From Resource Abundance to Industrial Constraint: Managing Upgrading and Structural Dependencies in Indonesia's Nickel Value Chain

Hanan Nugroho[1*], Achmanto Mendatu[2], Usamah Widiatmoko[3], Muhyiddin Muhyiddin[1]

[1]National Development Planning Agency, Jakarta, Indonesia

[2]The Indonesia Think Tank & Policy Lab, Jakarta, Indonesia

[3]Ministry of Investment and Downstream Industry, Jakarta, Indonesia

[1*]Corresponding Author: Hanan Nugroho

DOI: https://doi.org/10.47772/IJRISS.2026.1014MG0098

Received: 24 April 2026; Accepted: 30 April 2026; Published: 21 May 2026

ABSTRACT

Indonesia's nickel sector has undergone a rapid structural transformation following the implementation of downstream industrial policies, shifting from a primary exporter of raw materials to a major global hub for nickel processing. While this transition has significantly expanded domestic value addition and strengthened Indonesia's position in global supply chains, its long-term developmental implications remain contested. This paper examines Indonesia's position within the global nickel value chain through the lens of industrial upgrading and structural dependency. Drawing on the global value chain framework, the study argues that Indonesia's upgrading trajectory remains incomplete and uneven, characterized by concentration in upstream and midstream activities, continued reliance on foreign technology, and vulnerability to critical input dependencies. The findings suggest that rather than following a linear progression toward higher-value activities, resource-based industrialization may become locked in an intermediate stage of "midstream entrapment," in which industrial expansion does not translate into technological autonomy or innovation capacity. The paper contributes to the literature by refining the concept of industrial upgrading in resource-rich economies and highlighting the structural constraints that shape their development pathways. Policy implications emphasize the need for deliberate capability-building strategies, including technological learning, domestic innovation, and stronger industrial linkages, to enable a transition from resource-driven growth toward sustainable, innovation-led development.

Keywords: global value chains, nickel industry, Indonesia, industrial upgrading, resource-based development, structural dependency

INTRODUCTION

Indonesia holds one of the world's largest lateritic nickel reserves and has emerged as the leading global producer of nickel ore (United States Geological Survey [USGS], 2024). This position is not merely a function of geological endowment, but also the result of a deliberate policy shift toward resource-based industrialization. Since the enactment of Law No. 4/2009 on Mineral and Coal Mining, later reinforced by Law No. 3/2020, the Indonesian government has pursued an ambitious downstreaming agenda to increase domestic value addition. The prohibition of raw nickel ore exports—initially introduced in 2014 and fully enforced in 2020—marked a decisive turning point, signaling a transition from a primary commodity export model toward domestic processing, refining, and industrial deepening (Nugroho & Al-Wafiy, 2026).

This transformation coincides with a fundamental restructuring of global nickel demand. While nickel has historically been used predominantly in stainless steel production, demand is increasingly driven by the rapid expansion of electric vehicles (EVs) and energy storage systems. As part of the broader global energy transition, nickel has become a critical mineral in decarbonization pathways, with demand projected to grow significantly in the coming decades (International Energy Agency [IEA], 2023a; World Bank [WB], 2020). This shift creates a strategic opportunity for Indonesia to reposition itself from a raw material supplier to a key player in higher value-added segments of the global nickel value chain.

However, insights from the global value chain (GVC) literature suggest that participation in global production networks does not automatically translate into structural transformation or sustained economic upgrading. Value-added and strategic control are unevenly distributed along the value chain, with higher returns concentrated in downstream, knowledge-intensive activities such as advanced materials processing, battery manufacturing, and system integration. In contrast, upstream extraction and midstream processing typically generate lower margins and are more vulnerable to price volatility (Gereffi, Humphrey, & Sturgeon, 2005; Kaplinsky, 2000). Thus, the key challenge for resource-rich countries lies not only in entering global value chains but in upgrading their position within them.

Indonesia's downstreaming policy has succeeded in rapidly expanding domestic processing capacity, particularly through the development of Rotary Kiln Electric Furnace (RKEF) and High-Pressure Acid Leaching (HPAL) facilities. These developments have significantly increased the country's share in global nickel processing. Nevertheless, Indonesia's industrial structure remains largely concentrated in upstream and midstream segments, with limited control over core technologies, innovation systems, and high-value downstream activities such as precursor, cathode, and battery cell production (IESR, 2025; WB, 2020). As a result, Indonesia risks becoming a large-scale production hub without achieving corresponding gains in technological sovereignty and value capture.

This paper argues that Indonesia has achieved substantial progress in terms of participation in the global nickel value chain, but has yet to realize full functional upgrading. The central issue is therefore not whether Indonesia can integrate into global production systems, but whether it can transition from a production-based role toward a technology- and innovation-driven industrial structure.

The contribution of this paper is threefold. First, it provides a structured analysis of Indonesia's position within the global nickel value chain by integrating global value chain theory with sector-specific technological assessment, particularly of RKEF and HPAL pathways. Second, it identifies the key structural constraints—technological dependence, capital structure, human resource limitations, and weak innovation linkages—that hinder functional upgrading, drawing on insights from industrial policy and development economics (Amsden, 2001; Andreoni & Chang, 2019). Third, the paper advances a comprehensive policy framework that links industrial upgrading to technological capability development, strategic financing, and the strengthening of the innovation ecosystem. By doing so, the paper contributes to the broader debate on resource-based industrialization, offering insights into how resource-rich countries can move beyond intermediate processing toward higher value-added and more resilient economic structures.

This paper, therefore, asks: to what extent has Indonesia achieved functional upgrading in the global nickel value chain, and what structural constraints limit its transition toward higher value-added and innovation-driven activities?

METHODOLOGY

Literature Review: The Nickel Industry Value Chain

The global nickel industry has undergone a profound transformation, driven by technological change and shifting demand patterns. While nickel has traditionally been used in stainless steel production, the rapid expansion of electric vehicles (EVs) and energy storage systems has repositioned nickel as a critical mineral in the global energy transition (IEA, 2023b; WB, 2020). This shift has extended the nickel value chain beyond conventional metallurgical processes toward advanced materials and battery manufacturing.

From a value chain perspective, the nickel industry can be conceptualized as a sequential and functionally differentiated production system comprising upstream extraction, midstream processing and refining, and downstream manufacturing. Upstream activities include exploration and mining; midstream processes involve smelting and refining through technologies such as Rotary Kiln Electric Furnace (RKEF) and High-Pressure Acid Leaching (HPAL); and downstream segments encompass the production of battery precursors, cathodes, battery cells, and electric vehicles. Existing studies consistently show that value-added and strategic control increase significantly toward downstream segments, particularly those characterized by high technological intensity and strong innovation capabilities (Gereffi et al., 2005; Kaplinsky, 2000).

In the Indonesian context, the literature highlights a rapid transition from a raw material exporter to a major global processing hub following the implementation of downstreaming policies and the nickel ore export ban (Arif, 2018). While this transformation has strengthened Indonesia's position in midstream segments, persistent challenges remain, particularly in terms of technological dependence, reliance on foreign investment, and limited participation in high-value downstream activities. These dynamics underscore the importance of examining not only industrial expansion but also the depth and quality of structural upgrading.

Analytical Framework

This study is primarily conceptual-analytical, supported by secondary data and sectoral evidence rather than econometric estimation.

This study adopts the Global Value Chain (GVC) framework as its primary analytical lens. The GVC approach conceptualizes production as a fragmented and geographically dispersed process in which different stages are allocated across countries based on cost structures, technological capabilities, and institutional conditions (Gereffi et al., 2005). A key insight of this framework is that value-added is unevenly distributed, with higher returns concentrated in knowledge-intensive and innovation-driven segments.

Within this framework, industrial upgrading is understood as the process by which firms or countries move into higher-value-added activities. The literature identifies four forms of upgrading: process upgrading, product upgrading, functional upgrading, and chain upgrading (Gereffi et al., 2005). This study focuses primarily on functional upgrading, defined as the transition into higher value-added functions such as engineering, design, innovation, and strategic control over production systems.

To complement the GVC perspective, the analysis also draws on insights from industrial policy and development economics, which emphasize that upgrading is not an automatic outcome of market participation but requires deliberate policy intervention, capability building, and institutional coordination (Amsden, 2001; Andreoni & Chang, 2019). By integrating these perspectives, the study conceptualizes Indonesia's nickel industry as part of a global production system in which upgrading depends critically on the development of technological capabilities, domestic institutions, and innovation ecosystems.

Research Design

This study employs a qualitative research design aimed at analyzing Indonesia's position within the global nickel value chain and identifying the structural constraints and opportunities for industrial upgrading. The research design is structured around three interrelated analytical components.

First, a value chain mapping approach is used to conceptualize the nickel industry as an integrated continuum, extending from mining and extraction to smelting (RKEF), refining (HPAL), and further downstream to precursor, cathode, battery cell, and electric vehicle production. This mapping enables a systematic assessment of the distribution of value-added, technological intensity, and strategic control across different stages of the value chain.

Second, the study conducts a sectoral analysis of Indonesia's nickel industry, focusing on the structure and dynamics of key industrial clusters, particularly the Indonesia Morowali Industrial Park (IMIP) and the Indonesia

Weda Bay Industrial Park (IWIP). This analysis examines the technological configuration of production, including the roles of RKEF and HPAL technologies, the composition of capital—especially the role of foreign direct investment—and the degree of integration into global production networks.

Third, the study incorporates a capability-based assessment to evaluate the extent of industrial upgrading. This includes an examination of technological capabilities, human resource development, and the strength of linkages between industry, research institutions, and universities. Particular attention is given to the extent to which Indonesia has progressed beyond operational capabilities toward innovation and technology development.

Through this multi-layered approach, the study provides a comprehensive assessment of Indonesia's industrial position and identifies key barriers to functional upgrading within the global value chain.

Data Sources

The study relies primarily on secondary data from a range of authoritative, widely recognized sources. International datasets and reports from institutions such as the U.S. Geological Survey, the World Bank, and the International Energy Agency are utilized to analyze global production trends, demand dynamics, and the strategic role of nickel in the energy transition.

At the national level, statistical publications and official reports from the Ministry of Energy and Mineral Resources, the National Development Planning Agency, the Ministry of Investment and Downstream Industry, and Statistics Indonesia are systematically reviewed to provide context-specific insights and support the analysis.

In addition, the study draws on academic literature related to global value chains, industrial upgrading, and resource-based development to establish a robust theoretical foundation. Policy documents and industry reports, including those published by the Asian Development Bank and other relevant institutions, are also incorporated to capture recent developments in Indonesia's industrial policy and sectoral transformation.

By triangulating these sources, the study ensures analytical robustness and reliability, enabling a nuanced assessment of Indonesia's position within the global nickel value chain and the challenges associated with achieving higher levels of industrial upgrading.

RESULTS

Structure of the Global Nickel Value Chain

Based on value chain mapping, the global nickel industry exhibits a clear hierarchical structure in which value-added, technological intensity, and strategic control are unevenly distributed across different stages of production. This pattern is consistent with the broader insights of global value chain (GVC) theory, which emphasizes that higher returns are typically concentrated in downstream, knowledge-intensive activities, while upstream extraction and basic processing generate relatively lower margins (Gereffi et al., 2005; Kaplinsky, 2000).

At the upstream level, nickel mining is characterized by relatively low value-added and limited technological complexity. Although mining operations require capital investment and operational expertise, they remain fundamentally commodity-based and are highly exposed to global price volatility (USGS, 2024). Consequently, the degree of strategic control at this stage is generally limited, particularly for countries that rely on raw material exports without downstream integration (WB, 2020).

Moving into the midstream segment, value-added increases through processing and refining activities. Smelting technologies, particularly Rotary Kiln Electric Furnace (RKEF), play a central role in converting nickel ore into intermediate products such as nickel pig iron (NPI) and ferronickel. While these processes generate higher value compared to raw ore, they remain moderately technology-intensive and yield medium-level margins. The level of control at this stage is also constrained by the technology's relatively standardized nature and the strong presence of established industrial players.

A more substantial increase in value-added occurs at the refining stage, particularly through High Pressure Acid Leaching (HPAL) technology. HPAL enables the processing of low-grade laterite ore into mixed hydroxide precipitate (MHP), which is a key intermediate input for battery manufacturing. This stage is characterized by higher technological complexity, greater capital intensity, and elevated operational risk (IEA, 2023b). As such, it occupies a transitional position within the value chain, linking midstream processing with downstream advanced manufacturing.

The highest levels of value creation occur in downstream segments, including the production of battery precursors, cathodes, battery cells, and electric vehicles. These activities involve advanced materials engineering, electrochemistry, and system integration, requiring sophisticated technological capabilities and strong innovation ecosystems (WB, 2020; IEA, 2023b). Control over these segments is typically concentrated in technologically advanced economies, where firms possess intellectual property, research capabilities, and established market access.

In particular, battery cell manufacturing and electric vehicle production represent the most strategic segments of the value chain. These stages integrate multiple layers of technology and generate the highest margins, reinforcing the asymmetrical distribution of value across the chain (Gereffi et al., 2005). Overall, the nickel value chain reflects a progression from low-value, resource-based activities to high-value, innovation-driven functions, underscoring the importance of upgrading for resource-rich countries seeking long-term economic transformation.

To synthesize the discussion above, Table 1 presents a structured overview of the nickel value chain**,** illustrating the distribution of value-added, technological intensity, and the degree of Indonesia's control across different stages of production. The table highlights the systematic escalation of value and complexity from upstream extraction to downstream manufacturing, while also revealing Indonesia's uneven positioning within this hierarchy.

Table 1: Value Distribution Along the Nickel Value Chain and Indonesia's Position

Stage	Activity	Value Added	Technology Intensity	Indonesia's Position/Control
Upstream	Mining	Low	Low	Medium
Midstream	Smelting (RKEF)	Medium	Medium	Medium
Midstream	Refining (HPAL)	Medium-High	High	Low
Downstream	Precursor/Cathode	High	Very High	Low
Downstream	Battery Cell	Very High	Very High	Very low
Downstream	EV Manufacturing	Extremely High	System-Level	Very low

Source: Authors' elaboration based on Arif (2018), Gereffi et al. (2016), and industry data

Indonesia's Position: Still Primarily a Processing Hub

Within this global structure, Indonesia occupies a distinctive position as both the world's largest producer of nickel ore and a rapidly expanding processing hub. The country has significantly increased its output of intermediate products, including NPI, ferronickel, and MHP, following the implementation of downstreaming policies and the nickel ore export ban.

This transformation reflects a successful shift from raw material exports to domestic processing, supported by large-scale investments in smelting and refining facilities. As a result, Indonesia has strengthened its position in midstream segments of the global value chain, particularly in supplying materials for stainless steel production and, increasingly, battery materials.

However, despite these achievements, Indonesia's participation remains heavily concentrated in upstream and midstream activities. Its presence in downstream segments—such as precursor production, cathode

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue XIV May 2026 | Special Issue on Management

manufacturing, battery cell production, and electric vehicle integration—remains limited (WB, 2020; IEA, 2023a). These segments continue to be dominated by technologically advanced countries with established industrial ecosystems.

This condition becomes even more evident when examining the market share of indigenous Indonesian firms within the domestic nickel industry itself.

In the mining phase, activities are carried out predominantly by Indonesian companies, particularly domestic private firms. Nickel mining technology—applicable to both laterite and limonite deposits—is relatively simple, relying mainly on open-pit (strip) mining rather than underground methods. According to a report by the Indonesian Nickel Miners Association (APNI, 2026), there are 420 active nickel mining permits, of which only about 30 percent are operated by joint-venture companies with Chinese or other foreign partners.

In the processing segment, Indonesia hosts 55 Rotary Kiln Electric Furnace (RKEF) smelters, 10 High-Pressure Acid Leach (HPAL) facilities, and 6 stainless steel (SS) plants, or the largest in the world in total. While RKEF smelters produce nickel pig iron (NPI) or ferronickel, stainless steel plants generate higher-value-added products such as stainless-steel slabs, hot-rolled coil (HRC), and cold-rolled coil (CRC). However, stainless steel production capacity remains limited within Indonesia. Consequently, a significant share of RKEF output continues to be exported, particularly to China.

From a technological standpoint, Indonesia’s position is relatively weak. The core technologies underpinning RKEF, HPAL, and stainless-steel production are largely relocated from China and subsequently operated in major nickel processing industrial parks such as IMIP and IWIP.

Investment in the development of these nickel industrial parks has also been dominated by Chinese capital, especially from the Tsingshan Group, which holds substantial ownership stakes in several key processing zones in Indonesia (China Global South, 2026). Although most downstream smelter outputs are still exported, there are ongoing efforts to develop domestic downstream processing capabilities, including in Java Island.

Taken together, these patterns suggest that while Indonesian firms maintain a strong presence in upstream mining activities, their participation in higher value-added and technology-intensive segments of the nickel value chain remains limited.

This structural positioning implies that Indonesia captures only a portion of the total value generated within the global nickel value chain. While the shift toward processed exports has increased domestic value-added, the highest-value activities remain located outside the country. Consequently, Indonesia functions primarily as a processing hub, rather than a center of technological innovation and advanced manufacturing.

This condition reflects what GVC scholars describe as partial upgrading, in which countries move beyond raw material exports but remain confined to intermediate stages with limited control over high-value functions (Kaplinsky, 2000; Gereffi et al., 2005).

Industrial Clusters: IMIP and IWIP

The emergence of large-scale industrial clusters, particularly the Indonesia Morowali Industrial Park (IMIP) in Central Sulawesi and the Indonesia Weda Bay Industrial Park (IWIP) in North Maluku, illustrates Indonesia’s rapid industrial transformation. These clusters are characterized by high levels of vertical integration, combining mining, smelting, and refining activities within geographically concentrated zones.

IMIP and IWIP have attracted substantial foreign direct investment (FDI), predominantly from China, enabling the development of large-scale production capacity and integration into global supply chains. Their strong export orientation and logistical efficiency have positioned Indonesia as a key supplier of processed nickel products to international markets.

However, despite their success in expanding production, these clusters exhibit several structural limitations. First, the core technologies used in these facilities—particularly in RKEF and HPAL processes—are largely imported, with engineering design and process optimization controlled by foreign firms (WB, 2020). This limits the development of domestic technological capabilities.

Second, the financing structures of these projects are heavily reliant on external capital, predominantly from China. Many investments are tied to foreign financing arrangements and long-term offtake agreements, which integrate production into global networks controlled by multinational corporations (Andreoni & Chang, 2019).

Third, linkages between these industrial clusters and the domestic innovation ecosystem remain weak. The absence of strong connections with universities, research institutions, and local suppliers constrains the potential for knowledge spillovers and technological learning (Amsden, 2001).

As a result, IMIP and IWIP can be characterized as globally integrated production hubs with limited domestic embeddedness. While they contribute to economic growth and export expansion, their capacity to drive deeper structural transformation remains constrained.

Technology Structure: RKEF and HPAL

The technological structure of Indonesia's nickel industry is dominated by two key processes—Rotary Kiln–Electric Furnace (RKEF) and High-Pressure Acid Leach (HPAL)—each with distinct implications for industrial upgrading. Nearly all of the 55 RKEF smelters, 10 HPAL facilities, and 6 stainless steel plants installed across Indonesia's nickel industrial parks have been sourced from China, with no well-developed institutional framework or clear roadmap for technology transfer.

RKEF technology has played a central role in the initial phase of downstream industrialization. It is a relatively mature and widely adopted process for converting high-grade nickel ore into nickel pig iron (NPI) and ferronickel. Its advantages include operational stability, scalability, and relatively low technical risk, making it suitable for rapid industrial expansion. However, domestic technological mastery remains limited among Indonesian firms, which control only around 30 percent of RKEF smelters, while the majority are operated by Chinese companies.

RKEF also has significant limitations. It is highly energy-intensive and, in Indonesia, is largely powered by coal-fired generation, resulting in high carbon emissions (IEA, 2023b). Electricity supply has predominantly relied on coal-fired power plants due to the country's abundant and low-cost coal resources, reflecting Indonesia's position as one of the world's largest coal producers. However, looking ahead, the expansion of export markets—particularly those with stricter environmental standards—will require a gradual reduction in coal dependence. This can be achieved through the development of renewable energy sources, especially hydropower, located in proximity to nickel processing industrial zones. Moreover, the products generated through RKEF processes offer relatively low value-added compared to battery-grade materials. As such, while RKEF provides an important foundation for industrialization, it does not by itself constitute a pathway toward higher-value upgrading.

In contrast, HPAL technology represents a more advanced and strategic stage of the value chain. It enables the processing of low-grade laterite ore into MHP, which is essential for battery production. HPAL is characterized by high technological complexity, requiring precise control of chemical processes, high-pressure systems, and advanced materials handling (IEA, 2023b).

The adoption of HPAL technology has enabled Indonesia to enter the battery materials segment, marking a critical step toward upgrading. However, control over HPAL technology remains largely external. Key aspects of process design, engineering, and equipment manufacturing are dominated by foreign firms, limiting domestic capability development.

Thus, while HPAL provides a gateway to higher value-added activities, it does not automatically lead to technological sovereignty. Without deliberate efforts to build domestic expertise, Indonesia risks remaining a technology user rather than a technology innovator.

Structural Constraints and the Processing Trap

The analysis identifies four major structural constraints that hinder Indonesia's ability to achieve functional upgrading within the global nickel value chain.

First, technological dependence remains a central challenge. Despite increased processing capacity, core technologies are largely controlled by foreign firms, limiting domestic learning and innovation (Amsden, 2001). This challenge needs to be addressed through strengthening domestic capabilities.

Second, financial dependence reinforces this constraint. The dominance of foreign direct investment (FDI) and externally driven financing structures reduces national control over strategic decision-making and the overall direction of industrial development (Andreoni & Chang, 2019).

Nevertheless, under Law No. 3 of 2020 and Government Regulation No. 96 of 2021, foreign mining companies holding mining licenses are required to gradually divest their shares to Indonesian stakeholders, reaching at least 51 percent ownership within 15 to 20 years of operation. Greater equity participation by Indonesian stakeholders is expected to strengthen domestic control over the implementation of key policies, including those related to technology transfer, human resource development, research and innovation, and broader industrial capability building (Ramadhani & Paksi, 2025)

Third, the domestic research and development ecosystem remains underdeveloped. Weak linkages between industry, universities, and research institutions limit the generation and diffusion of knowledge (WB, 2020).

Fourth, human resource capacity at the innovation level remains limited. While Indonesia has developed operational capabilities, there is a shortage of engineers and researchers capable of designing and improving advanced technologies (Amsden, 2001).

Together, these constraints create a processing trap, defined as a condition in which a country successfully expands processing capacity but remains confined to segments with relatively low value-added. In this scenario, industrialization increases production and exports but does not result in deeper structural transformation or technological upgrading.

Escaping this trap requires a shift toward capability-based development, in which technological mastery, innovation, and institutional strengthening become central to industrial strategy. Only through such a transformation can Indonesia move beyond its current role as a processing hub and achieve a more advanced and resilient position within the global nickel value chain.

DISCUSSION

Industrial Upgrading and the Ladder of Capability

Industrial upgrading in Indonesia's nickel sector can be understood as a cumulative and staged process in which capabilities are progressively deepened and diversified. This process is often conceptualized as an "upgrading ladder," reflecting a transition from resource-based activities toward more knowledge-intensive and innovation-driven industrial structures (Gereffi & Fernandez-Stark, 2016). Each stage of this ladder requires distinct capabilities, ranging from basic extraction to advanced design and innovation.

At the initial stage (Level 1), Indonesia has long been firmly established as a global leader in nickel extraction, supported by its vast lateritic reserves and high production volumes (USGS, 2024). This resource advantage provided the foundation for subsequent industrial development. Moving to Level 2, the country has achieved substantial progress in processing, particularly through the rapid expansion of rotary kiln–electric furnace (RKEF) technology for ferronickel and nickel pig iron (NPI). This phase has been strongly driven by foreign direct investment, especially from Chinese firms, enabling Indonesia to scale up industrial capacity within a

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue XIV May 2026 | Special Issue on Management

relatively short period. It is important to note that Indonesian national companies are not the primary contributors to this capacity expansion.

The transition to Level 3, refining, represents a more recent and complex phase of upgrading. The introduction of high-pressure acid leach (HPAL) technology allows Indonesia to process low-grade limonite ores into mixed hydroxide precipitate (MHP), a key intermediate for battery production. However, this stage remains technologically demanding and operationally sensitive, with high capital costs and dependence on imported inputs such as sulfur. As a result, Indonesia's position at this level can be characterized as "emerging," marked by ongoing efforts to improve efficiency and operational stability.

At higher levels of the upgrading ladder, progress remains limited. Level 4, which involves the production of advanced materials such as precursors and cathode components, is still underdeveloped. Level 5, battery manufacturing, remains weak, with Indonesia playing only a marginal role in global battery production despite its strong resource base. Finally, Level 6—encompassing innovation, design, and intellectual property—remains very limited, reflecting constraints in domestic research and development (R&D) capacity and weak integration into global innovation networks. Taken together (Table 2), this pattern indicates that Indonesia is currently transitioning from refining toward advanced materials, but faces significant structural barriers in moving further up the ladder.

Table 2: Indonesia's capability in the nickel value chain

Level	Capability	Indonesia's Status
1	Extraction	Achieved
2	Processing (RKEF)	Achieved
3	Refining (HPAL)	Emerging
4	Advanced Materials	Limited
5	Battery Manufacturing	Weak
6	Innovation & Design	Very Limited

Source: Authors' elaboration based on industry data

This framework highlights that Indonesia is currently transitioning from Level 3 to Level 4, but faces structural constraints in advancing further.

The Global Value Chain and the Smiley Curve in Nickel

The uneven distribution of value-added across these stages can be further understood through the global value chain (GVC) "smiley curve" framework. Originally conceptualized by Stan Shih, the smiley curve illustrates how value creation tends to concentrate at both ends of the value chain—upstream activities such as research, design, and intellectual property, and downstream activities such as branding, advanced manufacturing, and market-facing services—while midstream activities, including processing and assembly, typically generate lower margins (Mudambi, 2008; Baldwin, 2013).

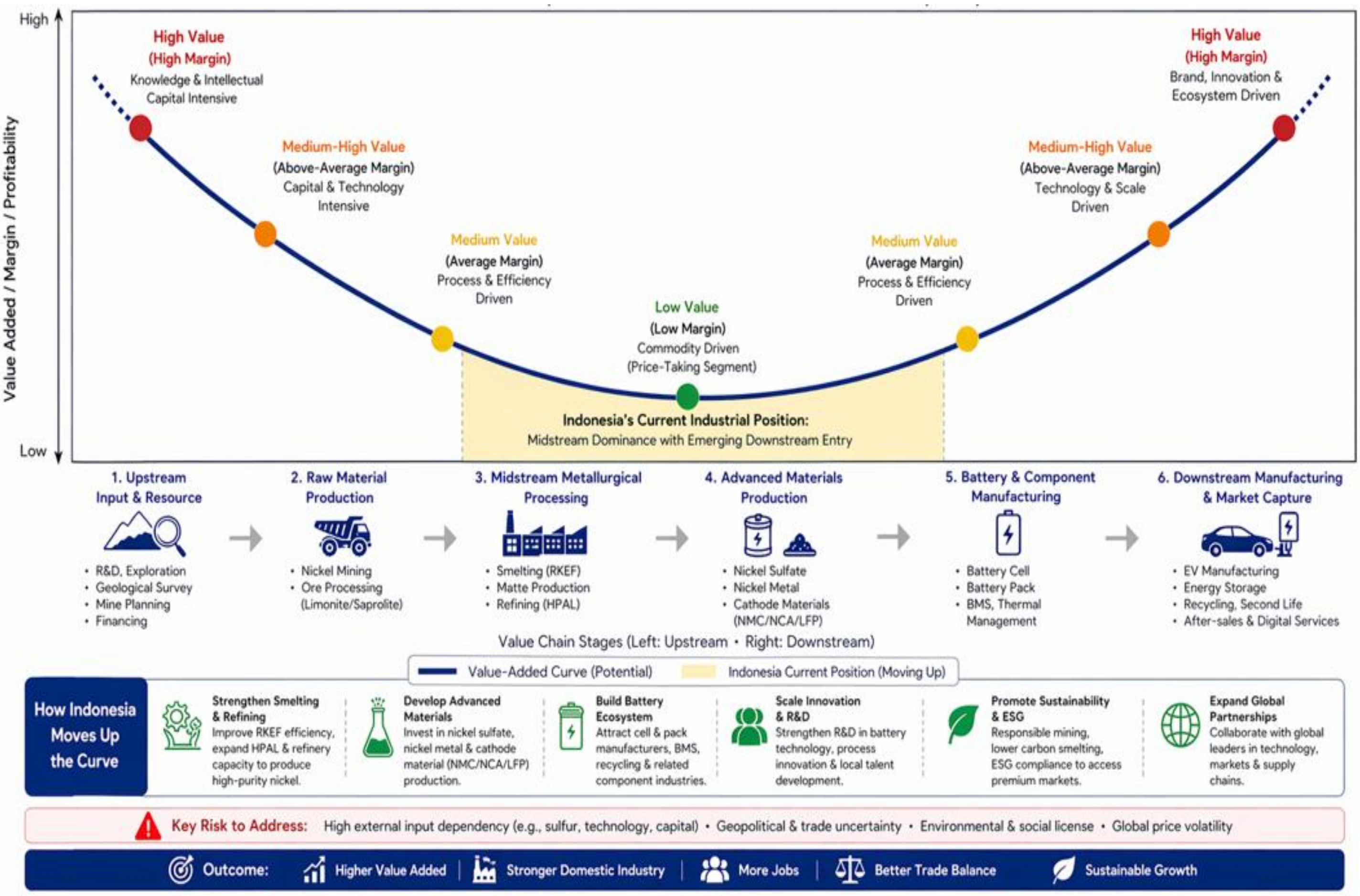
In the nickel industry, upstream activities include mining and extraction. Although these activities are capital-intensive, they generally yield limited value-added compared to downstream segments (Humphrey & Schmitz, 2002). Indonesia has historically been dominant at this stage due to its abundant resource endowment and its relatively strong capabilities in mining technology (Arif, 2018). However, resource control alone does not confer strategic control over global markets.

The midstream segment—comprising processing and refining—has been the focal point of Indonesia's industrial policy. The development of RKEF and HPAL technologies has enabled the country to move beyond raw ore exports and establish itself as a major processor of nickel intermediates. Nevertheless, these activities remain situated in the lower portion of the smiley curve, where value capture is constrained, and competition is intense.

At the downstream end of the value chain lie advanced materials, battery manufacturing, electric vehicles (EVs), and associated services. These segments are characterized by high levels of technological sophistication, innovation, and market power, allowing firms and countries operating in these areas to capture a disproportionate share of value-added (Gereffi, 2018). Currently, these segments are dominated by technologically advanced economies such as Japan, South Korea, and China.

As shown in Figure 1, Indonesia predominantly occupies the middle segment of the smiley curve. The country has successfully transitioned from a raw material exporter to a major midstream processor, particularly following the implementation of the nickel ore export ban under Law No. 4/2009 and its revision under Law No. 3/2020. However, its presence in high-value downstream segments remains limited.

Figure 1: Smiley Curve of Indonesian Nickel Industry – Upgrading Value Chain



Source: Authors' elaboration based on Gereffi et al. (2016), Mudambi (2008), and industry data.

The figure also highlights a critical constraint in Indonesia's upgrading trajectory: its continued reliance on external inputs, including sulfur for HPAL operations, foreign technology, and capital investment. This dependence exposes the industry to external risks, such as geopolitical tensions and global price volatility, which can erode margins and constrain further upgrading (Gereffi, 2018; Ponte & Sturgeon, 2014). While Indonesia has begun to enter downstream segments—such as nickel sulfate production and early-stage battery manufacturing—its capabilities in these areas remain relatively shallow. Consequently, further upgrading requires not only expansion in scale but also functional upgrading into knowledge-intensive and market-controlling activities.

Technology as the Core Constraint

Building on the upgrading ladder and Indonesia's position in the smiley curve, technological capability emerges as the central constraint and determinant of industrial upgrading. The transition from lower- to higher-value activities requires not only capital accumulation but also the development of knowledge, skills, and innovation capacity (Lall, 2000). In this regard, Indonesia's nickel industry remains largely at the "operator" stage, where firms are capable of running industrial processes but continue to rely heavily on imported technologies and foreign expertise.

Over the past decade, Indonesia has made substantial progress in building a midstream industrial base. The adoption of RKEF technology for ferronickel and NPI production, along with HPAL technology for MHP production, has enabled large-scale processing of both saprolite and limonite ores. These developments have been supported by the emergence of integrated industrial parks, such as those in Morowali and Weda Bay, which provide critical infrastructure and facilitate economies of scale. As a result, Indonesia has established itself as a key global player in midstream nickel processing.

Despite these advances, significant technological gaps persist in higher value-added segments. Domestic capabilities in advanced cathode and precursor material production remain underdeveloped. Similarly, Indonesia's participation in battery cell manufacturing—whether in lithium-ion or emerging solid-state technologies—is still limited and largely dependent on foreign investment and expertise. The absence of proprietary metallurgical process design further constrains the country's ability to innovate independently and capture higher technological rents. In addition, recycling technologies for nickel and battery materials are at an early stage, limiting participation in the circular economy, while digital and smart manufacturing systems have yet to be widely adopted.

This imbalance between relatively strong midstream capabilities and weak downstream and innovation-oriented technologies explains Indonesia's concentration in the middle segment of the smiley curve. Although the country has achieved significant industrial deepening, its limited control over advanced technologies continues to constrain its ability to move into higher-value, knowledge-intensive activities.

Capital, Dependency, and Structural Constraints

The rapid expansion of Indonesia's nickel industry has been driven largely by foreign direct investment (FDI), particularly from China. While this inflow of capital has enabled rapid industrialization and capacity expansion, it has also created new forms of structural dependency (Gereffi, 2018). Investment arrangements are often bundled with engineering, procurement, and construction (EPC) contracts, technology transfer agreements, and long-term offtake contracts, ensuring integration into global supply chains but limiting domestic control over key aspects of production and market access.

These dynamics constrain Indonesia's policy space. Although the government has effectively used export bans and investment incentives to attract capital, its ability to shape higher-value segments of the value chain remains limited. This raises the risk of a resource-based "middle-income trap," in which countries achieve industrialization but fail to move into innovation-driven activities (Auty, 2001).

Addressing these constraints requires a strategic shift in which capital is deployed as an instrument of industrial policy. This includes strengthening domestic financial institutions, leveraging state-owned enterprises, and imposing more robust requirements for technology transfer and local content development.

Human Capital and Innovation Ecosystems

Ultimately, sustained industrial upgrading depends on the development of human capital and innovation ecosystems. While Indonesia has successfully built a workforce capable of operating large-scale industrial facilities, its capacity for technological adaptation and innovation remains limited (Lall, 2000).

Bridging this gap requires a systemic approach that strengthens linkages between industry, universities, and research institutions. Aligning engineering education with industrial needs, expanding vocational training, and introducing programs such as engineering residencies can enhance the practical and innovative capabilities of the workforce. To date, initiatives such as the establishment of the Metal Industry Polytechnic at Indonesia

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue XIV May 2026 | Special Issue on Management

Morowali Industrial Park (IMIP) and the China–Indonesia Joint Laboratory for Metallurgy and New Materials at Bandung Institute of Technology (ITB) have been undertaken; however, such efforts still need to be further strengthened and expanded.

In parallel, the establishment of national research centers in metallurgy and materials science would play a critical role in fostering domestic innovation. Such institutions could support the development of indigenous technologies, reduce reliance on foreign expertise, and enable Indonesia to move into higher-value segments of the nickel global value chain. In this context, human capital development is not merely a supporting factor but a central pillar of Indonesia's long-term industrial transformation.

Environment and Energy

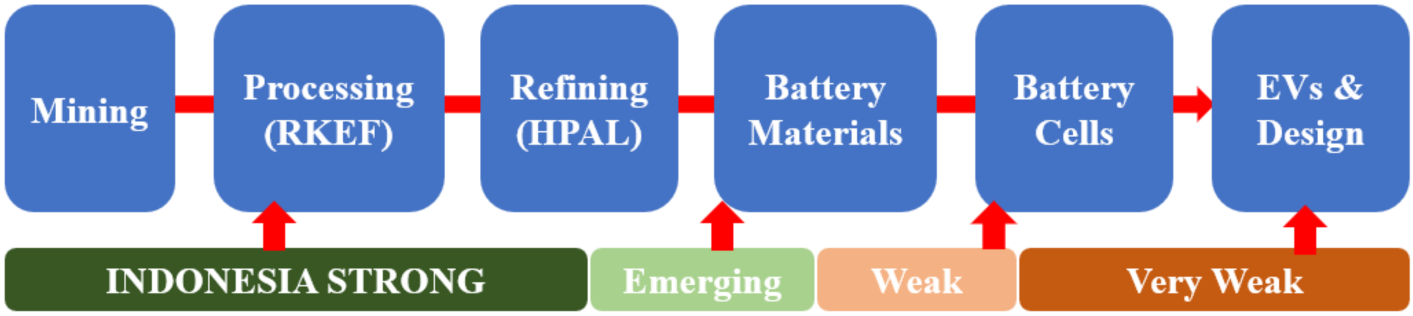
Indonesia's nickel industry is increasingly characterized by a "green paradox," in which critical materials for the global energy transition—particularly for electric vehicle batteries—are produced through environmentally intensive processes (International Energy Agency, 2023; World Bank, 2020). Another major concern lies in the carbon intensity of nickel processing. The treatment of laterite ores, especially through RKEF technology, depends heavily on captive coal-fired power plants. While coal provides a relatively cheap and readily available energy source, it significantly increases the carbon footprint of Indonesian nickel, often exceeding global averages (International Energy Agency, 2023). These environmental pressures are exacerbated by regulatory and governance gaps. Weak enforcement of environmental standards, combined with mining activities on small islands, often leads to the circumvention of existing protections, increasing the risks of landslides, flooding, and long-term ecological degradation (Organisation for Economic Co-operation and Development, 2023). Despite these challenges, efforts to improve environmental governance and sustainability practices are gradually emerging, both from the Indonesian government and industry stakeholders.

Looking ahead, the energy transition within the nickel industry will be a critical determinant of its sustainability. The continued reliance on coal—particularly for RKEF smelters—reflects current economic and technical realities, as coal remains the most cost-effective and scalable option in the short term. However, there is growing recognition of the need to reduce coal dependency over time. This transition is expected to align with the expansion of alternative energy sources, including hydropower and natural gas, which are being developed in several industrial regions, particularly in Sulawesi (Asian Development Bank, 2023b). In the longer term, there are also discussions around the potential use of nuclear energy as a low-carbon power source for industrial applications (International Atomic Energy Agency, 2022).

A Synthetic View: Indonesia in the Global Nickel Supply Chain

The following simplified figure (Figure 2) summarizes Indonesia's position within the global nickel supply chain.

Figure 2: Indonesia's position within the global nickel supply chain



Source: Author's elaboration

This representation highlights the sequential nature of industrial upgrading. Indonesia has made significant progress in upstream and midstream segments but remains constrained in downstream and innovation-driven activities.

In conclusion, Indonesia's experience in the nickel sector reflects both the opportunities and limitations of resource-based industrialization. While the country has successfully leveraged its natural endowments to build a substantial industrial base, it has yet to achieve technological leadership and high-value economic transformation. Bridging this gap will require coordinated efforts in technology development, capital mobilization, and human capital investment, enabling Indonesia to transition from a resource-based economy to an innovation-driven industrial powerhouse.

The findings above reveal a structural pattern in which Indonesia has achieved significant expansion in midstream processing but remains constrained in higher value-added segments. To interpret these patterns more systematically, the following section applies the upgrading ladder and smiley curve frameworks to analyze the depth and limitations of Indonesia's industrial transformation.

CONCLUSION

Indonesia's nickel industry has undergone a profound structural transformation, shifting from a primary exporter of raw materials to a major global hub for nickel processing. This transition, driven by downstream industrial policies and supported by large-scale investment, has significantly expanded domestic value addition and strengthened Indonesia's position within the global nickel value chain.

However, this transformation remains structurally incomplete. Indonesia's role continues to be concentrated in upstream and midstream segments, where value capture is relatively limited and technological capabilities remain externally dependent. In particular, the development of high-value downstream industries—such as battery manufacturing and advanced materials—has been constrained by limited domestic technological capacity, continued reliance on foreign expertise, and structural dependencies on critical inputs.

This paper argues that Indonesia's experience challenges the conventional linear model of industrial upgrading often assumed in the global value chain literature. Rather than progressing smoothly from extraction to innovation, resource-based industrialization may become locked in an intermediate stage characterized by partial upgrading but persistent structural constraints. This condition reflects what may be termed a "midstream entrapment," in which countries achieve significant industrial expansion without corresponding gains in technological autonomy or high-value innovation.

The implications extend beyond Indonesia. For resource-rich developing economies pursuing downstream industrialization strategies, the findings highlight the importance of coupling resource-based industrial expansion with deliberate capability-building policies. Without parallel investments in human capital, technological learning, and innovation systems, downstreaming policies risk reproducing dependency in new forms rather than overcoming it.

From a policy perspective, advancing beyond midstream entrapment will require a strategic shift toward deeper industrial capabilities. This includes strengthening domestic research and development, fostering technology transfer with clear learning objectives, and promoting linkages between resource-based industries and broader manufacturing ecosystems. Such efforts are essential not only for enhancing value capture but also for ensuring long-term economic resilience in an increasingly competitive and geopolitically complex global economy.

In sum, Indonesia's nickel industrialization represents both a remarkable achievement and an unfinished project. Its future trajectory will depend on whether the country can move beyond resource-driven industrial expansion toward innovation-led development, thereby transforming geological advantage into sustained technological and economic leadership.

REFERENCES

1. Amsden, A. H. (2001). *The rise of "the rest": Challenges to the West from late-industrializing economies*. Oxford University Press.

2. Andreoni, A., & Chang, H.-J. (2019). The political economy of industrial policy. *Structural Change and Economic Dynamics, 48*, 136–150. https://doi.org/10.1016/j.strueco.2018.08.001
3. Arif, I. (2018). *Nikel Indonesia*. Gramedia.
4. Asosiasi Penambang Nikel Indonesia (APNI). (2026). *APNI report April 2026*. https://www.apni.or.id/apni-report/april-2026
5. Auty, R. M. (2001). *Resource abundance and economic development*. Oxford University Press.
6. China Global South Project. (2026, April). *Nickel*. https://nickel.chinaglobalsouth.com/
7. Gereffi, G. (2018). *Global value chains and development: Redefining the contours of 21st century capitalism*. Cambridge University Press.
8. Gereffi, G., & Fernandez-Stark, K. (2016). *Global value chain analysis: A primer* (2nd ed.). Duke University Press.
9. Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The governance of global value chains. *Review of International Political Economy, 12*(1), 78–104. https://doi.org/10.1080/09692290500049805
10. Humphrey, J., & Schmitz, H. (2002). How does insertion in global value chains affect upgrading in industrial clusters? *Regional Studies, 36*(9), 1017–1027. https://doi.org/10.1080/0034340022000022198
11. Institute for Essential Services Reform. (2025). *Indonesia Energy Transition Outlook (IETO) 2025: Menavigasi transisi energi Indonesia di persimpangan jalan: Momen penting untuk mendefinisikan kembali masa depan*. IESR.
12. International Atomic Energy Agency. (2022). *Nuclear energy for industrial applications*.
13. International Energy Agency. (2023a). *Critical minerals market review 2023*.
14. International Energy Agency. (2023b). *The role of critical minerals in clean energy transitions*.
15. Kaplinsky, R. (2000). Globalisation and unequalisation: What can be learned from value chain analysis? *Journal of Development Studies, 37*(2), 117–146. https://doi.org/10.1080/713600071
16. Lall, S. (2000). Technological change and industrialization in the Asian newly industrializing economies: Achievements and challenges. *Oxford Development Studies, 28*(1), 13–44. https://doi.org/10.1080/13600810050032180
17. Mudambi, R. (2008). Location, control, and innovation in knowledge-intensive industries. *Journal of Economic Geography, 8*(5), 699–725. https://doi.org/10.1093/jeg/lbn024
18. Nugroho, H., & Al-Wafiy, M. (2026). Evolusi industri nikel global dan Indonesia: Tinjauan historis dan pelajaran kebijakan. *Bappenas Working Papers, 9*(2), 236–255. https://doi.org/10.47266/bwp.v9i2.560
19. Ramadhani, E., & Paksi, A. K. (2025). The price of progress: An assessment of Indonesia's nickel downstreaming policy for the global energy transition. *BIO Web of Conferences, 199*, 02002. https://doi.org/10.1051/bioconf/202519902002
20. United States Geological Survey. (2024). *Mineral commodity summaries 2024: Nickel*. U.S. Geological Survey.
21. World Bank. (2020). *Minerals for climate action: The mineral intensity of the clean energy transition*. World Bank.