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Toward Sustainable Bauxite Chains: Comparing Indonesia and Global Practices to Advance SDG 9

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ABSTRACT

This study analyzes Indonesia's bauxite downstreaming strategy within the framework of United Nations Sustainable Development Goal 9 (SDG 9) and compares it with international experiences in Australia and Guinea. The research employs a qualitative design using case study and comparative policy analysis methods based on secondary data from government reports, statistical agencies, international organizations, and academic literature. The analysis is structured around three key SDG 9 dimensions: industrial capacity (target 9.2), process sustainability (target 9.4), and technological innovation (target 9.5). The findings show that Indonesia's alumina refining capacity increased from 1.4 million tons in 2021 to approximately 5.3 million tons in 2024, while value added rose from about US$40 per ton of bauxite ore to around US$400 per ton of alumina. Despite this progress, structural challenges remain, including dependence on imported aluminum to meet 54% of domestic demand, a workforce dominated by contractual workers with limited skills transfer, foreign capital controlling 56–63% of downstream projects, and red mud waste generation estimated at 6.36–7.95 million tons annually with minimal utilization. The study concludes that sustainable downstreaming requires comprehensive policies beyond export restrictions, including infrastructure strengthening, low-carbon energy transition, technology transfer, increased R&D investment, ESG adoption, and diversified international partnerships.

INTRODUCTION

Indonesia occupies a strategic position in the global mineral resource map as one of the countries with the largest bauxite reserves in the world. Based on data from the Ministry of Energy and Mineral Resources (ESDM, 2023), Indonesia has bauxite resources of 7.4 billion tons with reserves of around 2.7 billion tons, equivalent to 534 million tons of aluminum metal. Globally, Indonesia contributes about 4% of the world's total bauxite reserves, ranking sixth after Guinea (23.6%), Vietnam (18.5%), Australia (16.3%), Brazil (8.6%), and Jamaica

(Zhou et al., 2023). The spatial distribution of these resources is concentrated in West Kalimantan (approximately 82.8%), Riau Islands (13.3%), and Central Kalimantan (3.9%), making these three provinces the main hubs for the development of the national bauxite downstream industry (ESDM, 2023).

In the context of sustainable development, mineral resource management is not only required to generate economic added value, but must also take into account social and environmental aspects. Sustainable Development Goal 9 (SDG 9) explicitly emphasizes the importance of building resilient infrastructure, promoting inclusive and sustainable industrialization, and encouraging innovation. SDG 9.2 targets an increase in the proportion of manufacturing industries in employment and gross domestic product, while target 9.4 emphasizes improving resource efficiency and adopting cleaner process technologies, and target 9.5 focuses on enhancing the technological capabilities and innovation of the industrial sector (Halkos & Gkampoura, 2021). Within this framework, the downstreaming of Indonesian bauxite is directly relevant to this global agenda.

The Indonesian government has pursued a strategic policy through a ban on bauxite ore exports, which has been in effect since June 2023, as mandated by Law No. 3 of 2020 concerning Mineral and Coal Mining (Secretariat of the Cabinet of the Republic of Indonesia, 2022). This policy is designed to encourage the development of domestic processing and refining facilities, increase state revenue, create jobs, and strengthen the competitiveness of the national aluminum industry. Quantitatively, projections of added value show that six tons of raw bauxite ore worth US$23.1 after being processed into smelter-grade alumina (SGA) are worth US$325 per ton, an increase of more than tenfold (ESDM, 2023).

However, the implementation of downstreaming policies is not without structural challenges. The experience of nickel downstreaming shows that industrial development without mature environmental and social governance planning can lead to environmental degradation, social conflict, and dependence on fossil fuels (Putranta et al., 2025). In the context of bauxite, similar challenges arise in relation to industrial waste management (red mud), intensive energy requirements, and potential dependence on foreign technology and capital. Reports indicate that global alumina production in 2023 reached 141.8 million tons and generated more than 177 million tons of red mud, with a waste production ratio of between 1 and 1.5 tons for every ton of alumina (Majumder, 2024; Li et al., 2024).

International literature on natural resource downstreaming shows that the success of downstream beneficiation policies is largely determined by institutional capacity, infrastructure readiness, and the ability to manage relations with foreign investors. The study by Toledano & Maennling (2018) on best practices in Australia emphasizes that sustainable downstreaming requires a conducive business environment, competitive energy availability, and long-term policy stability. Meanwhile, Guinea's experience in managing the bauxite sector highlights the risk of international investment disputes when national policies are interventionist without considering commitments in bilateral investment agreements (Ekanem, 2025; Oswal, 2025).

Previous research on bauxite downstreaming in Indonesia has tended to be sectoral and fragmented. Joshua (2017) highlights the motivation behind the suspension of bauxite exports to China, Ardiyanti et al. (2023) discuss the potential macroeconomic impact of the export ban, Dewi et al. (2024) examine the policy's influence on the financial performance of mining companies, Wardianingsih & Riyono (2023) emphasize the legal aspects and readiness for implementation, while Shinta & Wikarya (2024) measure the economic impact of PT Bintan Alumina Indonesia through input-output analysis. On the other hand, broader literature places mineral downstreaming as an instrument for industrial upgrading so that resource-rich countries can transform from suppliers of raw materials to producers of intermediate inputs and value-added products in the global value chain. However, its success is not only determined by the availability of reserves, but also by the ability to build industrial linkages, productivity, logistics infrastructure, energy, and institutional capacity (Morris & Fessehaie, 2014). In the Indonesian context, downstreaming is also closely linked to resource nationalism and the state's strategy to capture greater added value from the extractive sector, although this approach also presents trade-offs in the form of increased perception of investment risk and dependence on certain actors in capital and technology (Winanti & Diprose, 2020).

Beyond the economic-political dimension, the literature shows that bauxite downstreaming needs to be viewed within the framework of sustainability. The aluminum value chain faces the challenge of cross-border emissions, so that decarbonization demands increasingly affect the competitiveness and market access of downstream products (Yang et al., 2025). Social risks also arise throughout the supply chain, from mining to final products, so that policy orientations that focus only on economic output have the potential to neglect the social dimensions of industrial development (Giorgio et al., 2025). Another critical issue is the management of red mud as the main residue of the Bayer process, which presents both an environmental challenge and an opportunity for the circular economy (Alfiyan & Rinova, 2025), although scalability, techno-economic aspects, and residue management remain major obstacles (Li et al., 2024). In the context of supply chain governance, responsible sourcing practices and sustainability standards such as the Aluminium Stewardship Initiative (ASI) are increasingly relevant for strengthening traceability, socio-ecological legitimacy, and reducing supply chain risks (Brink et al., 2019; Sauer, 2021). Meanwhile, the investment governance literature shows that more assertive downstreaming strategies can also increase exposure to investment disputes, as reflected in the case of Guinea, which faces a large ICSID claim (Oswal, 2025).

Despite the growing body of literature on bauxite downstreaming in Indonesia, a clear research gap remains: no study has systematically evaluated Indonesia's bauxite downstreaming policy using the SDG 9 framework while also drawing comparative lessons from international experiences. Specifically, existing studies focus largely on economic, legal, or financial aspects in isolation, without integrating the three interrelated dimensions of SDG 9, resilient infrastructure (target 9.1), inclusive and sustainable industrialization (targets 9.2 and 9.4), and innovation and technological capability (target 9.5) (Brodny & Tutak, 2023). Moreover, cross-country comparative analysis between Indonesia and major bauxite-producing nations such as Australia and Guinea is conspicuously absent in the current literature.

Thus, the central problem driving this research is: to what extent has Indonesia's bauxite downstreaming policy, particularly after the 2023 export ban, succeeded in achieving sustainable industrial development in line with SDG 9, and what can Indonesia learn from the successes and failures of other bauxite-producing countries? This problem is important because downstreaming policies carry significant trade-offs between economic gains, environmental risks, social conflicts, and governance challenges, which have not been holistically addressed in previous sectoral studies.

In light of the research gap and problem formulation outlined above, the objectives of this study are explicitly twofold. First, it aims to analyze Indonesia's bauxite downstreaming strategy and evaluate its achievements and challenges within the framework of SDG 9, specifically focusing on targets 9.2 (inclusive and sustainable industrialization), 9.4 (resource efficiency and cleaner technologies), and 9.5 (technological capabilities and innovation). Second, the study seeks to compare Indonesia's experience with downstreaming practices in Australia and Guinea, thereby deriving adaptive policy lessons for the development of a sustainable bauxite value chain.

METHOD

This study employs a qualitative research design, specifically combining case study and comparative policy analysis methods. This design is selected for three main reasons. First, the case study approach is appropriate because Indonesia's bauxite downstreaming policy following the 2023 export ban represents a contemporary, context-dependent phenomenon that cannot be separated from its institutional, political, and geographical setting (Yin, 2018). Second, comparative policy analysis is necessary to identify not only what happens in Indonesia but also why certain outcomes occur, by contrasting Indonesia's experience with two distinct reference cases: Australia (representing a mature, institutionally stable resource economy) and Guinea (representing a resource-rich developing country with high investment exposure). Third, the combination of case study and comparison enables both thick description and analytical generalization, which aligns with the study's dual objectives of evaluation and lesson-drawing.

Data for this study are obtained exclusively from secondary sources, which are deliberately selected to ensure coverage across three levels of analysis: national policy, statistical performance, and international benchmarking. Specifically, the data sources include: (1) national policy documents, such as Law No. 3 of 2020 on Mineral and Coal Mining, Minister of Energy and Mineral Resources Regulation No. 17 of 2020, and Minister of Energy and Mineral Resources Decree No. 268 of 2024 on the Reference Price of Bauxite Minerals, these documents provide the formal legal and regulatory framework for downstreaming; (2) statistical reports from the Central Statistics Agency (BPS), the Ministry of Energy and Mineral Resources, and the Ministry of Industry, these provide quantitative indicators on production, employment, and added value; (3) international publications from the United States Geological Survey (USGS), the World Bank, the Aluminium Stewardship Initiative (ASI), and the International Institute for Sustainable Development (IISD), these enable cross-country comparison and sustainability benchmarking; (4) sustainability reports from mining and smelter companies (e.g., PT Bintan Alumina Indonesia, Antam), these offer firm-level evidence on environmental and social practices; and (5) scientific journal articles and research reports from economic research institutions, these supply theoretical grounding and empirical findings from prior studies.

Data analysis is conducted interactively following the three-stage model of Miles et al. (2014), data condensation, data display, and conclusion drawing/verification. In the first stage (data condensation), thematic analysis is applied to code all collected documents according to the SDG 9 indicators. This coding process is performed manually through repeated reading and categorization of text segments that correspond to each indicator (e.g., industrial capacity, waste management, technological independence). In the second stage (data display), a comparative matrix is constructed with countries (Indonesia, Australia, Guinea) as rows and SDG 9 indicators as columns, allowing systematic side-by-side comparison of achievements and challenges across the three cases. In the third stage (conclusion drawing), findings are interpreted by identifying patterns of convergence and divergence across countries, while verification is achieved through source triangulation, cross-checking policy documents against statistical data and company reports, to enhance credibility and reduce single-source bias.

To ensure systematic evaluation, this study develops an analytical framework that operationalizes SDG 9 into measurable indicators. As detailed in Table 2, the framework comprises three main dimensions: (1) inclusive industry (SDG 9.2), measured by industrial capacity (alumina refinery output), economic added value (contribution to GDP per ton of bauxite), and employment (direct and indirect jobs); (2) process sustainability (SDG 9.4), measured by waste management (red mud utilization rate), energy efficiency (energy intensity per ton of alumina), and land rehabilitation (rehabilitated area vs. mined area); and (3) technology and innovation (SDG 9.5), measured by technological independence (share of locally controlled refining capacity), research and development (R&D expenditure as percentage of revenue), and human resource capacity (skilled workforce availability). These indicators guide data collection, thematic coding, and comparative assessment. The framework draws on three interconnected strands of literature, resource-based industrialization (Morris & Fessehaie, 2014), the political economy of extractive industries (Winanti & Diprose, 2020), and the sustainability of global mineral value chains (Brink et al., 2019), which together justify the selection of indicators and the interpretive lens applied in the Results and Discussion section.

A methodological limitation of this study is its exclusive reliance on secondary data, which means that insider perspectives from policymakers, industry managers, and local communities are not directly captured. Consequently, the findings reflect documented policies and reported outcomes rather than implementation realities as experienced by actors on the ground. Future research should complement this analysis with primary data collection through interviews or surveys.

The Concept of Downstreaming and Industrialization Based on Natural Resources

Downstream processing refers to a series of activities that transform raw materials into intermediate or final products with higher added value (Ostensson, 2019). In the context of mineral resources, downstream processing includes refining, smelting, and fabrication activities that shift a country's position from being merely a supplier of primary commodities to a producer of processed products. This concept is rooted in the idea of resource-based

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industrialization, which views resource-rich countries as being able to leverage their comparative advantages to build domestic industrial capacity and upgrade their position in the global value chain (Altenburg, 2011).

Literature on natural resource-based industrialization distinguishes several stages in the mineral value chain. The upstream stage includes exploration and ore mining activities; the midstream stage includes refining and smelting into intermediate products such as alumina; while the downstream stage includes fabrication into final products such as aluminum sheets, automotive components, and consumer goods (Gereffi et al., 2005). The success of downstreaming is not only measured by an increase in export value, but also by the creation of local linkages, technology transfer, equitable distribution of economic benefits, and environmental sustainability. Ostensson (2019) asserts that downstreaming policies often become an arena of tension between national interests to increase added value and the interests of foreign investors who want business certainty. The success of downstreaming requires a balance between investment incentives, institutional capacity, and the readiness of supporting infrastructure.

SDG 9: Industry, Innovation, and Infrastructure

Sustainable Development Goal 9 is designed to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. The targets in SDG 9 that are relevant to bauxite downstreaming can be seen in Table 1.

Table 1. Targets in SDG 9

SDG 9 Target (relevant to bauxite downstreaming)	Target Formulation	Key Indicators	Operationalization in Bauxite Downstreaming
9.2	Promote inclusive and sustainable industrialization; by 2030, significantly increase the share of industry in employment and GDP in line with national conditions	(1) Proportion of manufacturing value added to GDP (2) Proportion of labor in the manufacturing sector	Measured by increases in production capacity (e.g., alumina), employment, and the contribution of the processing sector to the national and regional economies
9.4	By 2030, improve infrastructure and retrofit industries to be sustainable through resource efficiency and the adoption of clean/environmentally friendly process technologies	(1) CO_2 emission intensity per unit of value added (2) Industrial waste management (3) Energy and water efficiency	Related to red mud management, energy efficiency in purification/smelting, and post-mining land rehabilitation
9.5	Enhance scientific research and technological capabilities in the industrial sector; encourage innovation, including increasing the number of	(1) Industrial technology capabilities (2) Innovation/R&D activities (3) Number of	Measured through process technology mastery, technology transfer from foreign partners, and innovation

SDG 9 Target (relevant to bauxite downstreaming)	Target Formulation	Key Indicators	Operationalization in Bauxite Downstreaming
	researchers per million inhabitants	researchers per million inhabitants	(e.g., waste utilization and production efficiency)

Source: Author's adaptation from Halkos & Gkampoura (2021).

In the context of mineral downstreaming, achieving SDG 9 requires synergy between physical infrastructure development, technological capacity building, and policies that ensure industrial growth does not sacrifice environmental sustainability and social justice.

Bauxite Value Chain Sustainability Analysis Framework

This study develops an analytical framework that integrates the three main dimensions of SDG 9 outlined above. These three dimensions are operationalized into specific indicators to evaluate the downstreaming of Indonesian bauxite, as shown in Table 2.

Table 2. Analytical Framework for Bauxite Downstreaming in the Context of SDG 9

SDG 9 Dimension	Indicator	Sub-Indicator	Data Source
9.2: Inclusive Industry	Industrial capacity	Installed refinery capacity, alumina production, expansion projections	Ministry of Energy and Mineral Resources, Ministry of Industry
	Economic added value	Contribution to GDP, value of processed product exports	BPS, UN Comtrade
	Employment	Number of workers, job quality (permanent/contract), local labor absorption	Ministry of Energy and Mineral Resources, Ministry of Manpower
9.4: Process Sustainability	Waste management	Red mud volume, storage system, waste utilization program	Environmental Impact Assessment, Company Reports
	Energy efficiency	Energy intensity per unit of production, energy sources	Ministry of Energy and Mineral Resources
	Land rehabilitation	Area of reclaimed land, post-mining program	Sustainability Report
9.5: Technology & Innovation	Technology independence	Ownership structure, technology transfer contracts	Company Report
	Research and development	R&D budget, patents, process innovation	Ministry of Research and Technology, National Development Planning Agency
	Human resource capacity	Training programs, workforce certification	Company reports

Source: Compiled by the author from Halkos & Gkampoura (2021).

RESULT AND DISCUSSION

Indonesia's Bauxite Downstreaming Strategy: Achievements and Challenges within the Framework of SDG 9

This section is presented in stages through three interrelated analytical dimensions. The discussion begins by highlighting the dimensions of infrastructure and industrial capacity (SDG 9.2) as the foundation for strengthening the domestic processing base. Next, it reviews the dimension of industrial process sustainability (SDG 9.4) to assess the environmental consequences and resource efficiency in downstream operations. It then discusses the dimension of technological independence and innovation (SDG 9.5), particularly related to technology mastery, research agendas, and strengthening human resource capacity as prerequisites for sustainable industrialization.

a. Infrastructure and Industrial Capacity Dimension (SDG 9.2)

The implementation of Indonesia's bauxite downstreaming policy has led to a significant increase in domestic processing industry capacity. Based on data from the Ministry of Energy and Mineral Resources (2023), by early 2025 Indonesia will have four active alumina refining facilities in operation with a total input capacity of around 41.30 million tons of ore per year (ESDM, 2023). The four facilities are shown in Table 3 below.

Table 3. Bauxite downstream facilities in Indonesia

No	Company	Location	Product Type	Production Capacity	Operational Description
1	PT Indonesia Chemical Alumina (ICA)	Tayan, West Kalimantan	Chemical Grade Alumina (CGA)	±300,000 tons/year	Fully operational since 2014
2	PT Well Harvest Winning Alumina Refinery (WHW-AR)	Ketapang, West Kalimantan	Smelter Grade Alumina (SGA)	±1,000,000 tons/year (expanded to ±2,000,000 tons/year in 2022)	Capacity expanded in 2022
3	PT Bintan Alumina Indonesia (BAI)	Bintan, Riau Islands	Smelter Grade Alumina (SGA)	±350,000 tons/year	Fully operational
4	PT Borneo Alumina Indonesia (SGAR Mempawah)	West Kalimantan	Smelter Grade Alumina (SGA)	±1,000,000 tons/year	Inaugurated in September 2024; collaboration between PT ANTAM and PT INALUM under the MIND ID consortium

Source: (Azzahra, 2025; ESDM, 2023, 2024).

With the operation of these facilities, the national alumina refining capacity increased from 1.4 million tons in 2021 to ±5.3 million tons in 2024, or an increase of 279% in three years. Future projections target national alumina production capacity to reach 13.9 million tons per year by 2027, in line with the Grand Strategy for Minerals and Coal (ESDM, 2023). From a trade perspective, structural changes are beginning to be seen in alumina export-import data. The Ministry of Industry noted that in the January-August 2025 period, alumina exports reached around 3.66 million tons, while imports fell to around 816 thousand tons. This decline in imports indicates an increase in domestic supply for industrial needs and the beginning of a surplus in the alumina trade balance as an intermediate product (Mulyana & Perwitasari, 2025). Before the export ban policy, bauxite ore exports reached 17-18 million tons in 2022, but after the ban was implemented, ore exports fell sharply to less than 2 million tons in 2023 (USGS, 2023).

However, this achievement still leaves structural challenges. The total national demand for aluminum reaches around 1.024 million tons per year, with the automotive sector as the largest user (327,680 tons or 32%), followed by the extrusion sector (296,960 tons or 29%), sheet/plate (174,080 tons), cable (153,600 tons), and foil (71,680 tons). Indonesia still imports around 54% of its total national aluminum demand, indicating that downstreaming has not yet fully reached the downstream stage (Muliawati, 2025). Primary aluminum imports mainly come from China and several other ASEAN countries.

From an employment perspective, the construction and operation of processing facilities have created new jobs. Data from the Ministry of Energy and Mineral Resources shows that the downstream bauxite sector will absorb around 3,734 direct workers in 2024. Projections for the Galang Batang Special Economic Zone (KEK) in Bintan show the potential for employment of up to 23,200 people at the full development stage (Ministry of Manpower of the Republic of Indonesia, 2023). A study by(Shinta & Wikarya, 2024) using an input-output model shows that the downstream operations of PT Bintan Alumina Indonesia could create an average of 107,105 job opportunities per year spread across 52 national economic subsectors during the 2021-2030 period.

However, the quality of employment remains a concern. Approximately 61% of workers in the downstream bauxite sector are contractual with limited skills development. The ratio of foreign workers to local workers in several strategic projects reaches 1:10 for technical and managerial positions, indicating limited skills transfer. This indicates the existence of a dual labor market structure, where high-paying jobs tend to be filled by skilled workers from outside the region or abroad, while local workers are in lower-paying positions with limited opportunities for skills development.

b. Industrial Process Sustainability Dimension (SDG 9.4)

From a sustainability perspective, bauxite downstreaming poses significant environmental challenges. The Bayer process for refining alumina produces bauxite residue (red mud) that is highly alkaline (high pH) and voluminous. Based on projected alumina production capacity of 5.3 million tons/year, estimated red mud production reaches 6.36-7.95 million tons per year, assuming a ratio of 1.2-1.5 tons of waste per ton of alumina. Red mud management is a crucial issue in the framework of SDG 9.4, which emphasizes improving resource efficiency and adopting clean industrial process technologies. Globally, of the approximately 4 billion metric tons of red mud stored in various storage sites around the world, only a small percentage has been successfully reused (USGS, 2023). The main risks associated with red mud include the stability of storage facilities, the potential for seepage into water bodies, and the long-term impact on ecosystems and public health.

In Indonesia, red mud management is regulated through Environmental Impact Assessment (EIA) and Environmental Permit requirements. Several companies have made efforts to utilize red mud as a construction raw material, but the scale is still limited. Research on the recovery of valuable metals from red mud and its use as an adsorbent is still in the development stage (Dewi et al., 2024; Hakim et al., 2022). On the other hand, bauxite downstreaming also requires a large and stable energy supply. The alumina refining and aluminum smelting industries are energy-intensive industries. Data shows that the construction of one bauxite smelter unit requires approximately US$1.5 billion, with a significant component for energy infrastructure (Wardianingsih & Riyono, 2023). Dependence on fossil fuels has the potential to conflict with Indonesia's commitment to achieving its target of reducing greenhouse gas emissions by 31.89% by 2030 and net-zero emissions by 2060.

Another dimension of process sustainability is post-mining land rehabilitation. Laterite bauxite mining practices involve the removal of topsoil, which is key to successful reclamation. The study by(Putri et al., 2024) Putri et al. (2024) emphasizes that the restoration of former bauxite mining sites requires proper topsoil management and revegetation so that ecosystem functions can gradually recover. Several companies have implemented reclamation programs, but their consistency and effectiveness still vary.

c. Dimension of Technological Independence and Innovation (SDG 9.5)

An analysis of the ownership structure of downstream projects reveals challenges in achieving technological independence. PT Well Harvest Winning Alumina Refinery (WHW-AR), the largest alumina refining facility in Indonesia, has a shareholder structure dominated by foreign capital, with China Hongqiao Group Co. Ltd. holding approximately 56% of shares, while PT Cita Mineral Investindo Tbk (part of the Harita Group) holds only about 30%, with the remainder held by Winning Investment (HK) Co. Ltd and other foreign entities. A similar structure is also seen in PT Bintan Alumina Indonesia, which is dominated by Zhongse Group (China) (Whwalumina, 2026).

Data from the Indonesian Bauxite Association (ABI) shows that by 2025, foreign capital, mainly from China, will dominate around 56-63% of all planned bauxite smelter projects. This dominance has implications for technological control, access to production processes, strategic decision-making, and the direction of industrial development. In terms of technological mastery, all alumina refining facilities in Indonesia use standard Bayer technology supplied by foreign engineering, procurement, and construction (EPC) companies. EPC contracts and equipment procurement generally involve companies from China, Europe, or Australia that have extensive experience in similar projects. This situation creates ongoing technological dependence, where process innovation and technological development remain in the hands of foreign suppliers.

In terms of research and development, investment in R&D in the downstream mineral sector remains limited. Data from the National Development Planning Agency (Bappenas) shows that the R&D budget for the mining and mineral processing sector is far below that of developed countries such as Australia. Several companies have collaborated with universities on research into waste utilization and process efficiency, but the scale remains limited and has not been integrated into the national industrial strategy. In the context of SDG 9.5, achieving technological independence and innovation still requires systematic efforts, including structured technology transfer policies, increased R&D investment, and human resource development through vocational programs and continuous training.

Evaluation of SDG 9 Achievement in Indonesian Bauxite Downstreaming

Based on the above analysis, the achievements and challenges of Indonesian bauxite downstreaming within the framework of SDG 9 can be summarized as follows as Table 4.

Table 4. Evaluation of Indonesian Bauxite Downstreaming within the SDG 9 Framework

SDG 9 Dimension	Indicator	Achievement	Challenges	Recommendations
9.2: Inclusive Industry	Production capacity	1.4 million tons (2021) → 5.3 million tons (2024); projected 13.9 million tons (2027)	Aluminum imports 54%; spatial imbalance in industry	Acceleration of aluminum smelter development; downstream industry integration
	Economic added value	Value added of ore US$40/ton → alumina US$400/ton	Value added is not yet optimal due to alumina exports	Development of an integrated aluminum industry
	Employment	3,734 direct workers; projected 23,200 in Galang Batang Special Economic Zone	61% contractual workers; limited skills transfer	Vocational training programs; local hiring policies
9.4: Process Sustainability	Waste management	Environmental Impact Assessment (EIA) and Environmental Permits for all projects	Red mud production of 6.3-7.9 million tons/year; limited utilization	Research on red mud utilization; strengthening of supervision
	Energy efficiency	Energy needs are met for operations	Fossil fuel dependence; GHG emissions	Transition to renewable energy; energy efficiency incentives
	Land rehabilitation	Reclamation programs by companies	Consistency and effectiveness vary	Standardization of reclamation; strengthening of law enforcement
9.5: Technology & Innovation	Technological independence	4 refineries operating with standard Bayer technology	56-63% foreign ownership; technology control overseas	Structured technology transfer policy; increase in local content

SDG 9 Dimension	Indicator	Achievement	Challenges	Recommendations
	Research and development	Limited cooperation with universities	Low R&D budget; minimal patents	Research incentives; triple helix collaboration
	Human resource capacity	Internal company training programs	Competency gap; dependence on foreign workers	Competency certification; strengthening vocational education

Source: Compiled by the author from various sources (ESDM, 2023; USGS, 2023; Shinta & Wikarya, 2024; Whwalumina, 2026).

Comparison with International Experience

This section provides a comparative analysis of Indonesia's bauxite downstreaming strategy by looking at the experiences of Australia and Guinea. Australia's approach is characterized by a market-based model that is underpinned by strong infrastructure, which has allowed it to successfully manage its bauxite resources. In contrast, Guinea's situation highlights the complex balance between maintaining resource sovereignty and the risks associated with investment disputes. By examining these international experiences, valuable lessons can be drawn to improve Indonesia's approach and address the challenges it currently faces in its bauxite downstreaming efforts.

a. Australia: Market-Based Model with Strong Infrastructure

Australia represents a market-led industrial upgrading model that is fundamentally different from the approach of direct intervention through export bans. Instead of restricting exports as the main instrument, Australia relies more on regulatory certainty, investment incentive structures, and strengthening competitiveness prerequisites, particularly infrastructure, energy, and workforce skills, to encourage value-added activities throughout the mineral value chain. Within the framework of resource political economy, this approach can be interpreted as an effort to create an enabling environment that reduces transaction costs and policy risks, so that downstream integration decisions are driven more by calculations of long-term profitability and productivity than by discretionary trade restrictions. Empirical evidence shows that policy uncertainty has a negative effect on capital-intensive mining sector investment decisions; therefore, regulatory stability and institutional credibility are important determinants of downstream investment attractiveness (Ma, 2015).

The strengths of the Australian model are primarily supported by mature, integrated, and large-capacity commodity logistics infrastructure, particularly in mineral-producing states such as Western Australia (WA). The mine-to-port logistics system in Pilbara reflects the integration of bulk ports, stockyard facilities, and heavy haul rail networks that have been consistently built and upgraded through large private investments operating within a relatively stable regulatory framework. Quantitatively, Port Hedland, as the main hub for ore exports, recorded iron ore export volumes of around 536 million tons (2022), with plans to increase export capacity to 660 million tons per year (Government of Western Australia, 2023). This enormous port capacity is supported by an extensive mining rail corridor, with four major mining rail networks in the Pilbara region reportedly covering more than 3,800 km of track, connecting mining clusters directly to export ports (Port Hedland and Dampier). This configuration reduces logistics costs per ton, increases throughput and supply reliability, and strengthens the export competitiveness of minerals and (potentially) investment in processing based on stable supply (Pilbara, 2021).

The mineral processing industry is an energy-intensive sector; therefore, adequate energy availability and managed price risk are key factors in downstream investment feasibility. Australia has a large gas production base and infrastructure (including LNG exports), which is macro-level reflected in the value of LNG exports: Australia's LNG export revenue is projected to be around A$65 billion in 2024–25 (before declining in the following year's projections) (Department of Industry Science and Resources Australia, 2025). At the subnational policy level, WA implements the WA Domestic Gas Policy, which requires LNG exporters to set aside gas equivalent to 15% of LNG production for the WA domestic market, a mechanism that aims to strengthen domestic supply security within the framework of market transactions (Government of Western Australia, 2025).

On the other hand, Australia is also experiencing an acceleration in renewable energy that is relevant to strengthening industrial competitiveness (including process electrification and premium decarbonization in the supply chain). Official Australian government data shows that renewable energy contributed 36% of total national electricity generation in 2024 (with solar contributing 18%, wind 12%, and hydro 5%) (Australian Government, 2025). Additionally, within the NEM system, AEMO reports that the renewable share reached a record 46% in Q4 2024 (AEMO, 2025). The literature also confirms that the integration of renewable energy in Australian mining operations is developing rapidly and is increasingly positioned as a response to energy costs, emission risks, and global supply chain demands, which indirectly strengthen the clean energy-based downstream ecosystem (Strazzabosco et al., 2022).

The availability of skilled labor is a prerequisite for downstream investment not to be hampered by skills bottlenecks. Australia relies on vocational education and training (VET), apprenticeships, and continuing education as engines for supplying technical competencies. Quantitatively, the NCVER reports that the completion rate of participants who started apprenticeships/traineeships in 2019 was 54.8% (2023 report), illustrating the scale and dynamics of the supply of skills based on training contracts (NCVER, 2023). Although this figure is not specific to the mining sector, it indicates the existence of an institutionalized training pipeline that can be aligned with the needs of the mining and processing cluster through industry partnerships and competency-based curricula.

Australia's advantage in attracting large-scale investment is largely attributed to the credibility of its institutions, policy predictability, and legal certainty, thereby reducing the risk of sudden regulatory changes. The key lesson from Australia is that the effectiveness of downstreaming is not only determined by restrictive instruments (e.g., export bans), but also by the readiness of structural foundations that reduce logistics costs, mitigate energy risks, and ensure the availability of skills. In other words, downstreaming will be more sustainable if it is simultaneously supported by: (i) large-capacity industrial logistics corridors (mine–processing–port); (ii) reliable access to energy with an increasingly clean mix; and (iii) a technical training ecosystem that is directly linked to industry needs. In this context, policy emphasis on infrastructure development, investment climate reform, and strengthening technical human resources has the potential to increase the probability of downstreaming success, while reducing the risk of policy backlash due to supply disruptions, high energy costs, or a shortage of skilled workers.

b. Guinea: Between Resource Sovereignty and the Risk of Investment Disputes

Guinea is one of the epicenters of the global aluminum supply chain due to its vast bauxite resources. The U.S. Department of Commerce notes that Guinea has approximately 23% of the world's bauxite reserves and has been the leading exporter since 2019 (Department of Commerce United States of America, 2024). In line with this quantitative data, the USGS (Mineral Commodity Summaries) places world bauxite reserves at around ±30 billion tons (reserves category), so Guinea's often-cited share is in the range of ±23–25% (depending on the year and estimation method) (USGS, 2024). In terms of trade flows, Guinea exported around 102–103 million tons of bauxite in 2022 (with an export value of around US$5.1 billion), and in 2025 its exports are reported to have increased to 182.8 million tons (about 74% shipped to China), confirming Guinea's dominance in the global aluminum ore supply (Department of Commerce United States of America, 2024).

In the context of industrial policy, Guinea shows a pattern that is relevant to Indonesia's experience, namely the push for downstreaming/domestic processing to increase added value, state revenue, and industrial upgrading. Reuters reports that the Guinean government is encouraging a reduction in raw material exports through investment in processing facilities (e.g., alumina), including plans to build an alumina refinery with a capacity of 2 million tons (targeted for phased operation) with an estimated investment of around US$4 billion (Reuters, 2024). However, efforts to restructure the sector are also being carried out through tougher administrative measures, including the revocation of licenses for a number of operators as part of the state's tightening of control over mining (Ekanem, 2025; Oswal, 2025).

However, Guinea's experience shows that interventionist policies in the extractive sector have the potential to trigger material international legal risks, particularly through the Investor–State Dispute Settlement (ISDS) mechanism. The most notable case is the claim by Axis International Ltd at the ICSID (World Bank arbitration) with a compensation claim of approximately US$28.9 billion related to the revocation of a bauxite mining permit in the Boffa region. In a Reuters report, Axis stated that the mine had been operating, producing around 18 million tons in 2024, and had proven reserves of >800 million tons, which were used as the basis for its argument of loss. The significance lies not only in the size of the claim, but also in the spillover effect: the same report emphasizes that the escalation of disputes can have an impact on the country's risk perception, including the potential disruption of access to external funding/support if the country is not cooperative in the dispute resolution process (NES Africa Group, 2025; Oswal, 2025).

The main lesson from Guinea is the need for a precise balance between (i) resource sovereignty and development agendas (e.g., downstreaming), and (ii) investment legal certainty shaped by BITs/IIAs and investment arbitration practices. The literature shows that waves of resource nationalism and downstreaming policies in the mineral sector often emerge as a response to unequal global value structures, but at the same time increase a country's exposure to disputes and regulatory risk when policy changes are perceived to violate legitimate expectations or protection standards in investment agreements (Winanti & Diprose, 2020). At this point, policy design (e.g., transition, proportional compensation , due process, and administrative consistency) becomes crucial to reduce the probability of claims while maintaining the state's regulatory space (right to regulate), including by mainstreaming sustainable development clauses in the architecture of modern investment agreements (Gazzini, 2014).

For Indonesia, Guinea's relevance is growing stronger because Indonesia is already embroiled in a trade dispute related to mineral policy, DS592 (Indonesia—Measures Relating to Raw Materials) filed by the European Union at the WTO concerning nickel export restrictions and downstreaming policies (WTO, 2022). Therefore, anticipating the risk of disputes (both through the WTO and potential ISDS) needs to be done by strengthening arguments based on the principle of permanent sovereignty over natural resources and justifying sustainable development policies, accompanied by the structuring of domestic instruments to be compatible with international obligations without sacrificing industrialization goals.

To clarify the nature of Indonesia's bauxite downstreaming within the framework of SDG 9, this section briefly compares it with Australia (a market-based model with a strong infrastructure-energy-human resources foundation) and Guinea (downstreaming driven by investment dispute risks). A comparison of bauxite downstreaming between Indonesia, Australia, and Guinea can be seen in Table 5.

Table 5. Comparison of Bauxite Downstreaming (Indonesia–Australia–Guinea)

Aspect	Indonesia	Australia	Guinea
Policy model	Stronger intervention through a ban on ore exports to encourage domestic refining	Market-based: investment incentives, regulatory certainty, enabling environment (without major restrictive instruments)	Encouraging local processing + tightening permits (revoking permits/industrial sanitation)
Infrastructure & logistics	Upgrading of refinery facilities (4 active units); supporting infrastructure remains a bottleneck in some areas	Very strong & integrated (mine-to-port logistics); Port Hedland 536 million tons (2022); mining railways >3,800 km	Main focus on large-scale bauxite exports; policy and governance issues are more prominent than downstream infrastructure strengthening
Downstream capacity (alumina)	Refining capacity increased by 1.4 million tons (2021) → ±5.3 million tons (2024) (+279%); target of 13.9 million tons (2027)	Downstreaming is supported by structural readiness (infrastructure–energy–human resources); specific data on alumina capacity is not emphasized in this narrative	There are plans for a 2 million ton alumina refinery (estimated investment of US$4 billion)
Trade impact	Alumina exports of 3.66 million tons (Jan–Aug 2025); imports down by ±816 thousand tons.	Relying on logistics efficiency and competitiveness; model promotes added value	Dominant bauxite exports: 102–103 million tons (2022); increase of 182.8

Aspect	Indonesia	Australia	Guinea
	Ore exports down from 17–18 million tons (2022) → <2 million tons (2023)	without export restrictions as the main instrument	million tons (2025), ±74% to China
Energy for industry	Energy-intensive industries; 1 smelter requires ±US$1.5 billion, significant energy component; challenges in transitioning from fossil fuels	Competitive energy: domestic gas base; domestic gas policy WA 15%; renewable power plants 36% (2024); NEM 46% (Q4 2024)	Downstream energy needs are an issue, but the biggest risk in this example is investment and governance disputes.
Employment & Human Resources	Direct downstream workforce 3,734 (2024); Galang Batang SEZ potential 23,200; quality issues: 61% contractual, foreign worker to local worker ratio 1:10 (technical/managerial positions)	VET ecosystem; apprenticeship/traineeship completion rate (since 2019) 54.8% (2023 report)	Human resource impact is not a primary focus; sector dynamics are more influenced by policy and legal risks
Sustainability of the process (SDG 9.4)	Red mud projected at 6.36–7.95 million tons/year (ratio of 1.2–1.5/ton of alumina); utilization still limited; reclamation/topsoil issues	Sustainability pressures are addressed through decarbonization and renewable energy integration (increasing supply chain competitiveness)	Environmental challenges exist at the production scale; however, the main narrative highlights the risk of disputes and international positioning
Technology & innovation (SDG 9.5)	Technology dependence (Bayer) and foreign EPC; foreign capital dominance ±56–63% of projects; WHW-AR: Hongqiao 56%	Strength in institutions and industrial ecosystems; policy stability mitigates investment risk	State control through license revocation raises legal risks that could hamper the investment climate & technology transfer
Key risks	Downstream gap: aluminum imports still ±54% of demand; dependence on foreign workers; environmental & energy burdens	Relatively lower risk in terms of investment certainty due to regulatory stability; challenges remain in energy/market dynamics	High risk of ISDS/ICSID: Axis' US$28.9 billion claim; impact on reputation & access to funding

Aspect	Indonesia	Australia	Guinea
Policy lessons	Downstreaming needs to be complemented by infrastructure, energy, and human resource strengthening + technology strategies so that it does not stop at alumina	Structural foundations (logistics, energy, human resources, legal certainty) enhance the viability of downstream investment without export restrictions	Policies must maintain a balance between natural resource sovereignty and investment certainty (due process, consistency, dispute mitigation)

Sources: Compiled by the author from (AEMO, 2025, Australian Government, 2025, Department of Commerce United States of America, 2024, Department of Industry Science and Resources Australia, 2025, Ekanem, 2025; Oswal, 2025, ESDM, 2023; Shinta & Wikarya, 2024; USGS, 2023; Whwalumina, 2026, Gazzini, 2014, Government of Western Australia, 2023, Ma, 2015, NCVER, 2023, NES Africa Group, 2025, Pilbara, 2021, Reuters, 2024, Strazzabosco et al., 2022, USGS, 2024, Winanti & Diprose, 2020, WTO, 2022).

Based on an evaluation of the achievements and obstacles of bauxite downstreaming in Indonesia and lessons learned from international experiences, the synthesis of this research findings leads to several strategic and complementary policy implications. First, strengthening infrastructure and energy foundations. The long-term sustainability of downstreaming is not solely determined by regulatory instruments (such as export restrictions), but rather by the structural capacity that supports production and logistics efficiency. Australia's experience confirms that industrial infrastructure, including ports, access roads, logistics connectivity, and electricity networks, serves as a key determinant of cost competitiveness. Therefore, Indonesia needs to accelerate the development of supporting infrastructure in priority bauxite/alumina/aluminum industrial areas through integrated planning and credible financing schemes, including strengthening grid reliability and supply certainty. On the other hand, the transition to low-carbon energy for the processing industry needs to be positioned as an agenda that cannot be delayed, both to fulfill national climate commitments and to maintain market access amid growing global preferences for low-carbon footprint products and sustainable production practices.

Second, harmonization of downstream policies with global standards and commitments. Guinea's experience shows that interventionist policies can expose the country to legal and reputational risks if they are not designed in line with international commitments. In the Indonesian context, the design of downstreaming policies needs to take into account the provisions of relevant trade and investment agreements, including the principles of legal certainty, due process, and consistency of governance. This harmonization is important to minimize potential disputes, maintain the country's risk perception, and ensure that policy space remains available without sacrificing Indonesia's credibility in the international economic regime. Complementarily, the adoption of voluntary standards such as the Aluminium Stewardship Initiative (ASI) can be a reputational instrument that strengthens the legitimacy of Indonesian downstream products, increases market acceptance, and encourages the convergence of domestic industry practices with global sustainability standards.

Third, strengthening technological capacity and human resources. One of the most prominent challenges in strengthening the downstream industry is the limitation of technological independence, innovation capabilities, and workforce readiness (Syukri et al., 2025). To that end, Indonesia needs to design a more structured technology transfer policy framework in partnership with investors, for example through mandatory training, competency improvement programs, realistic local content requirements, and the development of domestic supply chains so that the benefits of downstreaming do not stop at the accumulation of production capacity, but also extend to the improvement of national capabilities. At the same time, increasing investment in research and development (R&D), strengthening the university-industry collaboration ecosystem, and revitalizing vocational education and continuous training need to be prioritized so that the productivity and quality of the local workforce increase in line with the complexity of processing technology.

Fourth, diversify international partnerships to reduce vulnerability. High dependence on a single partner country as a source of investment, technology, and export markets creates concentration risk, which can increase vulnerability to external shocks, changes in partner policies, or geopolitical dynamics. Therefore, Indonesia needs to develop a partnership diversification strategy by expanding its investor and market base, including with Japan, South Korea, the European Union, and Australia. This diversification is important not only to expand access to capital, but also to open up alternative technologies, production standards, and market networks, so that the downstream structure becomes more resilient and adaptive to changes in the global environment.

CONCLUSION

The conclusion of this article confirms that the downstreaming of Indonesian bauxite following the 2023 export ban has resulted in tangible progress in SDG 9.2 through the expansion of alumina refining capacity and a shift in trade structure. Quantitatively, alumina refining capacity increased from 1.4 million tons (2021) to ±5.3 million tons (2024) (a 279% increase) with a target of 13.9 million tons (2027); alumina exports for the January–August 2025 period reached ±3.66 million tons while imports fell to ±816 thousand tons, and bauxite ore exports declined sharply from 17–18 million tons (2022) to <2 million tons (2023). However, these achievements have not fully translated into downstream industrialization because Indonesia still imports around 54% of its national aluminum needs (±1.024 million tons/year), while also facing issues of job quality (around 61% of workers are contractual), limited skills transfer (the ratio of foreign workers to local workers in technical/managerial positions is reported to be 1:10), and the dominance of foreign ownership/capital in projects (around 56–63%), which has implications for technology control and the direction of industrial development.

In terms of SDG 9.4 and SDG 9.5, findings show that process sustainability and innovation independence remain critical issues: red mud residue production is projected to reach ±6.36–7.95 million tons/year at current alumina capacity, while its utilization remains limited. At the same time, energy-intensive refining/smelting industries confront downstream policies with energy transition demands to align with emission reduction targets and market competitiveness that increasingly emphasizes sustainability aspects. International comparisons reinforce the argument that successful downstreaming requires structural prerequisites: Australia stands out through its market-based enabling environment (infrastructure–energy–human resources and regulatory certainty), while Guinea highlights the risk of investment disputes when state intervention is not balanced by policy design compatible with international commitments. Thus, the downstreaming of Indonesian bauxite should be understood not merely as an export restriction, but as a sustainable industrialization agenda that requires strengthening logistics infrastructure, competitive and low-carbon energy supplies, measurable technology transfer strategies, strengthening R&D and vocational training, adoption of ESG standards (e.g., ASI), and diversification of investment/market partners to build a more inclusive, resilient bauxite value chain that is aligned with SDG 9.

Based on these findings, several avenues for future research are recommended. First, longitudinal studies are needed to assess the long-term environmental and social impacts of bauxite downstreaming, particularly regarding red mud management and post-mining land rehabilitation. Second, comparative research involving other bauxite-producing countries such as Brazil and Vietnam could provide broader insights into diverse policy models and their outcomes. Third, quantitative analysis employing input-output or computable general equilibrium (CGE) models would be valuable to measure the multiplier effects of downstreaming on national and regional economies, including employment and value-added distribution. Fourth, further investigation into technology transfer mechanisms and their effectiveness in building local technological capabilities is essential to inform more structured industrial partnership policies. Finally, research examining the integration of global sustainability standards, such as the Aluminium Stewardship Initiative (ASI), into Indonesian downstream practices would contribute to understanding how domestic industries can enhance their international competitiveness while meeting environmental and social governance expectations.

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