines, and electric vehicles. Second, it opens up greater potential for

Table 2. Mining companies and mineral-producing countries EV

Mineral (ores and concentrates)	Top 5 mining companies based on 2019 production output and their home countries	Top 5 largest producing countries (based on USD value, 2019)
Nickel	Vale (Brazil), Norilsk Nickel (Russia), Jinchuan (China), Glencore (UK/Swiss), BHP Billiton (Australia/UK)	Indonesia, Philippines, Canada, Russian Federation, New Caledonia
Aluminum	Chinalco (China), Hongqiao (China), UC Rusal (Russia), Rio Tinto (UK/Australia), Emirates Global Aluminum (UAE)	Australia, Guinea, Brazil, Indonesia, Jamaica
Copper	Freeport-McMoran (US), Codelco (Chile), BHP Billiton (Australia/UK), Glencore (UK/ Swiss), Southern Copper (Mexico)	Chile, Peru, Australia, Indonesia, Canada

Note: Several minerals are needed to support the EV industry, namely Graphite, Cobalt, Nickel, Manganese, Aluminum, Copper, Lithium, and Rare earth.
Source: Dominish et al. (2019)

achieving low-carbon economic development in line with the Paris Agreement COP21. Dallas et al. (2021) identify eight minerals and mineral groups critical for renewable energy and energy storage technologies: Lithium, Gallium, Selenium, Silver, Indium, Tellurium, Rare Earth Elements, and Platinum.

Considering the context of electric vehicles, Indonesia is the fifth largest supplier of nickel, aluminum, and copper. This indicates that Indonesia's position is very important in the global value chain for electric vehicle production. The current challenge is how Indonesia can build downstream industries that add greater value to these natural resources. The development of electric vehicles requires the support of seven critical minerals, namely natural graphite, lithium, cobalt, and rare earth elements such as dysprosium, terbium, praseodymium, and neodymium (Ballinger et al., 2019). In this case, Indonesia needs to cooperate with many countries. From the study results, Srivastava (2023) found a need to study the impact of emerging bilateral and regional agreements and collaborative arrangements to access critical minerals for the energy transition.

The study by Fikru and Awuah-Offei (2022) makes three points: (i) production of critical minerals can be expanded by investing in technically efficient technologies and technologies with increasing returns to scale; (ii) regulations that require companies to process a certain percentage of geological inputs to recover critical minerals will have unintended consequences such as an increase in the marginal cost of producing critical minerals; and (iii) the elasticity of supply of critical minerals depends on the returns to scale of production.

Furthermore, Dallas et al. (2021) assert that sustaining the supply of critical minerals necessitates a combination of extraterrestrial resources and effective recycling of terrestrial resources from end-of-life products, where it is technologically and economically feasible. Potential future innovations could result in the development of less resource-intensive renewable energy generation and storage technologies and an increased utilization of low-risk minerals, potentially alleviating some of the environmental, social, and scarcity challenges.

Simultaneously, advancements in the space industry may continue reducing the costs associated with space travel, rendering space object mining an increasingly attractive prospect.

Some argue that the growing demand for critical minerals is intricately linked to efforts to recover green after the COVID-19 pandemic. The need for minerals is expected to persist in line with changes in behavior and consumption stemming from the COVID-19 pandemic (Giese, 2022). Giese (2022) emphasizes that optimizing the utilization of critical minerals necessitates industrial design and scientific strategies. It is imperative to fortify the critical minerals value chain and assume a role as an industrial hub rather than merely serving as a supplier of raw materials.

Amidst the rising demand for critical minerals, it is also essential to consider the dimension of justice. Qurbani et al. (2021) examined the development of critical minerals through the lens of "justice," which encompasses principles of fairness, quality, and equity. In their analysis, Qurbani et al. (2021) applied a just framework comprising five critical elements, as Heffron and McCauley (2017) established in the energy life cycle. These five aspects include distributive justice, procedural justice, recognition justice, cosmopolitanism justice, and restorative justice.

Qurbani et al. (2021) provided four crucial notes from their study. Firstly, critical minerals have high strategic value and, therefore, need to be managed to provide maximum benefits for the welfare of society. Second, Indonesia needs to consider establishing regulations related to critical minerals. Third, it is necessary to consider the establishment of regulations related to the law on the protection of indigenous peoples and state property funds. Fourth, pay attention to China, which needs a lot of critical minerals to achieve its low-carbon economy ambitions in 2050 and 2060.

The utilization of critical minerals has also become an area of public concern. Heffron (2020) reviewed the non-sciences literature and categorized critical minerals into three focuses: building a critical minerals business, increasing demand, and increasing financing. Agusdinata and Liu (2023) showed that the results of a media review related to the development of critical minerals for electric vehicle development have expanded to other issues such as customary rights, access to material and non-material resources, social benefits, and conflict.

Furthermore, Dominish et al. (2019) revealed the environmental degradation of freshwater and marine ecosystems due to nickel mining. Most impacts can be categorized into community land conflicts, livelihood disruptions, access to water, air quality, and health. Based on information from the Environmental Justice Atlas, it is known that the development of copper, nickel, and manganese has had an impact on the local indigenous population viz: Amungme and Kamoro people, Karonsi'e Dongi people, and Manggarai people.

Dominish et al. (2019) argued that the positioning of each critical mineral presents distinct sustainability challenges. Nevertheless, three factors require attention: (i) the availability and characteristics of extraction and processing, (ii) the socioeconomic and environmental conditions surrounding the mining site, and (iii) the geopolitical context within the supply chain of minerals, batteries, and EVs (Conde and Le Billon, 2017).

Sachs and Warner (2001) found a negative relationship between GDP growth rates and natural resource wealth for a sample of large countries. According to Coxhead (2006), four key factors must be considered to succeed in downstream implementation: (i) the manufacturing sector must grow along with downstream development. This is necessary to maximize value-added and growth of the manufacturing sector, (ii) investment in human capital also needs to be increased in line with the implementation of downstream, (iii) regulation plays an essential role in this context, especially in the political economy related to the role of government and local government in supporting downstream policies; and (iv) non-natural resource sectors must also receive sufficient attention in downstream development. This is important to prevent shrinkage of the non-natural resource sector as downstream implementation progresses.

By considering the results of previous studies, the development and utilization will always be related to five essential elements: (i) high risk, (ii) the final product requires a mixture of various elements, (iii) requires green industry support (downstream), (iv) requires collaboration from many countries, and (v) social and environmental impacts that need attention. It is essential to explore these five elements on a micro level from a firm perspective (bottom-up approach) to understand their characteristics based on the type of minerals (supporting minerals downstream for developing end products such as EVs) to be selected. Indonesia cannot work alone in developing an industry based on critical minerals. This industry is part of a global production network supported by capital and evolving technological capabilities.

3. Methodology

The research will be limited to three types of minerals: nickel, copper, and aluminum-bauxite. The other two critical minerals, tin, and gold, are not included in this study due to considerations such as gold being a precious metal. The primary reason for choosing nickel, aluminum, and copper is that all three are minerals owned by Indonesia with a strong global position. According to OECD (2023), Indonesia holds the top position in nickel production, contributing 36% to global nickel production. It ranks sixth globally in copper production and fifth in bauxite production as of 2022. Therefore, downstream development of these three minerals can play a significant role in Indonesia's future economy.

The data used in the research consists of primary and secondary data. Primary data will be obtained through Focus Group Discussions (FGD), in-depth interviews, and field surveys. The field survey locations will include case studies in East Java, one of Indonesia's provinces that produces critical minerals such as nickel, copper, and aluminum-bauxite. Secondary data required for the research includes prices of semi-finished minerals (before processing) and prices of processed minerals.

The data used were primary data and secondary data. Primary data were obtained through Focus Group Discussions (FGDs), in-depth interviews, and field surveys. The location of the field survey is a case study in one of the selected provinces, the largest producer of critical minerals in Indonesia (nickel, copper, and aluminum-bauxite). The secondary data required in the research are the price of semi-finished minerals (before processing) and the price of minerals after processing.

This research uses a mixed method approach through qualitative and quantitative approaches. The qualitative approach is directed at understanding the existence of the four types of minerals in five contexts: risk, mixed elements, green industry, collaboration between countries, and social and environmental impacts. Through in-depth interviews, observations, and FGDs, information related to these five contexts will be extracted. Keywords in positive and negative terms will be analyzed and presented narratively and visually through tables and graphs.

Through a qualitative approach, a consonance analysis will be conducted to see the prospects of the firm to continue to create value, namely how the primary economic foundation of the business tends to develop (Rumelt, 1980). Meanwhile, the firm's ability to create value will be affected by changes in market demand, technological changes, and threats from other companies in the industry and other industries. These matters will be explored in a qualitative approach.

The quantitative approach was conducted using value-added analysis. Besanko et al. (2013) stated that value-added analysis is a tool to identify where value creation occurs along the value chain. Market prices of intermediate and finished goods are required to estimate the incremental value for parts of the value chain.

Using value-added analysis techniques, a better picture of the downstream stages and the value that can be created from each value chain can be obtained. According to Arief (2022), added value generally is not merely the ratio between the price of the product and the price of raw materials. Taking the case of matte, the added value created is not the ratio between the matte concentrate and the price of nickel ore but the ratio between the price of matte and all the cost components involved in the production of matte, which requires at least 72 tonnes of nickel ore with a Ni content of 80% and requires electricity, coal, carbon electrode, and other costs.

Table 3 shows the general template that will be developed. Specific templates will be created for each mineral. These specific templates are prepared from the qualitative findings and literature studies. Based on the information from Table 3, Net Present Value (NPV), Internal Rate of Return (IRR), and payback period for each

Table 3. Standard template - value-added analysis

Stage - Macro	**Stage - Micro**	**Technology Option**	**Investment cost**	**Main Product**	**Sub Product**	**Input Cost**	**Selling price main product**	**Selling price sub-product**
Upstream	Ore mining							
	Core Processing							
Midstream	Further Processing (Intermediate Products)							
Down Stream	Advance processing (Refining)							
	High end processing (End Product)							

End Industry	End user (Application)							

value chain will be calculated. Subsequently, a descriptive quantitative cost and benefit analysis will be conducted using a mixed approach, combining the findings from the qualitative approach and value-added analysis.

NPV is a method that measures the difference between the present value of cash inflows and outflows from a project or investment using a specific discount rate. NPV is used to assess whether the project generates profit or loss and the magnitude of its net profit. If the NPV is positive, it indicates that the project can generate a worthwhile profit, while a negative NPV suggests that the project may not be profitable. NPV is employed to aid in investment decision-making. The basic information used for financial feasibility analysis is obtained from the book 'Grand Strategy for Minerals and Coal' published by the Directorate General of Minerals and Coal in 2021. However, not all fundamental information related to investment costs and technology is adequately available. Therefore, a uniform standard for the analysis of the three critical minerals cannot be applied.

On the other hand, IRR represents the rate of return obtained from the investment. If the project's IRR exceeds the discount rate used in NPV calculations, the project is considered profitable. In this study, NPV and IRR are calculated based on the adjusted net cash flows until achieving a positive NPV. The analysis uses a discount rate of 10%, representing the investment interest rate. Information on parameters for calculating NPV, IRR, and other details is sourced from the Ministry of Energy and Mineral Resources (ESDM, 2021). The NPV and IRR equations refer to Magni and Marchioni (2020) and Zhang et al. (2023), with the NPV equation as follows:

$$NPV = \sum_{t=1}^{n} \frac{cf_t}{(1+r)^t} \tag{1}$$

where:
cf_t = cash flow in each period
n = number of cash flows
t = time for each cash flow
r = project discount rate

IRR represents the profitability of a project expressed in the periodic compounded interest rate, based on cash flows for the same period, as per the equation:

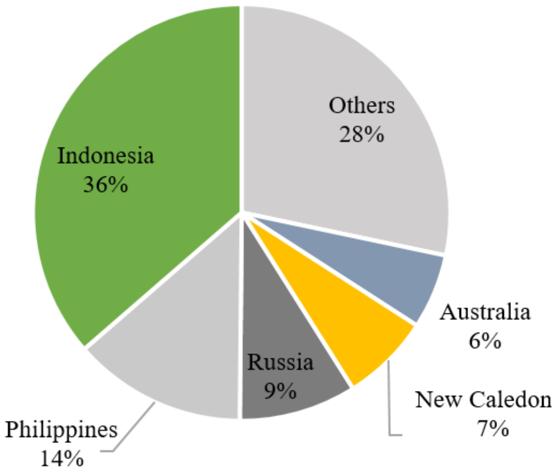
$$0 = NPV = \sum_{t=1}^{n} \frac{cf_t}{(1+IRR)^t} - cf0 \tag{2}$$

where:
$cf0$ = cash flow in period 0
cf_t = cash flow in each period
n = number of cash flows
t = time for each cash flow
r = project discount rate

4. Results / Analysis

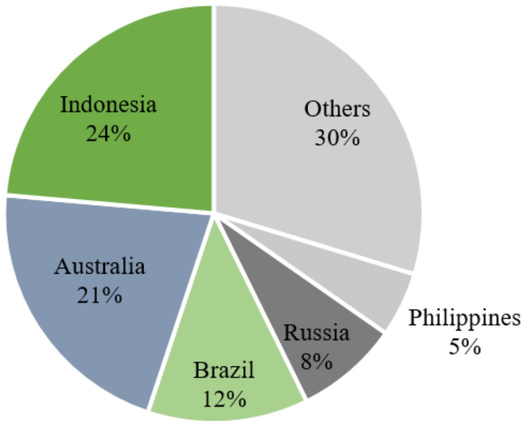
4.1. Nickel Value Added

In the context of shares of the top 3 producers and reserve holders of selected critical raw materials in 2022, it is known that Indonesia holds the first position globally in nickel production with a production of 1.6 million metric tons, accounting for 36% of the world's total nickel production. Following Indonesia, the Philippines holds the second position with 14%, and Russia with 8.3% (Figure 1). On the other hand, regarding nickel reserves, Indonesia holds the top position with 23.6%, followed by Australia with 21.3%, and Brazil with 12.4% (Figure 2). With this dominant share in nickel production and reserves, Indonesia has a strong foundation to develop a more sustainable and high-value-added manufacturing sector.



Source: OECD (2022)

Figure 1. Global nickel production



Source: OECD (2022)

Figure 2. Global nickel mining reserves

In its efforts to become an advanced nation, Indonesia requires a strong manufacturing industry structure with high-added value. This will also aid in achieving a healthy and stable current account balance. Building a high-value-added industry will further assist Indonesia in integrating into a more favourable position within the global value chain. Figure 3 shows that nickel plays a key role as a vital component in battery industry development. The downstream efforts to enhance added value, focusing on developing the industrial ecosystem, are crucial in achieving this goal. The ideal condition is when the developed industry falls into the category of green industry or has controlled and minimal environmental impact, as reflected in recycling efforts, particularly in the later stages of value creation.

The nickel industry involves a crucial upstream process chain in producing various nickel products. In the upstream stage, nickel is obtained by extracting two main types of ore: saprolite and limonite. Saprolite ore undergoes the pyrometallurgical RKEF (Rotary Kiln Electric Furnace) process, resulting in nickel pig ore, ferro nickel, and nickel matte. Meanwhile, limonite ore is subjected to the hydrometallurgical HPAL (High-Pressure Acid Leaching) process to produce products like nickel matte, often used in specific industrial applications.

This upstream-downstream process chain reflects the complexity of the nickel industry and underscores the importance of efficiency in managing these resources from the extraction stage to the final products (Table 4).

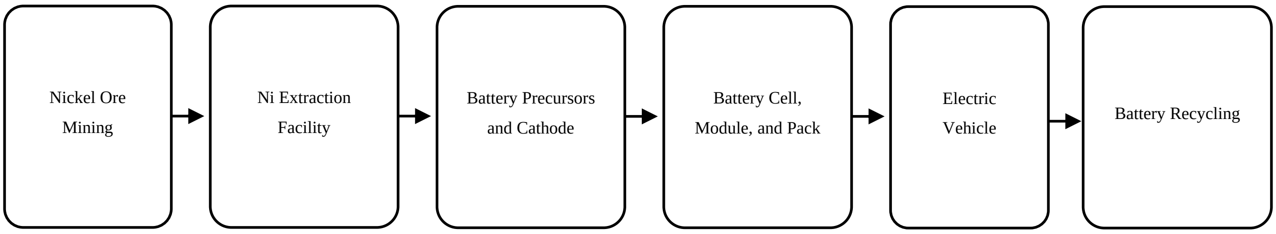


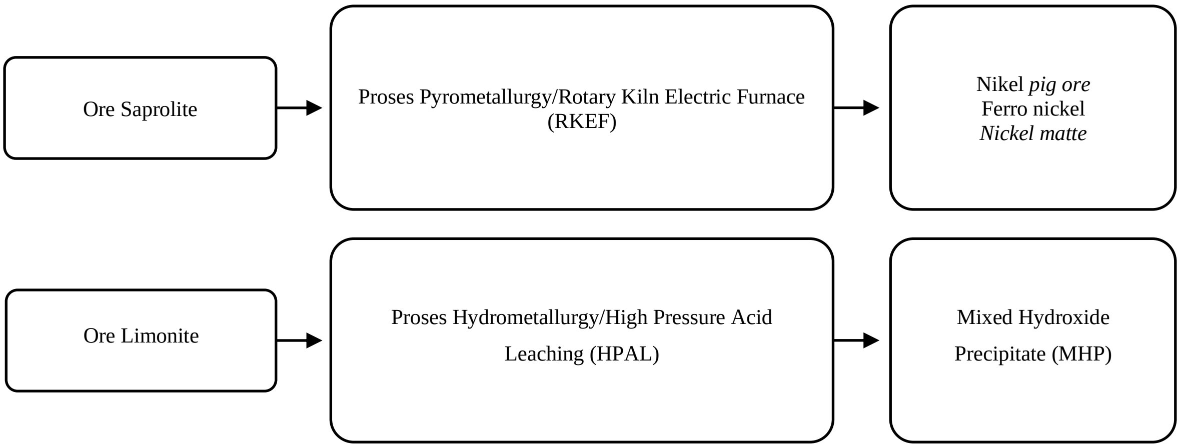
Figure 3. The development of the value chain for batteries

Table 4. Overview of resources, technologies, processes, products, and nickel content

Type	Process	System/ Technology	Product	Nickel contents	Company
Saprolite/ high grade nickel/ low iron content/ 1,5%-3% nickel contents	Pyrometalurgy	*Rotary Kiln Electric Furnance* (RKEF)	Ferronickel (FeNi)	78%	Company A
			Nickel Matte	20%	Company B
			Nickel Pig Iron (NPI)	< 16%	Company C
Limonite/ low grade nickel/ 0.8%-1.5% nickel grade	Hydrometallurgy	*High Pressure Acid Leaching* (HPAL) / suitable for low MgO content	Nickel sulphide/nickel hydroxide / metal material nickel based/ Element EV Battery/Nickel Sulfate/ Cobalt Sulfate		

The process of extracting nickel ore, known as nickel ore processing, relies on various technologies, such as producing stainless steel or components for electric vehicles using Mixed Hydroxide Precipitate (MHP) batteries (Figure 4). Currently, the nickel industry is dominated by pyrometallurgical technology, and only a few plants have adopted hydrometallurgical technology to produce grade 1 nickel, particularly used in electric vehicle batteries. The percentage of nickel content in nickel ore will affect the proportion of saprolite and limonite ore used in this process. However, no data is available to categorize resources and reserves based on the types of saprolite and limonite ore. For example, if the desired nickel content limit is approximately 1.5%, the proportion of ore used in pyrometallurgical and hydrometallurgical technology will be relatively balanced. On the other hand, if the nickel content limit is increased to 1.7%, the proportion of ore used in pyrometallurgical technology will be less than that used in hydrometallurgy.

The calculation of financial feasibility begins with establishing basic information. The information shown in Table 1A (Appendix) is sourced from the 'Grand Strategy' book (ESDM, 2021). Furthermore, 3



Source: ESDM (2021)

Figure 4. Upstream and downstream of nickel

production capacity scenarios were developed to see the sensitivity of changes in indicators of financial viability conditions.

The NPV and IRR calculations for the HPAL process for MHP with a 100% capacity show that a positive NPV is achieved only in the 20th year. It should be noted that the calculations are based on the assumption of 'fixed cash flow.' Based on Table 2A (Appendix), it is highly likely that the nickel price will change over time. Table 3A (Appendix) demonstrates that using pyrometallurgical technology provides a faster payback period, approximately around 13 years. NPI products offer a quicker return on investment but require substantial investment costs (Table 4A). Most of Indonesia's NPI is exported to China, and there is currently a shift in production from NPI to nickel matte.

Table 5A in Appendix shows the economic feasibility of producing nickel matte, which will be achieved in the 27th year. The period is relatively longer than MPH, FeNi, and NPI. It's worth noting that FeNi products produced from the RKEF pyrometallurgy can be converted into nickel matte. With the additional installation of matte converters, autoclaves, and solvent extraction, nickel matte can be further converted into nickel sulfate (ESDM, 2021). The nickel sulfate price is higher compared to nickel in NPI, nickel matte, and MPH. Although the nickel processing and refining industry in Indonesia is dominated by NPI, the production of nickel matte is still larger compared to FeNi.

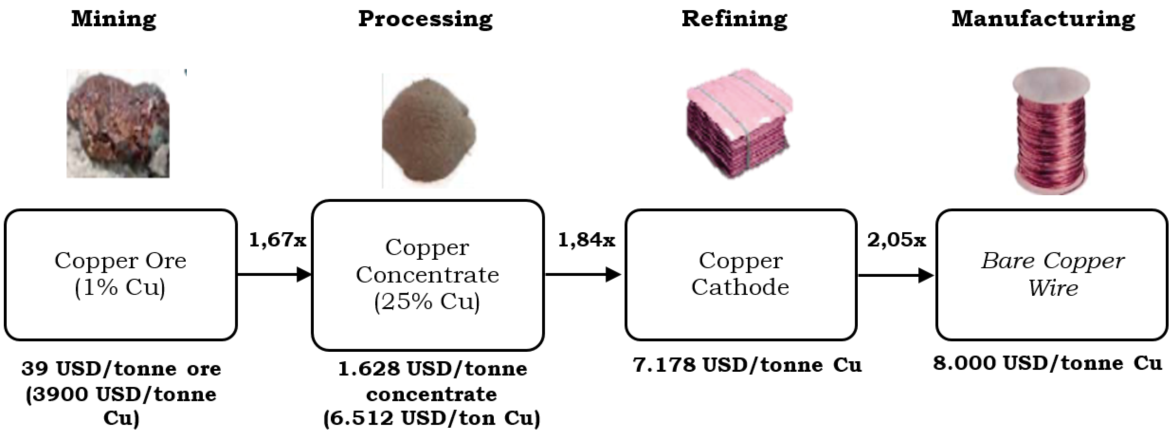
4.2. Copper Value Added

Indonesia is the seventh-largest country in the world in terms of copper reserves. According to ESDM (2022), the national production of copper concentrate was 2.2 million tons, and the national production of copper cathodes amounted to 268,000 tons in 2022. In Indonesia, there are two copper extraction plants in operation, Company D and Company E. Pure copper is obtained through the processes of concentration, extraction, and purification. Copper concentrate is extracted through pyrometallurgical processes to produce copper anodes, then refined into copper cathodes. For low-grade ores, a hydrometallurgical route is employed, which involves leaching and is followed by solvent extraction-electrowinning (SX-EW) processes to produce the final product of copper cathodes (Figure 1A).

The demand for copper is expected to continue to rise. Indonesia still imports many bars, rods, wires, and tubes. Bars and rods are processed into cables and can help reduce imports. The same applies to tubes, which serve as a critical component in heat exchangers for refrigerators and air conditioners. However, protective policies for fabrication are still necessary to ensure the absorption of copper cathodes in the domestic market, including the implementation of Indonesian National Standards (SNI). Another potential development for the copper industry is to support the supply of raw materials for the electric vehicle industry (KBLBB - Electric Vehicle Industry).

Figure 5 shows that constructing a new smelter plant to process copper concentrate into copper cathodes increases the selling price by 1.84 times compared to the selling price of ore. Similarly, if copper cathodes are processed into bare copper wire, the selling price will increase by 2.05 times compared to the ore price.

Based on the information provided by Company E, an NPV (Net Present Value) and IRR (Internal Rate of Return) analysis was conducted. When Company E was established in 1996-1998; it required an investment cost of 500 USD for a capacity of 200,000 tons of Cu per year (ESDM, 2021). Currently, the input capacity for copper concentrate is 1 million tons. Therefore, the required investment cost is 2,500 USD for this input capacity condition. The estimated selling price for copper concentrate is approximately 2,038 USD per ton of Cu. Meanwhile, the value added from copper ore (1% Cu) to copper concentrate (25% Cu) is 2,612 USD per ton of Cu (6,512 USD per ton of Cu minus 3,900 USD per ton of Cu). Based on this information, the calculation results can be seen in Table 6A (Appendix).



Source: ESDM (2022)

Figure 5 Increased added value for each stage of copper processing

Table 6A (Appendix) shows that the return on investment for the copper smelter plant occurs in the second year of operation. This rate of return is quite rapid, with an IRR value of 24%. While the economic feasibility of the copper processing industry is relatively very good, the existence of this industry requires strong infrastructure support. Furthermore, caution is needed when interpreting these financial feasibility results because ESDM (2021) notes that one of the issues with the copper commodity is the suboptimal collection and validation of data. This condition is present both upstream and downstream in the copper industry.

Furthermore, Table 7A (Appendix) shows the various technologies for processing. The pyrometallurgical process works at high temperatures and the hydrometallurgy is carried out using extractor solutions (ESDM, 2021). The pyrometallurgical process is suitable for refining where starting metals such as Au and Ag are still present. Hydrometallurgical processes are best used for low-grade copper oxide or sulfide ores (ESDM, 2021). The capital costs of these technologies are important to identify and will affect the financial viability for downstream purposes.

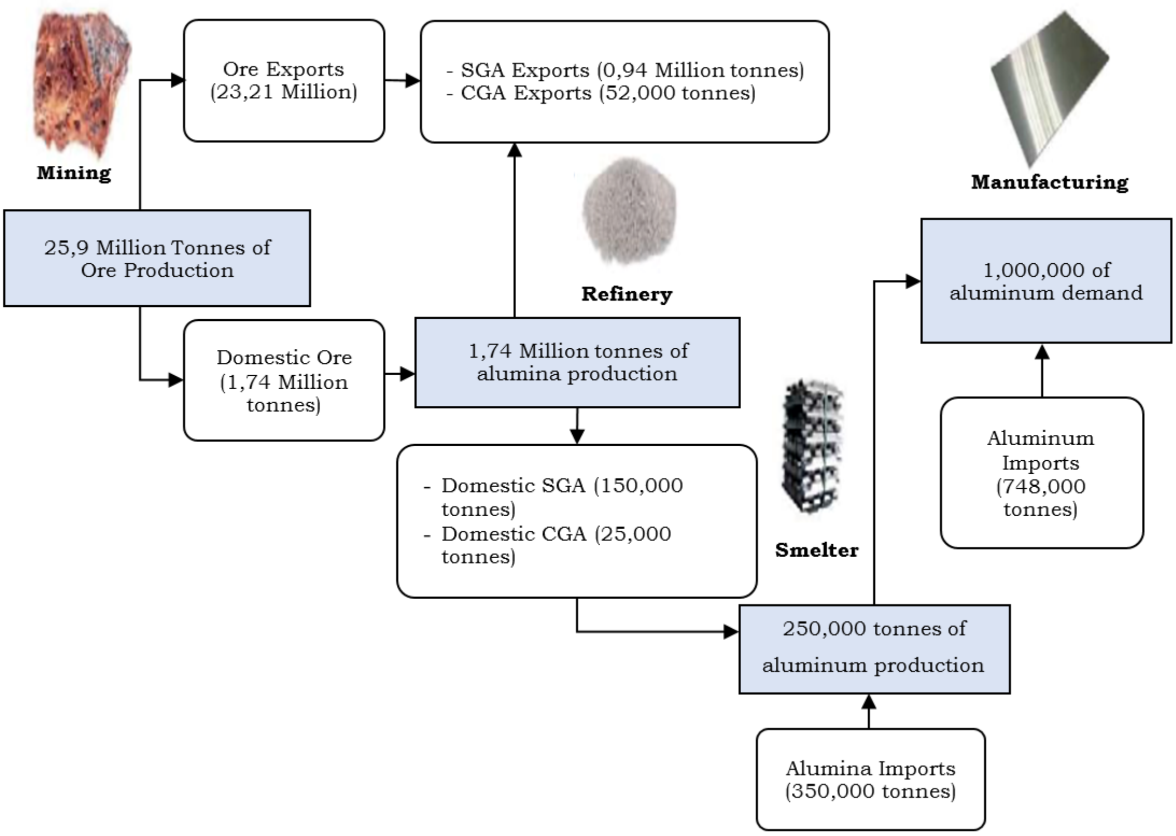
In Indonesia, 2 copper extraction plants have been operating, namely Company D and Company E (Table 8A). Company E is currently facing challenges related to the need for clean energy sources and the increasing demand for copper, driven by the needs of electric transmission, electric vehicles, and other factors. This will impact the price of copper, which is expected to continue rising due to increasing demand, while the supply tends to decrease.

In efforts to promote downstream processing (downstream), it is crucial to ensure that the industry's needs are aligned with the goals of downstream processing itself. If downstream processing does not meet domestic needs, it's likely that raw material imports will remain high. It's also important for Indonesia to be integrated into the supply chain of this industry.

4.3. Bauxite-Alumunium Value Added

The aluminum industry begins with bauxite mining. Alumina is an essential component of the ore, which can yield both chemical-grade alumina (CGA) and smelting-grade alumina (SGA). Alumina used as a chemical substance constitutes a small portion of the total output, with the majority being utilized in the metallurgical industry, accounting for approximately 90% of bauxite ore processed into aluminum metal. Bauxite mining production in Indonesia increased from around 1.3 million tons in 2016 to 25.9 million tons in 2020. In the context of global bauxite mining production, Indonesia's role accounted for no more than 1% during the period 2016-2020. In the upstream sector, Indonesia has industries for bauxite ore washing, alumina processing and refining, and aluminum smelting. Meanwhile, the shaping industry produces aluminum sheets, aluminum profiles, aluminum foil, and aluminum sheets.

In the process context, after bauxite ore is washed, it produces washed bauxite for export (Figure 6). Subsequently, through the Bayer process, washed bauxite yields products such as alumina hydrate, SGA, and CGA. SGA represents the largest production order (about 90%). Through overseas smelting plants, SGA is processed to produce aluminum metal. Company H, as the sole plant producing aluminum metal, still imports SGA as a raw material for pure aluminum metal



Source: ESDM (2021)

Figure 6 Aluminum Supply Chain

production. In Indonesia, there are currently two plants producing alumina, namely Company G produces SGA (meeting the needs of aluminum smelting plants) and Company F produces CGA (meeting the demands of the chemical and ceramic industries).

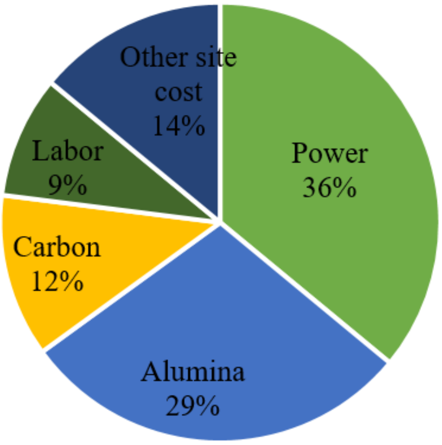
The current challenge for Indonesia is the significant domestic demand for SGA and CGA. In 2020, the national demand for aluminum metal reached 1 million tons—currently, Company H has a capacity of 250,000 tons per year. As a result, a shortage of 748,000 tons of Company H metal needs to be imported. New smelters with a capacity of 3 x 250,000 tons of aluminum annually would require an investment cost of approximately USD 1 - 2 billion.

Alumina processing and refining plants and aluminum smelters that have been in operation are based on data from 2021. The demand for aluminum is expected to continue increasing, reaching 0.94 million tons by 2045. This growth is driven by the need for aluminum in various sectors, including electric vehicle-based battery electric vehicles (BEVs), batteries, the new and renewable energy transition, conventional automotive, the aviation industry, the fabrication industry, and others.

Between 2021 and 2040, aluminum's price is estimated at approximately 412 USD per ton. Meanwhile, the price of Al Metal is around 2,471 USD per ton. The detailed cost components for aluminum production can be seen in Table 8A (Appendix).

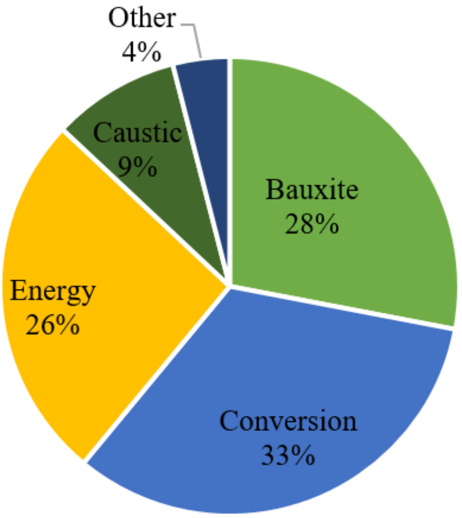
The total net cash cost of aluminum in Indonesia compared to the global average can be seen in Table 9A (Appendix). Based on the table, production costs in Indonesia are quite competitive with producers from other countries. The technology for processing and refining alumina and smelting aluminum is standardized. The challenge for Indonesia in terms of infrastructure is the development of alumina and aluminum industries close to the presence of bauxite ore deposits. Several parameters, including infrastructure, raw material and product transport systems, and production capacity influence the capital cost of an alumina refinery. Typical capital costs for an alumina refinery are as follows: (i) Greenfield project: USD 930 - 1100 per annum per tonne of alumina (USD/AnntA); and (ii) Brownfield project: USD 450 - 750 per annum per tonne of alumina (USD/AntA).

The difference between the two is the 40% infrastructure cost component (Figure 7 and Figure 8). This makes brownfield projects much more attractive. However, only one alumina plant has been developed Company G. Energy plays a very important role in operating costs. Thus, relatively low energy costs can be achieved by using hydroelectric power plants, nuclear power plants, and mine-mouth steam power plants.



Source: AWAC (2010)

Figure 7 Distribution of aluminum total cost



Source: AWAC (2010)

Figure 8 Distribution of total cost of alumina

The significant capital requirements necessitate funding support from foreign sources, typically requiring the company to possess a long-term stable legal project. Therefore, negotiations with the government are necessary to secure a long-term contract.

Table 12A shows that the financial viability of the aluminum processing industry is quite good, with a payback period of 7 years and an IRR of around 12%. The current challenge is how to maintain the availability of raw material supply. The condition of this industry is still unbalanced because almost all bauxite is exported abroad. In contrast, the aluminum raw materials needed for the domestic forming and manufacturing industries must still be imported (ESDM, 2021).

Table 13A and Table 14A show the financial feasibility of greenfield and brownfield projects. Brownfield projects have a larger NPV, faster return times, and higher IRR than greenfield projects. This condition reinforces the arguments presented in the previous section. The current challenge is how to prepare the necessary supporting infrastructure to ensure that the investment burden borne by the private sector is not overly expensive.

For derivative products of aluminum, they can be used in several industries, including the automotive wheel industry. Company J is one of the manufacturers that produce wheels. Globally, Company J produces two types of wheels: alloy wheels and steel wheels. However, in Indonesia, they only produce alloy wheels. In terms of the company's cost structure, most of it is used to purchase new molten aluminum, paint, and only a small portion is allocated for labor costs. The business financing comes from the parent company located in Japan. Research and development activities, as well as product design, are also carried out in Japan. In the context of company operations, constraints related to the supply of gas from PGN, electricity (PLN), and water (PDAM) are still common. Gas supply often falls below the standard, electricity supply is unstable (requiring the company to set up its own substation), and water shortages have necessitated water purchasing.

A strong supply chain supports the success of downstream industries in achieving efficiency. Company J is supported by Company K, which is located nearby. Both companies optimize co-location to reduce transportation and logistics costs. Key determinants of competitiveness in this industry are competitive paint material prices, which will enhance competitiveness, a stable energy supply (gas), and technology to improve gas utilization efficiency.

Downstream activities are closely tied to the global value chain. The parent company plays a crucial role in terms of technology, design, financing, and product purchases. Product quality and diversification are determined by the parent company. The largest cost component is the purchase of raw materials (molten aluminum), while value-added directly related to domestic circulation is dominated by utility and labor costs.

4.4. Analysis of Consumption Side

Demand Side Analysis

As mentioned in the previous section, the global consumption of critical minerals is expected to increase in line with global efforts to achieve 'net zero emissions'. The rapid growth in the capacity of solar and wind power plants in the last four years indicates an increasing need for critical materials. Similarly, the sales of electric vehicles have increased more than fourfold in the last four years. Alongside the rising demand for clean energy technology, the demand for critical minerals for clean energy is also increasing. Data shows a significant increase in demand for minerals such as lithium, nickel, cobalt, and neodymium. The market capitalization of nickel has increased by over 300% in the last five years, surpassing other critical minerals.

The Consumption of Nickel

The consumption of nickel is primarily for the production of stainless steel, with other applications including batteries, non-ferrous alloys, superalloys, and processes such as electroplating. The corrosion-resistant characteristics of nickel are also applied in various other industries. Information from ESDM indicates that the consumption of high-grade saprolite nickel ore will continue to increase as more

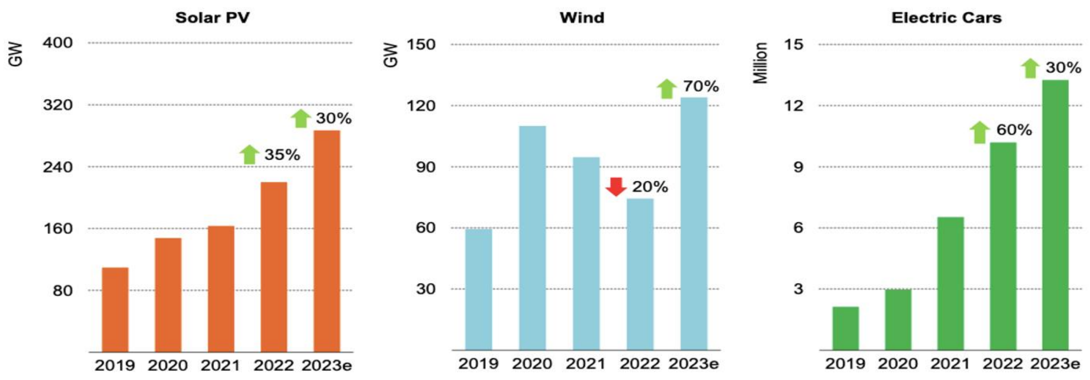


Figure 9 Application of Clean Technology in the Energy Sector (Additional Capacity for Power Plants and Sales of Electric Vehicles)[1]

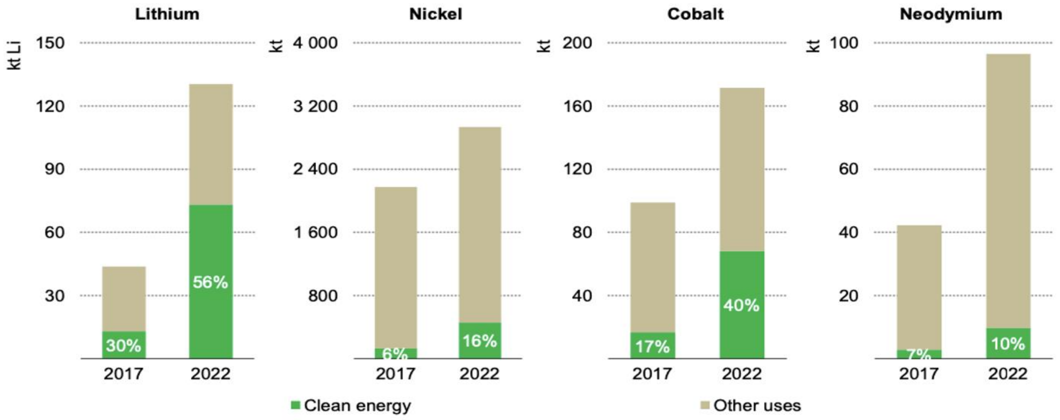


Figure 10 Demand for key materials and the proportion of clean energy to total demand[2]

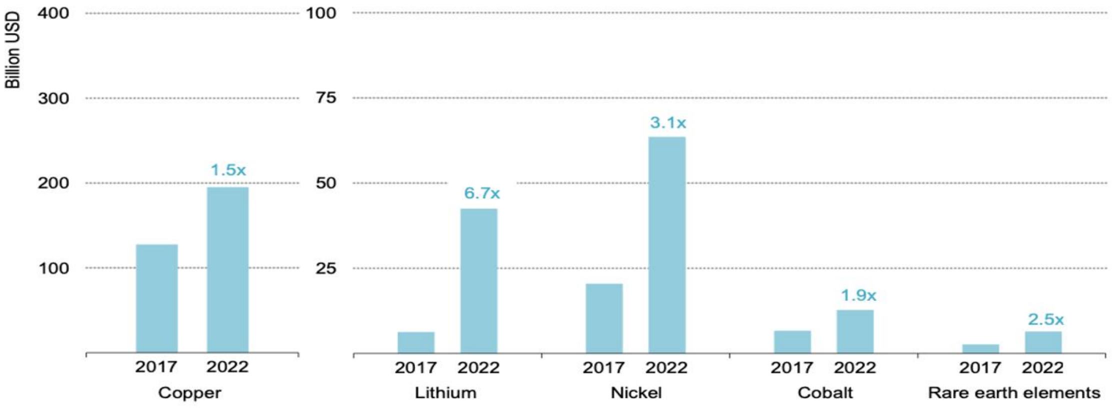


Figure 11 Market Size for Key Energy Transition Materials[3]

companies adopt pyrometallurgical technology. ESDM estimates that the consumption of high-grade nickel ore will reach 210 million tons per year. Meanwhile, the consumption of low-

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[1] Source: IEA (2023)

[2] Source: IEA (2023)

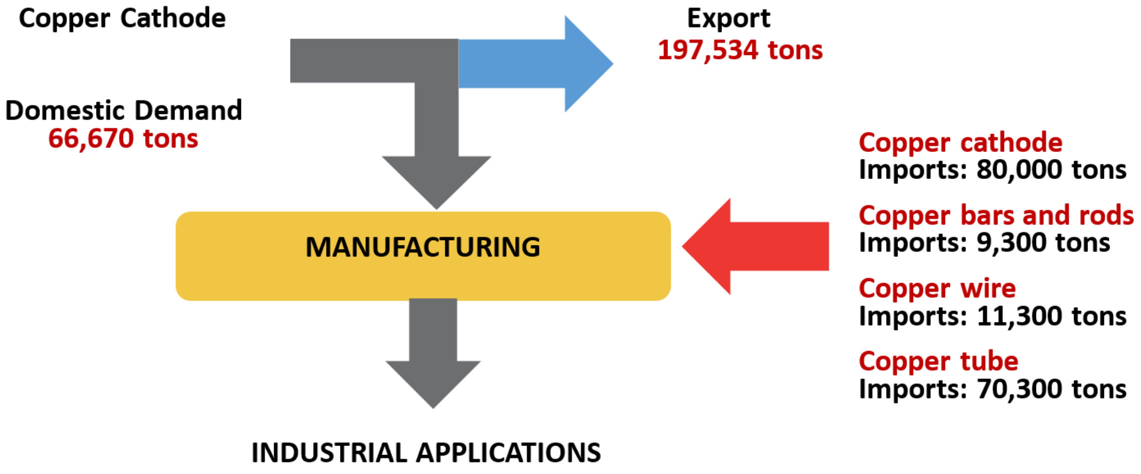
[3] Source: IEA (2023)

grade limonite ore is expected to grow to 58 million tons per year. This is because the number of companies using hydrometallurgical technology is not as high as those using pyrometallurgical technology. The raw material demand from companies using pyrometallurgical and hydrometallurgical technologies is skewed. There are even concerns that large-scale production in the pyrometallurgical path will accelerate the depletion of nickel reserves in Indonesia if not balanced by efforts to find new reserves. Thus, the high consumption rate of saprolite ore could threaten this industry's sustainability.

The government has recognized the need to limit nickel exploitation for two reasons (ESDM, 2021). First, the construction of class 2 nickel plants (NPI/FeNi) needs to be restricted because the lifespan of high-grade saprolite nickel ore reserves is predicted to be only about 15 years if consumed at the maximum rate of 210 million tons per year. Second, restricting the construction of class 2 nickel plants is to anticipate the possibility of smelters exporting NPI/FeNi products on a large scale without further downstream processing, such as into stainless steel products. The government also states that almost all domestic stainless steel production is exported, while most of the domestic demand for stainless steel is met through imports. Based on the trade balance, no downstream cobalt commodity industry is established in Indonesia.

The Consumption of Copper

Approximately 74% of the copper cathodes produced by PT. Smelting Gresik are intended for export, while the remaining portion is for domestic needs. Looking at the total consumption of copper cathodes in 2020, which amounted to 362,360 tons, and the import volume of 291,894 tons or about 80% of total consumption (ESDM, 2021). As acknowledged by the government, detailed data on the types of copper products exported, imported, and consumed domestically are not readily available or easily accessible. The export of Cu concentrate is expected to continue declining, and by 2026, there is expected to be no more copper concentrate exports. Through the construction of new smelter and hydrometallurgical plants, it will be possible to produce copper cathodes and meet domestic



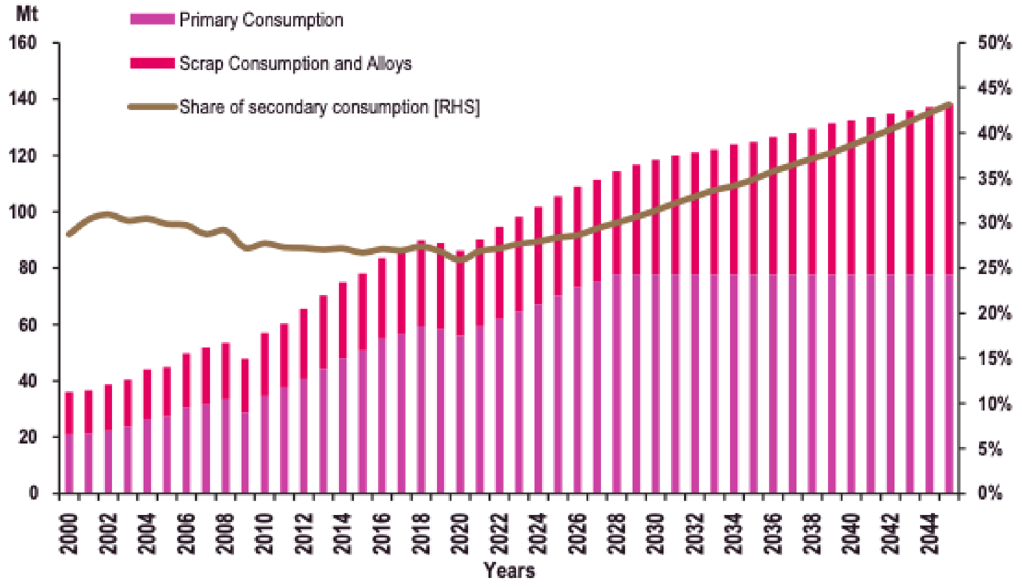
Source: ESDM (2021)

Figure 12 Copper Cathode Production Flow in Manufacturing/Fabrication Industry needs. Therefore, the absorption capacity of downstream industries domestically to absorb local production needs to be continually improved. Some industries that require a significant amount of copper include electricity, transportation, electronics, battery-based electric vehicles, as well as new and renewable energy.

The presence of smelter plants such as Company I and Company L will be able to increase the consumption of copper concentrate and boost copper cathode production. The figure below shows various industries still importing copper, and efforts to reduce imports are crucial to ensuring the availability of domestic products in the quantity and quality required by the local industry.

The Consumption of Aluminum

Figure 13 shows the global aluminum projection that will continue to grow. What is quite interesting about future trends is that primary consumption will tend to remain constant, while the proportion of secondary (scrap) will increase from around 30% in 2022 to nearly 45% in 2045. It is globally known that aluminum production is in an oversupply position. The increased demand for low carbon technology and the development of new and renewable energy make the consumption of secondary aluminum capable of suppressing the consumption of primary aluminum.



Source: ESDM (2021)

Figure 13 Projection of Global Primary and Secondary Aluminum Consumption Period 2000 – 2045

Developed and developing countries exhibit different behaviors in aluminum consumption. While developed nations utilize aluminum primarily in the transportation sector, developing countries employ aluminum for electricity transmission, production goods, and construction purposes (ESDM, 2021). The government notes that domestic consumption of downstream aluminum products is approximately 300 thousand tons for plate/sheet products and around 93 thousand tons for export purposes with wrought products. Meanwhile, in 2045, domestic aluminum consumption is projected to reach 11.8 million tons.

4.5. Downstreaming in the Manufacturing, Human Resources, Regulation, and Non-Resource Sectors

In the previous section, the need for strengthening in four aspects was mentioned: manufacturing, human capital, regulatory, and non-resource sectors. If we look at the direction of the development of nickel, aluminum, and copper commodities, it is designed to strengthen the manufacturing side, as mentioned in the following four main pillars: (i) reserve resilience and production optimization; (ii) development of processing and refining industries; (iii) development of fabrication and manufacturing industries, and enhancement of domestic components; (iv) optimization of domestic product use and strengthening recycling systems. Strengthening these four pillars requires good data support from upstream to downstream, such as completeness, standards, and data quality.

Optimizing the production chain within the circular economy framework, this system's strengthening needs to be designed optimally. By developing by-products in the form of waste that still has high added value, we can further strengthen the economy's competitiveness. To achieve this goal, strong research support is required.

Meanwhile, labour absorption for the mining and excavation sector at the national level is insignificant. BPS data shows that in February 2023, there were only about 1.7 million workers in this sector, which is approximately 1.22% of the total working population (BPS 2023). Consequently, the labour absorption in the upstream sector of critical mineral mining is not expected to create significant employment opportunities. This is also evident from the approximately 3.02 million additional people who were employed between February 2022 and February 2023, with only about 110,000 people working in the mining and excavation sector. This sector can only absorb about 3.6% of the total additional workforce.

Furthermore, it is crucial to consider symmetrical downstream development while strengthening domestic industries' strategic position. Finally, from a policy perspective, meeting domestic needs should be a priority, and this requires appropriate policies to ensure the industrial ecosystem remains healthy.

Nickel

A global alliance has been formed to market nickel products to the world market. This demonstrates the ability to meet product standards and establish direct and indirect connections with anchor firms, which is crucial. In the scheme below, Company M is an anchor firm. Efforts to build industrial clusters will be strengthened if there is already a globally networked anchor firm in place. Furthermore, capturing market shares in each industry will significantly impact downstream efforts, particularly in achieving economies of scale and competitive prices. For example, Company N limited controls approximately 25% of the world's consumption in stainless steel production.

In 2015, the number of workers in the mining industry was reported to be 3,232 local workers and 18 foreign workers. This workforce is relatively small compared to the employment in copper mining.

Efforts to increase the collection rate of nickel waste need to be improved. The proposed scenario suggests that only about 50% of it is currently utilized. Nickel applications for high-value-added products, such as aircraft using superalloys, are essential. Similarly, the extraction of magnesium requires research and development support. Regarding the domestic market obligation policy, it is still necessary for series 304 and 316L stainless steel, most of which are still being exported. With this policy, it is hoped that the import of these two stainless steel series can be minimized.

Copper

The experience of increasing the added value of copper shows that the process of adding value becomes more significant as we move from raw products to manufacturing. For example, bare copper wire has a value of 8,000 USD/ton of Cu, while raw copper ore (1% Cu) is 3,900 USD/ton of Cu. Therefore, it is evident that downstream efforts can more than double the added value. Copper is also a recyclable metal, so managing copper waste properly is essential for reuse. Studies show that the recovery value falls within the range of 15% - 20% with efficient collection systems. While this value may seem relatively small, improving collection efforts and preprocessing or selection can further increase the recovery value.

Copper holds significant importance for the development of electric-based industries and in supporting the energy transition process towards greater use of renewable energy and electric vehicles. Consequently, the demand for copper and aluminum will continue to rise. Support from the industrial sector is crucial. For instance, between 2025 and 2045, the demand for copper and aluminum is expected to increase by 18.67 times and 25.67 times, respectively. Meeting this increased demand will require a balanced response from manufacturing efforts. Additionally, policies to encourage downstream investments can be implemented by providing both fiscal and non-fiscal incentives. For example, up to this point, 100% of anode sludge, a byproduct of copper processing and refining, is still exported, despite its gold and silver content that could still be utilized.

Copper industry policies in the form of fabrication protection may be necessary to ensure the absorption of copper cathodes in the domestic market. Data shows a need to export 197,534 tons of copper in cathode form and a domestic consumption capacity of 66,670 tons. This indicates relatively low domestic demand conditions, making downstream efforts crucial. Fabrication efforts need to be encouraged to produce bars, rods, wires, and tubes that are currently imported.

Furthermore, efforts to implement national standards (SNI) are necessary to prevent the import of substandard products. This policy can also protect the domestic industry. Strengthening the supply chain and industrial infrastructure for the copper industry is still required, especially in anticipation of material needs in supporting the energy transition effort.

Government estimates suggest that the copper industry downstream can create approximately 22,500 new jobs. Meanwhile, the construction of smelters is expected to employ 35,000 workers. Of course, consideration should be given to the requirements for education, skills, and certification. If we consider the relatively significant demand for foreign labor, the challenge lies in transferring technology. Recruits should ideally involve as much local labor as possible. This would result in a better multiplier effect for local and national economic development.

Aluminum

Low-carbon technology and green aluminum products are in demand. Through circular economy practices, aluminum waste, also known as secondary aluminum, can be reused to produce low, medium, and high-end products. With an efficient collection system, approximately 30% of the aluminum demand in 2045 can be met by secondary aluminum. Indonesia needs to develop the capability to process secondary aluminum because the process requires less energy, produces lower waste output and emissions, and has lower investment costs compared to primary aluminum.

The demand for aluminum will continue to increase with the growth of the new and renewable energy industry, including batteries and electric vehicles. The aluminum waste processing industry is also crucial to develop, especially in the case of red mud. Research efforts to better understand this waste need to be ongoing. Thus, downstream should not only be viewed from the perspective of the main products but also from the optimization of the value of the waste produced. This approach will not only reduce environmental impact but can also provide economic and social added value.

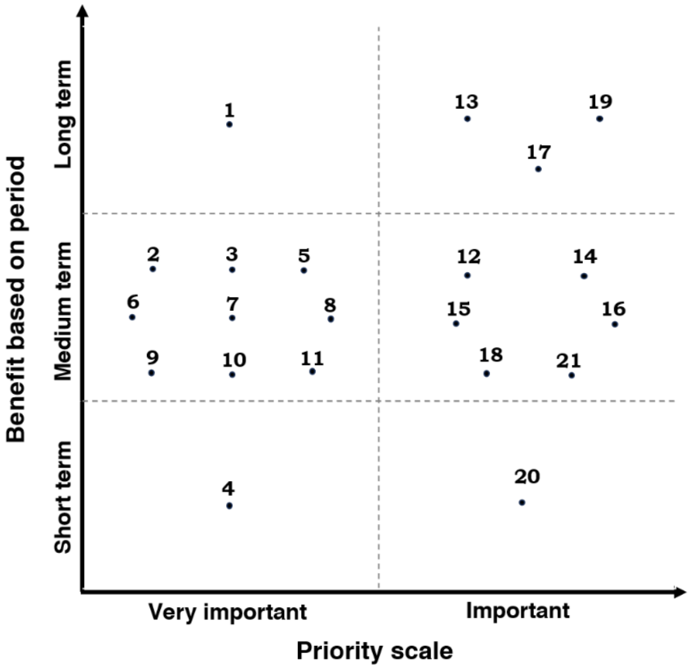
Efforts to optimize smelter-grade alumina (SGA) for domestic needs require a reconfiguration of unloading facilities. This can be observed in the conditions at Company H. Inalum cannot accommodate small-tonnage ships, which impacts the efficiency of loading and unloading. Therefore, to absorb local SGA, most of which is exported, it is necessary to optimize the unloading facilities at Company H. A domestic market obligation policy for SGA is also deemed necessary to reduce import dependence.

In terms of workforce absorption, it is known that the construction of an aluminum refinery requires 3,734 workers, with approximately 10% foreign labor. The same goes for the mining industry, which will also require labor. However, this information is not yet well-documented.

5. Implication / Policy Recommendation

Based on the conclusions of this research, the recommended policy measures are as follows: First, there is a need to improve critical mineral data from upstream to downstream by fostering intensive collaboration between the government and industry associations. Second, supporting infrastructure, such as roads, ports, energy, and logistics systems, needs enhancement through incentives provided to the private sector, including state-owned enterprises, to stimulate downstream development. Third, the development of local demand, referred to as "symmetric downstream," will establish a mutually beneficial industrial ecosystem, particularly considering the ongoing push for green energy-based industries. Finally, the oversight of good governance, risk, and compliance (GRC) practices combined with environmental, social, and governance (ESG) factors must be reinforced, with the integration of upstream and downstream value chains to ensure the integrity of critical mineral-based industries and meet the demands of a global market increasingly attuned to GRC and ESG considerations. As an illustrative example, the government can encourage companies to adopt green energy and improve waste management practices.

There are 21 policy recommendations presented in Table A1 in Appendix. If these policies are categorized based on perceived benefits, namely short-term (around 1-2 years), medium-term (3-5 years), and long-term (more than 5 years), and considering priority scale, i.e., very important and important, it appears that more policies will be beneficial in the medium term for both very important and important priority scales.



Note: Numbers refer to the policy recommendation in Table A1 (Appendix)

Figure 14 Policy Recommendation Matrix

This simultaneously emphasizes the need to implement policies based on stages (order), focus (focus), coherence (coherence), rationality (rationality), and continuity (continuity), as suggested by Boediono (2019). This is important so that the potential benefits of policies can be optimally realized. In the short term, 'consistently implementing downstreaming policies by all ministries' and 'forming a task force for downstreaming critical minerals to strengthen policy synergy and formulate attractive incentives' are two things that need to be prepared promptly. The mapping matrix of these policy recommendations is presented in Figure 15.

6. Conclusion and Further Research

The smelter industry is expected to develop significantly in line with government policies promoting downstream processing. Considering Indonesia's vast potential in critical mineral resources, efforts to enhance the efficiency and sustainability of the industry (based on green energy and adopting hazardous waste management, especially B3 waste) must be prioritized. The current challenge lies in achieving equilibrium between efforts to boost downstream processing and the needs of the local industry. Downstream processing efforts will succeed if they are supported by sufficient demand to reach economies of scale.

The assessment of downstream processing efforts is not an easy task due to various aspects that need to be evaluated, including technology, input materials, products, input and output price dynamics, logistics systems, and other resource requirements such as energy, water, land, waste, and emissions, as well as the utilization of waste for reprocessing. Furthermore, many companies are strongly interconnected in value chain networks, and sometimes, these companies are owned by large business groups, which is important for driving downstream processing. Field studies also show that there has been co-specialization between Company K and Company L. These two companies have high value when they work together compared to when they operate separately. Through ownership networks and the location of the companies in the same area, they can optimize their co-specialized advantages.

Efforts to enhance downstream processing are not solely dependent on having potential mineral resources but also require economic feasibility, as mentioned above. Even as an "infant industry", it may require support from the government, both in fiscal and non-fiscal forms. Establishing smelter industries involves substantial capital costs and significant risks. However, in NPV and IRR calculations, it is found that it takes about two decades for nickel to achieve the desired level of return. The IRR conditions are relatively not very high. On the other hand, by changing technology choices, NPV and IRR conditions can be improved. For instance, choosing pyrometallurgy technology results in better NPV and IRR than hydrometallurgy. Therefore, when considering NPV and IRR conditions across various product and technology options, it appears that large investments correlate with quicker returns.

The potential for downstream processing of copper is highly promising, particularly due to the increasing demand for clean energy supply. The number of copper smelter industries will continue to rise. The added value created in each link in the value chain indicates the economic potential of downstream processing. NPV and IRR evaluations demonstrate that the economic viability of processing copper concentrate is highly profitable. However, the experience of Company E suggests that the copper downstream processing business model seems to be built on a 'market' concept rather than 'integration.' This is evident from two main activities: the provision of oxygen and energy, carried out by third parties. Infrastructure reliability also determines the company's profitability.

The prospects for downstream processing of bauxite and aluminum are substantial. The demand for final aluminum metal products to support the energy transition will continue to grow. From an investment perspective, brownfield projects appear much cheaper than greenfield ones. This is because the infrastructure cost components in the context of brownfield projects are already more prepared. The NPV and downstream processing of aluminum seem favorable, but for alumina (greenfield), it appears to be less profitable. Meanwhile, it seems much better for brownfield projects, although the IRR conditions are less attractive.

Thus, downstream processing efforts cannot be solely entrusted to the private sector or, at the very least, require collaboration among companies, especially state-owned enterprises (BUMN). The government must ensure infrastructure reliability, as this will impact investment costs. Some products have NPV and IRR conditions that are not particularly attractive. From a policy perspective, there is a need for an optimal formulation, especially in accommodating the interests of strengthening the industry. NPV and IRR analyses have not considered the cost and benefit from externalities (social and environmental), and many economic, social, and environmental potential values can be derived from waste and emissions.

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Appendix

Table 1A Nickel data in firm-level

Input		**Ore Limonite**	**Ore Saprolite**		
Technology and End Product		**HPAL (Hydrometallurgy) - MHP (Grade 1)**	**RKEF (Pyrometallurgy) - FeNi (Grade 2)**	**RKEF (Pyrometallurgy) - NPI (Grade 2)**	**RKEF Nickel Matte**
Production in 2020 (000 tonnes)			25	604	74
Production capacity Company A 2021 (tonnes)		117,601	125,677	6,060,508	102,500
Capital cost (USD/tonne Ni)	Average	50,000	25,000	-	
	Lower	-	-	5,000	
	Upper	-	-	15,000	
Total Capital Cost (Rp/tonne Ni)		5,880,050,000	3,141,925,000	60,605,080,000	3,141,925,000
Price (USD/tonne Ni)		15,083	13,699	15,083	13,323
Assumption: total revenue for production (Rp/tonne Ni)	100% capacity	1,773,775,883	1,721,649,223	91,410,642,164	1,365,607,500
	75% capacity	1,330,331,912	1,291,236,917	68,557,981,623	1,024,205,625
	50% capacity	886,887,942	860,824,612	45,705,321,082	682,803,750
Cost (USD/tonne Ni)		7,200	8,880	6,000	8,880
Total cost (Rp/tonne Ni)	100% capacity	846,727,200	1,116,011,760	36,363,048,000	910,200,000
	75% capacity	635,045,400	837,008,820	27,272,286,000	682,650,000
	50% capacity	423,363,600	558,005,880	18,181,524,000	455,100,000
Profit (Rp/tonne Ni)	100% capacity	927,048,683	605,637,463	55,047,594,164	455,407,500
	75% capacity	695,286,512	454,228,097	41,285,695,623	341,555,625
	50% capacity	463,524,342	302,818,732	27,523,797,082	227,703,750
Profit after tax of the company (25%) (Rtonne Ni)	100% capacity	695,286,512	454,228,097	41,285,695,623	341,555,625
	75% capacity	521,464,884	340,671,073	30,964,271,717	256,166,719
	50% capacity	347,643,256	227,114,049	20,642,847,812	170,777,813

Source: Authors' calculations.

Table 2A NPV and IRR Calculation Results on HPAL (Hydrometallurgy) – MHP

Year	***Cash Flow***	***Present Value***
0	(5,880,050,000)	(5,880,050,000)
1	695,286,512	632,078,648
2	695,286,512	574,616,952
3	695,286,512	522,379,048
4	695,286,512	474,890,043
5	695,286,512	431,718,221
6	695,286,512	392,471,110
7	695,286,512	356,791,918
8	695,286,512	324,356,289
9	695,286,512	294,869,354
10	695,286,512	268,063,049
11	695,286,512	243,693,681
12	695,286,512	221,539,710
13	695,286,512	201,399,736
14	695,286,512	183,090,669
15	695,286,512	166,446,063
16	695,286,512	151,314,603
17	695,286,512	137,558,730
18	695,286,512	125,053,391
19	695,286,512	113,684,901
20	695,286,512	103,349,910

NPV HPAL (Hydrometallurgy) - MHP (Grade 1)	39,316,025,53
IRR HPAL (Hydrometallurgy) - MHP (Grade 1)	10.10%

Source: Authors' calculations.

Table 3A NPV and IRR calculation results on RKEF (pyrometallurgy) - FeNi

Year	Cash Flow	Present Value
0	(3,141,925,000)	(3,141,925,000)
1	454,228,097	412,934,634
2	454,228,097	375,395,122
3	454,228,097	341,268,292
4	454,228,097	310,243,902
5	454,228,097	282,039,911
6	454,228,097	256,399,919
7	454,228,097	233,090,836
8	454,228,097	211,900,760
9	454,228,097	192,637,054
10	454,228,097	175,124,595
11	454,228,097	159,204,177
12	454,228,097	144,731,070
13	454,228,097	131,573,700
NPV RKEF (pyrometallurgy) - FeNi (Grade 2)		84,618,972
IRR RKEF (pyrometallurgy) - FeNi (Grade 2)		10.52%

Source: Authors' calculations.

Table 4A NPV and IRR calculation results on RKEF (pyrometallurgy) - NPI

Year	Cash Flow	Present Value
0	(60,605,080,000)	(60,605,080,000)
1	41,285,695,623	37,532,450,566
2	41,285,695,623	34,120,409,606
NPV RKEF (pyrometallurgy) - NPI (Grade 2)		11,047,780,172
IRR RKEF (pyrometallurgy) - NPI (Grade 2)		23.35%

Source: Authors' calculations.

Table 5A NPV and IRR calculation results on RKEF - Nickel Matte

Year	Cash Flow	Present Value
0	(3.141.925.000)	(3.141.925.000)
1	341.555.625	310.505.114
2	341.555.625	282.277.376
3	341.555.625	256.615.796
4	341.555.625	233.287.088
5	341.555.625	212.079.171
6	341.555.625	192.799.246
7	341.555.625	175.272.042
8	341.555.625	159.338.220
9	341.555.625	144.852.927
10	341.555.625	131.684.479
11	341.555.625	119.713.163
12	341.555.625	108.830.148
13	341.555.625	98.936.498
14	341.555.625	89.942.271
15	341.555.625	81.765.701
16	341.555.625	74.332.455
17	341.555.625	67.574.960
18	341.555.625	61.431.781
19	341.555.625	55.847.074
20	341.555.625	50.770.067
21	341.555.625	46.154.607
22	341.555.625	41.958.733
23	341.555.625	38.144.303
24	341.555.625	34.676.639
25	341.555.625	31.524.217
26	341.555.625	28.658.379
27	341.555.625	26.053.072
	NPV pada RKEF - Nickel Matte	13,100,528
	IRR pada RKEF - Nickel Matte	10,05%

Source: Authors' calculations.

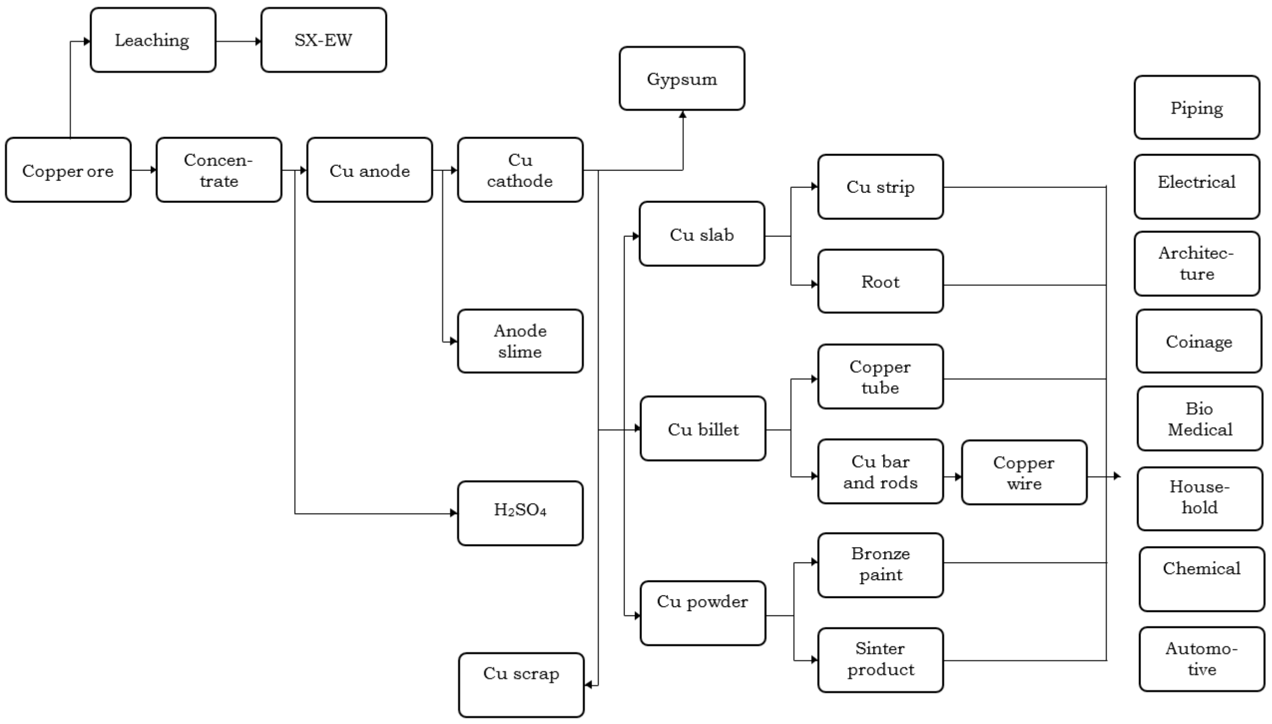

Figure 1A Upstream and downstream of nickel

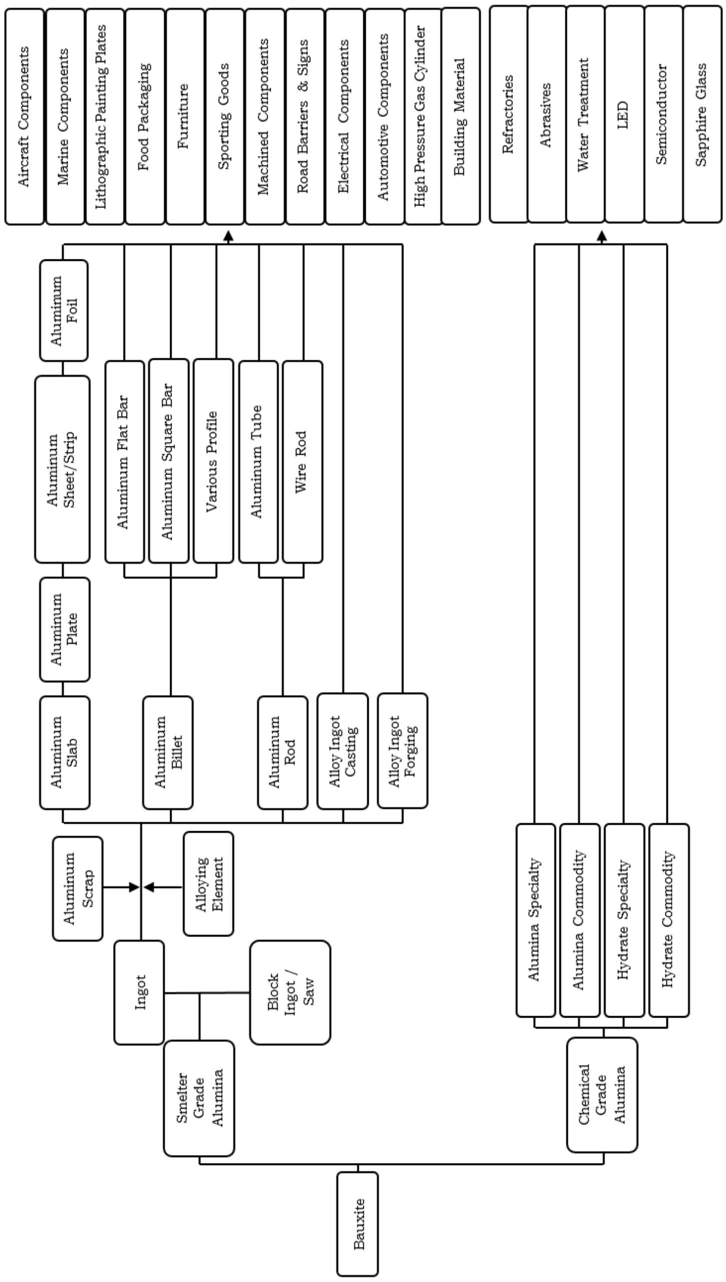

Figure 2B Upstream and downstream of aluminum

Table 6A NPV and IRR calculation results on copper

Year	Cash Flow	Present Value
0	(2,500,000,000)	(2,500,000,000)
1	1,959,000,000	1,780,909,091
2	1,959,000,000	1,619,008,264
	NPV Tembaga	899,917,355
	IRR Tembaga	24%

Source: Authors' calculations

Table 7A Copper processing and refining technologies

No	Processing Type	Technology
1	Pyrometallurgy	Mitsubishi Flash Smelting Technology (Atlantic Copper) Outotec Flash Smelting and Converting Technology Outotec's Direct Bister Flash Smelting Technology Outotec Ausmelt Smelting and Converting ISASMELT Process Inco Flash Smelting
2	Hydrometallurgy	Insitu Heap VAT Agitation

Table 8A Copper input and output commodities

No	Company Name	Input		Komoditas Output	
		Type	Capacity (tonnes)	Type	Capacity (tonnes)*
1	Company D	Copper ore	1,400,000	*Copper cathrode*	25,000
2	Company E	Copper concentrate	1,000,000	*Copper cathrode*	300,000

*) Production capacity in tonnes of product

Table 9A Aluminum input and output commodities

No	Company Name	Input		Commodity Output	
		Type	Capacity (tonnes)	Type	Capacity (tonnes)*
1	Company F	Alumina Refinery	1,000,000	CGA	300,000
2	Company G	Alumina Refinery	3,564,000	SGA	1,000,000
3	Company H	Aluminum Smelter	500,000	Aluminum Ingot and Billet	250,000

*) Production capacity in tonnes of product

Table 10A Total net cash cost of alumina and aluminum for Indonesia and the world average

No	Cost Components	Indonesia (USD/tonne)	World Average (USD/tonne)
1	Materials and Material Costs	118	
2	Fuel Cost	57	
3	Maintenance and Spare Parts Cost	11	
4	Other Costs (Production related costs)	11	
5	Royalties + Taxes	28	
	Total Cash Cost Alumina	225	259
	Total Cash Cost Aluminum	1,503	1,667

Table 11A Distribution of operating costs in aluminum smelters and alumina refining

Components	CGA	SGA	Al Ingot	Al Plate
Price (USD/tonnes)	333	333	1,896	2,700
EBITDA	80%	80%	48%	10%
Royalties	3%	3%	3%	-
Corporate Tax	25%	25%	25%	25%

Table 12A NPV and IRR calculation results on Aluminum

Year	Cash Flow	Present Value
0	(1,500,000,000)	(1,500,000,000)
1	331,500,000	301,363,636
2	331,500,000	273,966,942
3	331,500,000	249,060,856
4	331,500,000	226,418,960
5	331,500,000	205,835,419
6	331,500,000	187,123,108
7	331,500,000	170,111,916
	NPV Aluminum	113,880,838
	IRR Aluminum	12%

Sources and notes: Authors' calculations have not considered corporate tax

Table 13A NPV and IRR calculation results on alumina based greenfield project

Year	Cash Flow	Present Value
0	(4,632,460,000)	(4,632,460,000)
1	547,680,000	497,890,909
2	547,680,000	452,628,099
3	547,680,000	411,480,090
4	547,680,000	374,072,809
5	547,680,000	340,066,190
6	547,680,000	309,151,082
7	547,680,000	281,046,438
8	547,680,000	255,496,762
9	547,680,000	232,269,784
10	547,680,000	211,154,349
11	547,680,000	191,958,499
12	547,680,000	174,507,726
13	547,680,000	158,643,387
14	547,680,000	144,221,261
15	547,680,000	131,110,238

Year	Cash Flow	Present Value
16	547,680,000	119,191,125
17	547,680,000	108,355,568
18	547,680,000	98,505,062
19	547,680,000	89,550,056
20	547,680,000	81,409,142
NPV Alumina Based Greenfield Project		30,248,578
IRR Alumina Based Greenfield Project		0.087%

Note: The author's calculation and it has not considered corporate tax

Table 14A NPV and IRR calculation results on alumina based on a brownfield project

Year	Cash Flow	Present Value
0	(2,738,400,000)	(2,738,400,000)
1	547,680,000	497,890,909
2	547,680,000	452,628,099
3	547,680,000	411,480,090
4	547,680,000	374,072,809
5	547,680,000	340,066,190
6	547,680,000	309,151,082
7	547,680,000	281,046,438
8	547,680,000	255,496,762
NPV Alumina Based Brownfield Project		183,432,380
IRR Alumina Based Brownfield Project		1.65%

Note: The author's calculation and it has not considered corporate tax