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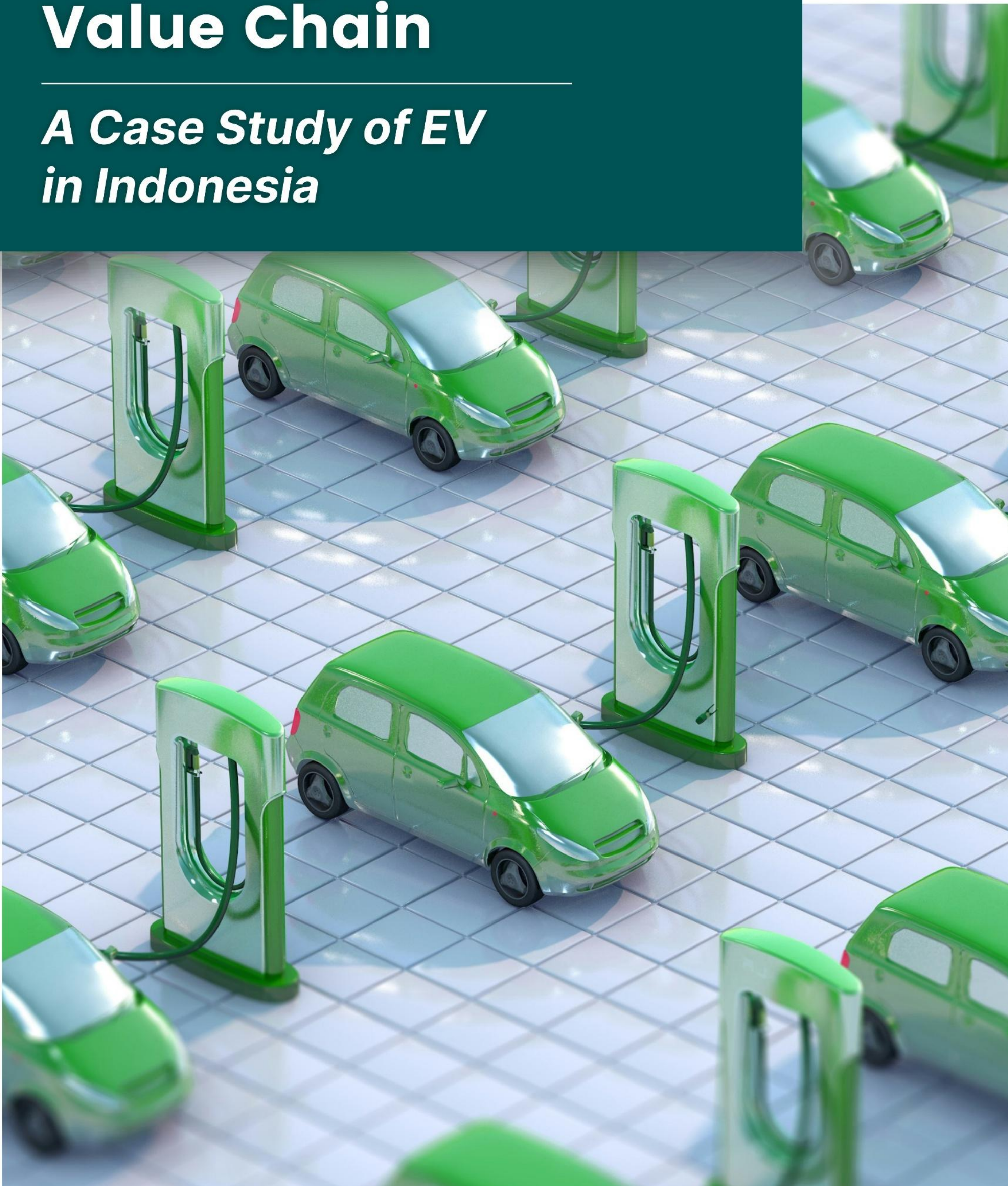
Greening Industrial Value Chain

A Case Study of EV in Indonesia



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CSIS

Greening Industrial Value Chain: A Case Study of EV in Indonesia

CENTRE FOR STRATEGIC AND INTERNATIONAL STUDIES

A Research Report by CSIS Indonesia

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Table of Contents

1 Introduction

The rapid acceleration of climate change, alongside rising global temperatures, has underscored the urgent need to expedite decarbonization efforts across sectors over the globe. In particular, in today's era of globalization, where the value chains of goods and services production are becoming increasingly large and complex, carbon emissions have surged alongside their growth. Hence, industrial decarbonization strategies can no longer be viewed solely from an industry-specific perspective; instead, a holistic value chain approach must be considered.

Efforts to decarbonize and green value chains have been promoted by many countries and international organizations, as they play a crucial role in achieving more effective climate goals while enhancing value chain resilience. However, these efforts are highly complex and require coordination across various stages. Therefore, adopting a holistic value chain approach is essential in the push for a greener industry, as it incorporates key enablers such as regulatory frameworks, sustainable standards, financial support, and international collaboration.

In particular, carbon emissions have surged alongside the growth of value chains, driven by increased production volumes in high-emission sectors. In this context, efforts to decarbonise and greening the value chain has been promoted by many countries and international organizations as they can contribute significantly to achieve climate goals while promoting resilience in the value chains. However, these efforts are complex and require coordination across various stages. Therefore, it is important to use holistic approach in greening the value chain that addresses key enablers, such as regulatory frameworks, sustainable standards, financial support, and international collaboration.

As part of Indonesia's decarbonization efforts, the government has introduced several initiatives aimed at reducing greenhouse gas emissions, with a particular focus on developing battery-based electric vehicles (EV). This initiative has been started with the implementation of an export ban on nickel ore, designed to accelerate the industrial downstreaming process by promoting the transformation of raw materials into final products (i.e. battery). According to the Ministry of Investment/BKPM, total investment in Indonesia's battery and electric vehicle ecosystem has reached approximately USD 11-12 billion as of July 2024. The government's prioritization of this sector is driven by two factors. First, the transportation sector is the second-largest contributor to global emissions, following the energy sector. Second, Indonesia's vast reserves of critical minerals present a strategic opportunity for the country to emerge as a leading global hub for EV battery production. Notably, Indonesia nickel reserves—a key materials for EV battery manufacturing—make up around 42% of the world's reserves. This resource positions Indonesia to play a pivotal role in enhancing its competitiveness within the global EV market.

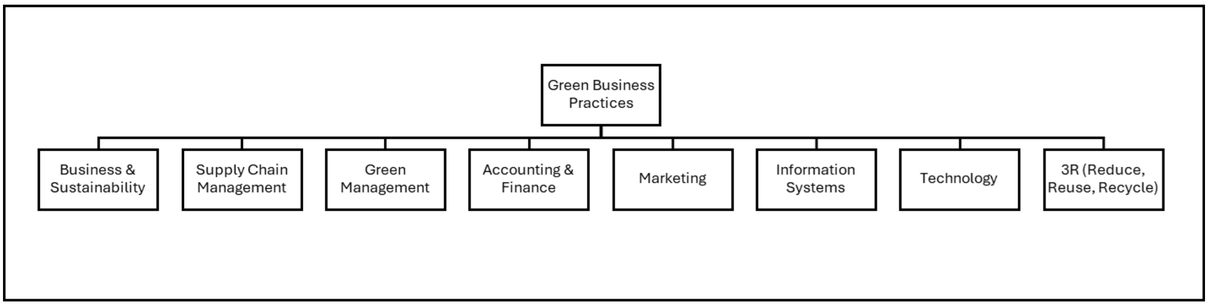
Despite the potential of Indonesia's EV development, several critical gaps remain. According to CSIS' study, the Indonesia's EV sector might be compromised by the excessive waste generated during mineral extraction, as well as the emissions from coal-based captive power plant, in which does not fully align with sustainability principles. Moreover, the country's ambition to become a global battery production hub is at risk due to its heavy reliance on coal-fired electricity which leads to higher emission and potentially undermine the industry's competitiveness. From a regulatory standpoint, Indonesia's EV development strategy is also heavily inward-focused, with an emphasis on Local Content Requirements (LCR). While intended to boost domestic industry, these policies may hinder the growth of both the battery and the EV sectors, by creating inefficiencies in the international supply chain. On the production side, lastly, most of Indonesia's nickel downstream products are processed only to the intermediate stage (Class 2) and are primarily used in steel production rather than refined into Class 1, battery-grade materials.

All these problems might not only undermined Indonesia's efforts to greenhouse emission, but also its comparative advantages in downstream nickel-related products, especially for battery and EV manufacturing, in global markets. In this regard, this research seeks to assess the competitiveness of Indonesia's EV and battery industries across the supply chain, in order to assess whether it is truly feasible for Indonesia to become a regional production hub for batteries and electric vehicles. Furthermore, the study examines the impacts of supply chain decarbonization not only on carbon emissions, but also on public health and broader socio-economic outcomes.

2 Green Value Chain: Framework, Opportunities, and Challenges

Greening the value chain refers to the systematic effort to reduce environmental impacts across a product's entire life cycle, start from raw material extraction to manufacturing, distribution, use, and end-of-life disposal. As defined by Sinclair-Desgagné, this process encompasses minimizing emissions and improving resource efficiency at every stage[1]. The GHG Protocol (2011) classifies emissions into Scope 1 (direct), Scope 2 (energy-related indirect), and Scope 3 (supply-chain indirect), with the latter forming the largest share of industrial emissions and thus becoming a central target for comprehensive decarbonisation strategies.

Figure 1. Greening Value Chain Framework



Source: Hasan et al (2019)

Several frameworks help identify the operational dimensions of a green value chain. Kung et al. (2012) highlight six key functions, including green sourcing, R&D, manufacturing, marketing, promotion, and recycling, while Rao & Holt (2005) categorize activities into greening inbound logistics, production processes, and outbound distribution[2]. Together, these frameworks emphasize cleaner production, sustainable sourcing, circular resource use, and traceability, linking firm-level competitiveness with system-wide environmental sustainability.

While the primary goal of greening value chains is to support decarbonization, by reducing greenhouse-gas emissions across product's life cycle, its benefits extend far beyond environmental outcomes. Greening value chains also enables firms to reduce climate-related, regulatory, and reputational risks while strengthening long-term

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[1] Bernard Sinclair-Desgagné (2013), "Greening Global Value Chains: Implementation Challenges", OECD Green Growth Papers, 2013-04, OECD Publishing, Paris.
[2] Rao, P. and Holt, D. (2005) Do Green Supply Chains Lead to Competitiveness and Economic Performance? International Journal of Operations & Production Management, 25, 898-916.

competitiveness (ADB, 2025). The underlying mechanism lies in how environmentally responsible practices simultaneously deliver operational and strategic advantages. Cleaner production, pollution prevention, and efficient waste and energy management not only enhance environmental performance but also help firms avoid compliance penalties[3] (Rao, 2003), which will help firms to maintain its competitiveness. Furthermore, adopting greener value chains might also lower operational costs and generate productivity gains through resource efficiency, process optimisation, and waste minimisation within the production cycle[4] (Hasan et al., 2019a). These efficiency gains become a source of profitability and resilience, particularly as global buyers increasingly demand sustainability compliance. Consequently, firms adopting green supply-chain practices tend to enjoy stronger financial performance, enhanced market credibility, and improved competitive positioning over time Rao & Holt (2005).

Empirical evidence from China illustrates how greening value chains can enhance competitiveness in global trade. Through initiatives such as the Green Supply Chain Pilot Programme, Chinese firms have integrated environmentally oriented practices across suppliers and production networks, leading to reduced financing and transaction costs, greater supply chain resilience, and improved corporate value, factors that underpin stronger performance in external markets[5] (Li et al., 2025). These benefits stem from operational efficiencies and positive market signalling associated with environmental performance. Furthermore, China's significant growth in exports of clean technologies, including solar panels and batteries, especially to emerging markets, reflects how greening production and supply chain practices can help firms capture global demand for green products and deepen their participation in international trade networks[6]. Such trends suggest that greening value chains not only reduces emissions but also enhances firms' ability to compete and expand into global markets, particularly where environmental performance increasingly influences trade and procurement decisions.

While greening the value chain offers long-term environmental and competitiveness benefits, it also entails non-trivial economic costs and adjustment burdens. Beyond direct compliance and investment costs borne by firms, greening value chains can affect competitiveness, trade performance, and sectoral employment, particularly in emissions-intensive and trade-exposed industries. Empirical evidence from the European Union and China shows that stricter environmental standards and green

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[3] Rao, P. H. (2003). Greening of the supply chain: a guide for managers in Southeast Asia. Manila: AIM Publication.
[4] Hasan, M. M., Nekmahmud, M., Yajuan, L., & Patwary, M. A. (2019). Green business value chain: A systematic review. Sustainable Production and Consumption, 20, 326–339.
[5] Li, J., & Zhu, C. (2025). Can Green Supply Chain Management Improve Supply Chain Resilience? A Quasi-Natural Experiment from China. Sustainability, 17(16), 7481.
[6] IEA (2023), Energy Technology Perspectives 2023, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2023, Licence: CC BY 4.0

industrial policies can raise production costs, shift comparative advantage, and accelerate structural change, sometimes leading to short-term output losses and job displacement in legacy industries such as conventional automotive manufacturing, mining, and fossil-fuel-based power generation[7]. In global value chains, these pressures are often unevenly distributed: upstream suppliers, SMEs, and firms in developing economies may face greater difficulty absorbing compliance costs or meeting certification requirements, increasing the risk of market exit or marginalization. SMEs and informal-sector actors are particularly vulnerable, as limited access to finance, technology, and administrative capacity can make compliance disproportionately costly[8]. Beyond these economic and distributional effects, greening value chains also involves broader social and dynamic risks. Labor displacement and skills mismatches can emerge if green sectors do not expand quickly enough to absorb workers from declining industries, creating transitional unemployment and regional disparities, as observed in the ongoing shift from internal combustion engines to electric vehicles in Europe and China[9].

At the macro level, governments frequently need to offset these adjustment costs through subsidies, retraining programs, or fiscal support, which can place additional strain on public budgets[10]. However, opportunity cost persists, as a strong policy support for specific green technologies or standards may lead to premature technology lock-in, potentially crowding out alternative solutions that could prove more efficient in the long run[11]. Recognizing these challenges, many countries complement green industrial policy with alternative or supporting approaches, such as carbon pricing, emissions trading systems, and performance-based regulations that internalize environmental costs while allowing firms flexibility in how to adjust. Compared to targeted industrial interventions, these market-based instruments are often found to be more cost-effective and less distortionary, highlighting that greening value chains is one pathway among a broader policy mix for.

To achieve greener value chains, it will require good investment ecosystems and strong policy support which aims to address the financing, greener industrial networks and infrastructure problems. Gentile et al. (2023) emphasize that national governments shape the enabling environment by establishing clear environmental standards, green

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[7] International Monetary Fund (IMF). 2023. Fiscal Monitor: Climate Crossroads: Fiscal Policies in a Warming World. Washington, DC: IMF, October.
[8] OECD (2021), Effective Carbon Rates 2021: Pricing Carbon Emissions through Taxes and Emissions Trading, OECD Series on Carbon Pricing and Energy Taxation, OECD Publishing, Paris
[9] IEA (2023), Global EV Outlook 2023, IEA, Paris, Licence: CC BY 4.0
[10] International Monetary Fund (IMF). 2023. Fiscal Monitor: Climate Crossroads: Fiscal Policies in a Warming World. Washington, DC: IMF, October.
[11] Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. "The Environment and Directed Technical Change." American Economic Review 102 (1): 131–66.

taxation, and incentives for R&D and clean technologies[12]. Access to green finance through concessional loans, green bonds, and targeted subsidies helps firms overcome high upfront costs and reduce adoption barriers for environmentally beneficial technologies. At the industry and firm levels, fostering strong linkages between lead firms and suppliers is essential. Instruments such as green procurement standards, supplier monitoring, and collaborative innovation platforms ensure that sustainability requirements diffuse across production networks. Strengthening technical and managerial capabilities through training, technology transfer, and research partnerships helps SMEs integrate sustainable practices despite resource constraints. On a systems level, green infrastructure such as recycling facilities, waste treatment systems, and low-carbon logistics supports circular resource flows and reduces material intensity. Effective monitoring, verification, and transparent reporting mechanisms ensure accountability, mitigate transition risks, and prevent uneven burdens on smaller firms. Together, these drivers support the transition toward cleaner and more resilient industrial ecosystems.

Industrial policy complements these drivers by coordinating interventions that lower the cost of adoption and accelerate diffusion of green practices. While traditional industrial policy focused on productivity and structural transformation, contemporary approaches increasingly integrate environmental objectives[13]. Green industrial policy strengthens greener value-chain while also maintaining its competitiveness through targeted subsidies for clean technologies, concessional finance, support for renewable energy, and regulatory signals that stimulate demand for low-carbon goods[14]. Harrison et al. (2017) highlight that in developing economies characterized by limited willingness to pay for environmental improvements, weak enforcement capacity[15], and extensive informal sectors industrial policy becomes essential in coordinating the transition to greener practices[16]. Through demand creation, risk reduction for new technologies, and targeted technical assistance, green industrial policy helps align incentives, build institutional

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[12] Gentile, E., Lema, R., Rabellotti, R., & Ribaudo, D. (2023). Greening Global Value Chains: A Conceptual Framework for Policy Action. In Global Value Chain Development Report: Resilient and Sustainable GVCs in Turbulent Times (2023 ed., pp. 228-260). World Trade Organization (WTO).
[13] Altenburg, T., & Assmann, C. (Eds.). (2017). Green Industrial Policy. Concept, Policies, Country Experiences. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE).
[14] Jonas Meckling; Making Industrial Policy Work for Decarbonization. Global Environmental Politics 2021; 21 (4): 134–147.
Fay, Marianne and Hallegatte, Stephane and Vogt-Schilb, Adrien, Green Industrial Policies: When and How (October 1, 2013). Available at SSRN: https://ssrn.com/abstract=2346540
[15] Ann Harrison, Leslie A. Martin, Shanthi Nataraj. 2017. Green Industrial Policy in Emerging Markets. Annual Review Resource Economics. 9:253-274. https://doi.org/10.1146/annurev-resource-100516-053445
[16] Blackman, A., & Harrington, W. (2000). The Use of Economic Incentives in Developing Countries: Lessons from International Experience with Industrial Air Pollution. The Journal of Environment & Development, 9(1), 5-44.

capacity, and mobilize private investment. This transforms greening the value chain from a regulatory obligation into a strategic avenue for upgrading and competitiveness.

3 Global Trend to shape Greener Value Chain

3.1 Global Climate Governance Architecture

As countries intensify efforts to align industrial development with climate objectives, greening value chains increasingly operates within a multilayered global governance environment. This environment combines binding climate commitments, market-driven norms, and rapidly evolving sustainability standards that shape how firms and governments design green industrial strategies. For low carbon technology sectors, such as batteries and electric vehicles (EVs), these global principles have become particularly influential, as market access, investment flows, and technological competitiveness are now increasingly tied to demonstrable environmental performance and supply-chain transparency.

Greening value chains itself are embedded in a broader governance structure that establishes the expectations, incentives, and constraints under which national policy operates. The **Paris Agreement** provides the overarching political framework, requiring all Parties to prepare and update Nationally Determined Contributions (NDCs) and implement emissions-reduction measures, yet it leaves the specific policy tools to national discretion. Its significance lies less in legal enforcement and more in its function as a global reference point that orients domestic regulation, investment priorities, and long-term decarbonisation planning.

International institutions reinforce these expectations by offering benchmarking, financing, and implementation support. The World Bank's Climate Change Action Plan (2021–2025) helps countries integrate climate targets into planning and budgeting; the OECD[17] (2024) highlights the mainstreaming of green industrial policy across advanced and emerging economies; and recent analyses emphasize the need for credible measurement, reporting, and verification (MRV) to ensure climate commitments translate into real domestic action[18]. These governance mechanisms collectively shape the environment in which countries design industrial strategies, pushing them toward higher transparency, accountability, and alignment with global norms. The operationalization of climate goals occurs through a mix of mandatory regulations and voluntary or market-driven standards. Together, these instruments shape how firms

[17] OECD. (2024). Green industrial policies for the net-zero transition (Net Zero+ Policy Papers No.2). OECD Publishing.
[18] Quirico, O., & Baber, W. (2024). Implementing climate change policy. Cambridge University Press & Assessment.

decarbonize across global value chains (GVCs), determine what "compliance" means in practice, and influence how countries design green industrial policy[19].

Mandatory (Hard-Law) Instruments

Hard-law instruments impose legally enforceable obligations backed by penalties, access conditions, and formal monitoring systems[20], which can assist in reaching climate goals. Carbon pricing through Emissions Trading Systems (ETS) remains the most prominent example. The EU ETS targeting a 62% emissions reduction by 2030 requires firms to monitor, verify, and surrender allowances annually, with sanctions for non-compliance (Directive (EU) 2023/959)[21]. Similar ETS frameworks now operate in China, South Korea, the UK, New Zealand, and Canada[22], making embedded emissions an increasingly measurable component of industrial competitiveness[23].

Another major instrument is the EU Carbon Border Adjustment Mechanism (CBAM), which conditions market access for products such as steel, cement, and aluminium on verified emissions reporting and the purchase of CBAM certificates. By applying carbon constraints to imports, CBAM extends hard-law climate requirements across international supply chains.

Sectoral regulations such as renewable portfolio standards, vehicle-emission rules, and mandated internal-combustion engine phase-outs further steer technological choices and investment in key industries[24]. Evidence shows that renewable-energy R&D improves CO_2 productivity significantly[25], highlighting the role of regulation in accelerating green industrial transformation.

Voluntary (Soft-Law) & Market-Driven Standards

Voluntary standards shape firm behaviour through disclosure expectations, investor pressure, procurement rules, and supply-chain norms, often influencing industries even

[19] Tagliapietra, S. (2022). Green industrial policy: a global perspective. United Nations Department for Economic and Social Affairs.

[20] OECD/Korea Development Institute. (2017). Improving Regulatory Governance: Trends, Practices and the Way Forward. Paris: OECD Publishing.

[21] European Parliament & Council of the European Union. (2023, May 10). Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system (OJ L 130, 16.5.2023, p. 134).

[22] ICAP. (2024). Emissions Trading Worldwide: Status Report 2024. Berlin: International Carbon Action Partnership.

[23] Black, S., Minnett, D., Parry, I., Roaf, I., and Zhunussova, K. (2022). A Framework for Comparing Climate Mitigation Effort Across Countries. Working paper 22/254. Washington, DC: International Monetary Fund.

[24] OECD. (2024). The Climate Action Monitor 2024. Paris: OECD Publishing.

[25] Eid, A. G., Mrabet, Z., & Alsamara, M. (2024). Correction: Assessing the impact of energy R&D on green growth in OECD countries: a CS-ARDL analysis. Environmental Economics and Policy Studies.

without legal enforcement[26]. Their importance for greening value chains lies in how they tighten reporting requirements, expand traceability, and make carbon transparency a market expectation.

A key cluster consists of corporate climate-disclosure frameworks notably the Task Force on Climate-Related Financial Disclosures (TCFD) which now underpins IFRS S1–S2, the European Sustainability Reporting Standards (ESRS), Carbon Disclosure Project (CDP) reporting, and the Global Reporting Initiative (GRI). These systems collectively create interoperable guidance for emissions measurement, risk disclosure, and supply-chain reporting[27]. Because TCFD-based frameworks increasingly require detailed disclosure of Scope 1–2–3 emissions, they directly support greening value chains by embedding carbon tracking and supplier transparency into financial and operational reporting[28]. With consolidation under the ISSB, these "voluntary" frameworks are quickly becoming quasi-mandatory components of global corporate governance[29].

Environmental management standards like ISO 14001 also function as market-driven requirements, where certification often acts as a ticket to enter tier-1 supply chains. Meanwhile, sustainability taxonomies such as the EU and ASEAN Taxonomies link access to finance with alignment to low-carbon pathways[30] (ASEAN Taxonomy Board, 2024). Voluntary carbon markets complement these efforts, though concerns over integrity remain[31] (IC-VCM, 2023).

Despite different legal foundations, hard-law and soft-law instruments reinforce the same two channels shaping modern industrial policy:

1. Incentives — shifting cost structures, market access, and investment signals.
2. Supervision — increasing expectations for verification, reporting, and traceability.

As voluntary disclosure frameworks become embedded in regulation and mandatory rules reference voluntary standards, a more harmonized system is emerging one in which industrial competitiveness increasingly depends on demonstrable decarbonization performance. For late-developing economies, this implies that domestic industrial

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[26] Partiti, E. (2021). The Place of Voluntary Standards in Managing Social and Environmental Risks in Global Value Chains. European Journal of Risk Regulation. Published by Cambridge University Press, 13(1), 114-137.
[27] UNEP Finance Initiative. (2025). Sustainability Disclosure Landscape Report for Risk Management. Geneva: United Nations Environment Programme.
[28] Hettler, M., & Graf-Vlachy, L. (2023). Corporate scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda. Business Strategy and the Environment, 33(2), 263-282.
[29] Barker, R. (2025). Corporate sustainability reporting. Journal of Accounting and Public Policy, 49(107280).
[30] Board, A. T. (2023). ASEAN Taxonomy for Sustainable Finance Version 2. ASEAN Taxonomy Board.
[31] Council, I. (2023). Core Carbon Principles, Assessment Framework, and Assessment Procedure for High-Integrity Carbon Credits.

support must be matched with the capability to meet global reporting, certification, and compliance regimes.

3.2 Global Initiatives Driving the Greening of Value Chains

A number of global initiatives are increasingly shaping how firms operationalize greening efforts, particularly by embedding transparency, traceability, and carbon accountability into cross-border production. Although these mechanisms apply across industries, their implications are clearly visible in resource- and technology-intensive sectors such as the battery and EV sectors, which provides a useful illustration of how international norms can steer greener supply chain practices later in the discussion.

1. Global Initiatives for Minerals and Mining

One of the important parts in discussing the means to achieve a greener value chain starts from the standards in the mining process. Currently, international mechanisms act as de facto requirements for accessing international markets through responsible sourcing frameworks, traceabilty systems, and mining assurance standards.

One of the well-known green standards in the mining areas are the Responsible Minerals Initiative (RMI) and the Initiative for Responsible Mining Assurance (IRMA), which set standards for environmentally and socially responsible extraction of critical minerals such as nickel, cobalt, and lithium. RMI provides due-diligence guidelines and risk-assessment tools widely used by downstream manufacturers[32], while IRMA offers one of the most comprehensive third-party audit frameworks for mines seeking certification against high ESG benchmarks[33]. Both systems are increasingly referenced in procurement requirements by global automakers and battery producers.

In addition to that, Global Battery Alliance (GBA), which is developing the Global Battery Passport (GBP) a digital product passport that discloses a battery's life-cycle carbon footprint, material provenance, circularity metrics, and ESG performance[34] is also gains a momentum in the international market. The GBP establishes a unified data and reporting framework that supports the implementation of the EU Battery Regulation and emerging disclosure rules in other regions. As global manufacturers adopt the passport, alignment with GBP metrics is becoming a prerequisite for participation in leading supply chains.

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[32] RMI. (2025). Responsible Minerals Assurance Process: Supply Chain Due Diligence Plus (Version 1.0). Responsible Minerals Initiative, Responsible Business Alliance.

[33] IRMA. (2022). An introduction to IRMA: In collaboration with BSR. Initiative for Responsible Mining Assurance.

[34] Global Battery Alliance. (2024). The GBA battery passport 2024 pilots: Overview, results and lessons learnt. Global Battery Alliance.

Together, these initiatives form a coherent governance layer linking upstream mineral sourcing with downstream battery production. By promoting interoperable traceability and verification mechanisms, they push countries especially emerging producers to adopt international sustainability principles and upgrade institutional capacities. In practice, these initiatives function as powerful *market gatekeepers*: they are non-treaty instruments, yet they shape which producers can access global value chains.

2. Carbon Accounting and Cross-Border Emissions Tracking

The growing emphasis on **supply-chain carbon accounting** reflects the increasing role of global reporting norms in governing industrial competitiveness. Frameworks such as *Greenhouse Gas Protocol*[35], *IFRS S2 Climate-related Disclosures*[36], and the *EU's Corporate Sustainability Reporting Directive (CSRD)* require firms to measure and disclose Scope 1–3 emissions, making carbon transparency the baseline for participating in international markets. As voluntary standards become embedded in mandatory regulations in the EU, US, and Asia, carbon disclosure is increasingly a *market entry requirement* rather than a voluntary practice[37].

3. Carbon Pricing and Market-Based Alignment Mechanisms

Carbon pricing mechanisms, including emission trading systems (ETS), carbon taxes, and the EU's Carbon Border Adjustment Mechanism (CBAM) further incentivize alignment by integrating climate costs directly into trade flows. Carbon pricing policies increasingly shape industrial competitiveness across borders. As of 2024, more than 70 carbon pricing instruments including carbon taxes and emissions trading systems are in operation globally[38]. These mechanisms directly influence production costs, investment incentives, and supply-chain decisions. ETS systems in the EU, China, Korea, New Zealand, Switzerland, and others apply binding caps and enforceable compliance rules[39]. The EU Carbon Border Adjustment Mechanism extends this logic by requiring importers of steel, aluminium, cement, and other carbon-intensive products to purchase certificates reflecting EU carbon prices[40]. This aligns external producers with internal

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[35] GHG Protocol. (2011). Greenhouse gas protocol: Product life cycle accounting and reporting standard.

[36] ISSB. (2023). IFRS S2 Sustainability Disclosure Standard. International Sustainability Standards Board.

[37] Hettler, M., & Graf-Vlachy, L. (2023). Corporate scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda. Business Strategy and the Environment, 33(2), 263-282.

[38] World Bank. (2024). State and Trends of Carbon Pricing 2024. Washington, DC: World Bank. DOI: 10.1596/978-1-4648-2127-1. License: Creative Commons Attribution CC BY 3.0 IGO

[39] ICAP. (2024). Emissions Trading Worldwide: Status Report 2024. Berlin: International Carbon Action Partnership.

[40] European Parliament & Council of the European Union. (2023, May 10). Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system (OJ L 130, 16.5.2023, p. 134).

climate standards and encourages partner countries to adopt compatible decarbonisation frameworks.

Regulations and standards are fundamentally grounded in the environmental burdens associated with different stages of a value chain. These burdens are unevenly distributed across activities, ranging from raw materials extraction and transportation to manufacturing processes and end-of-life treatment of products. Capturing the full environmental impacts along the value-chain is therefore essential to avoid fragmented approaches and to align greening efforts with global climate commitments.

Global value chains typically begin with raw materials extraction, particularly mineral extraction and mining activities. As the global transition toward low carbon technologies accelerates, demand for critical minerals continues to grow. The Global Critical Minerals Outlook 2025 reports[41] that global lithium demand rose by nearly 30% in 2024, while the demand for nickel, cobalt, graphite, and rare earths increased by 6-8% over the same period (IEA, 2025). This trend is also reflected in global material flows. In 2020, global material extraction was dominated by non-renewable resources, with non-metallic minerals accounting for 48% and metal ores for approximately 10% of total extraction[42] (UNEP, 2024).

While these extraction activities are central to enabling cleaner energy systems and reducing dependence on fossil fuels, the mining sector itself remains highly energy- and resource-intensive. Recent estimates suggest that mining accounts for approximately 1.7% of global final energy demand, largely driven by fossil-fuel consumption[43] (Aramendia et al., 2023). Beyond energy use, mining generates significant environmental challenges, including up to 65 billion tons of waste generated annually[44] (Kalisz et al., 2022). These impacts have affected an estimated 479,200 km of river channels and 164,000 km^2 of floodplains worldwide, exposing millions of people, livestock, and agricultural land to hazardous concentrations of toxic substances[45] (Macklin et al., 2023).

Logistics and transportation play a crucial role in global value chains by enabling raw materials, intermediate goods, and final products to move across geographic boundaries. These transportation activities account for around 8% of global greenhouse gas emissions[46] (IEA, 2018). In 2020, global freight activity reached approximately 140 trillion tonne-kilometers across road, rail, maritime, and air transport modes[47] (ITF, 2021).

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[41] International Energy Agency. (2025). Global Critical Minerals Outlook 2025, IEA.
[42] Bruyninckx et al. (2024), Global Resources Outlook 2024, UNEP.
[43] Aramendia et al. (2023), "Global energy consumption of the mineral mining industry," Global Environmental Change.
[44] Kalisz et al. (2022), Journal of Environmental Management.
[45] Macklin et al. (2023), "Impacts of metal mining on river systems," Science.
[46] International Energy Agency. (2018). CO2 Emissions from Fuel Combustion.
[47] international Transport Forum. (2021). ITF Transport Outlook 2021.

In value chains that depend on geographically concentrated raw materials, such as those supporting electric vehicles and batteries, materials and components often undergo multiple cross-border transport movements before final assembly. This pattern highlights logistics as a significant contributor to value-chain emissions and a key stage for decarbonisation efforts.

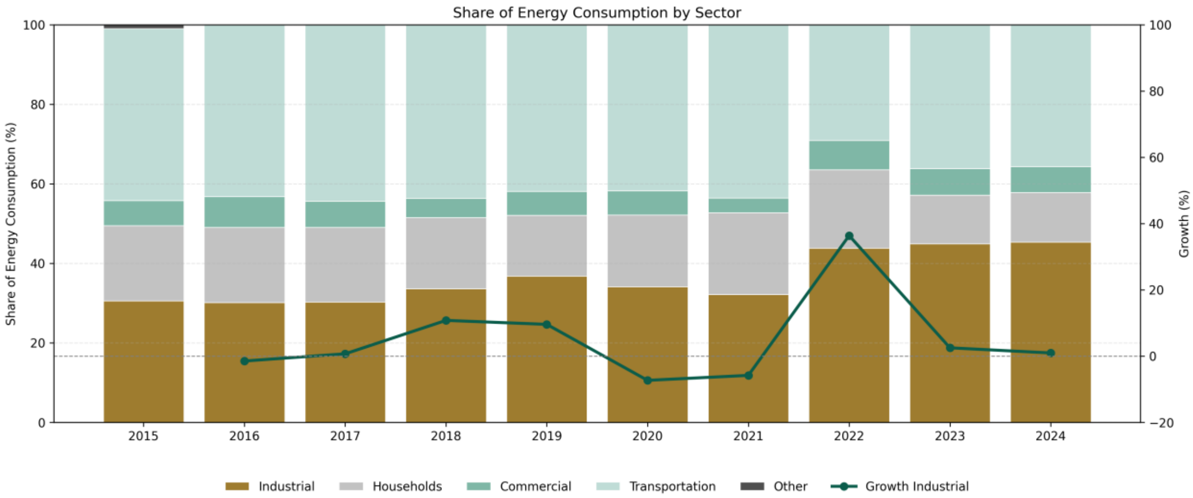
4 Indonesia's Context for Greening Value Chain: Current Condition and Challenges

4.1 Indonesia's Context in Greening Value Chain

Like many other countries, industrial decarbonization efforts have increasingly become a key agenda in Indonesia. The government has begun implementing various policies to achieve its NDC and Net Zero Emissions targets, ranging from measures to accelerate the development of renewable energy to macro-level policies such as carbon trading. As discussed earlier, industrial decarbonization is becoming increasingly important not only to fulfill environmental objectives, but also to sustain broader economic goals. Global principles and regulations, particularly those in the European Union, that require decarbonization along supply chains send a clear signal that greening value chains can provide broader access to markets.

Nevertheless, Indonesia continues to face significant structural and institutional challenges in its efforts to decarbonize value chains. To begin with, Indonesia's energy consumption profile provides an important contextual foundation for understanding the greening challenges faced by firms. Energy consumption serves as a core lens for assessing greening value chain, as it directly shapes the carbon intensity of sourcing, production, and downstream activities. Recent data indicate a persistent rise in total energy consumption, driven primarily by the industrial sector, which in 2022 surpassed the transportation sector and has consistently accounted for the largest share of final energy use. Sectoral figures further reveal a sharp surge in industrial energy consumption in 2022, reaching approximately 511.7 million BOE, equivalent to a 78.3 percent year-on-year increase compared to the previous year.

Figure 2. Share of Energy Consumption by Sector in Indonesia



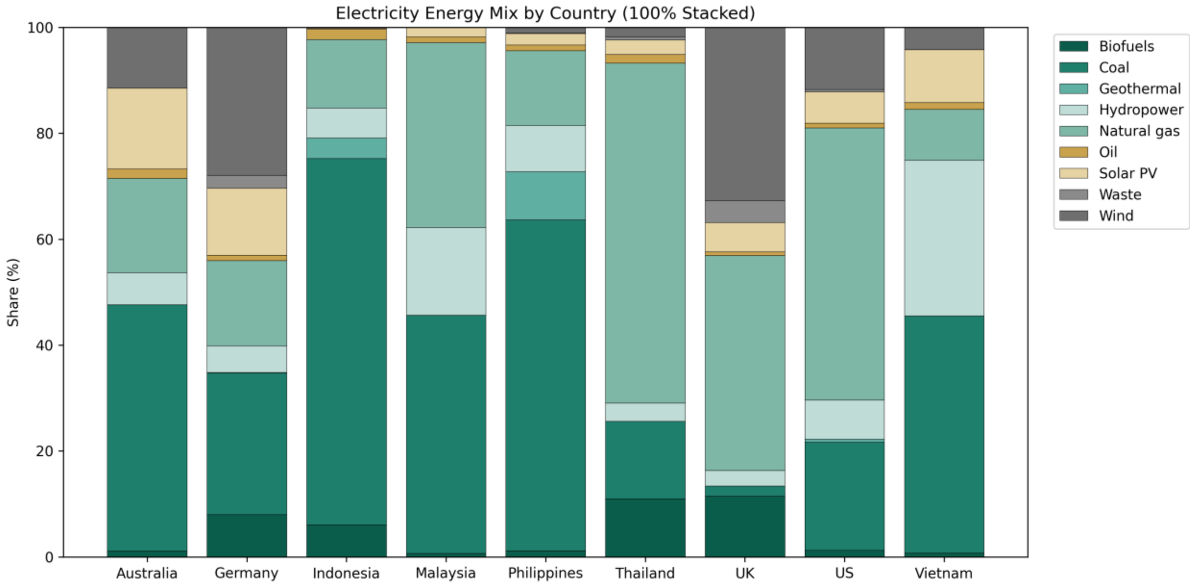
Source: IEA

The rising energy demand associated with industrialization serves as a clear signal that the need for renewable energy will continue to increase in the future. However, this growing industrial energy demand in Indonesia has also been accompanied by an increase in coal consumption. As shown in the Figure 3 below, Indonesia's electricity mix remains heavily dominated by coal. The continued provision of incentives, such as coal royalty schemes under flagship government programs, indicates that coal is likely to remain the dominant source in Indonesia's electricity mix for the foreseeable future. Although PT PLN's Electricity Supply Business Plan (RUPTL) 2025–2034 outlines a gradual reduction in coal usage within the electricity mix, the proposed trajectory is widely regarded as insufficiently ambitious, particularly given projections that renewable energy will play an increasingly dominant role in the global energy system over the next decade.

The dominance of coal in Indonesia's electricity mix therefore presents a significant challenge to efforts aimed at decarbonizing industrial value chains. From a value-chain perspective, one of the primary sources of industrial emissions originates from coal-fired power generation. Moreover, as shown in EMBER Climate's analysis[48], methane emissions from Indonesia's coal mining sector up to six to eight times higher than current estimates, pointing to substantial emissions embedded in coal-based energy supply. This underscores the extent to which greening the energy sector is not merely complementary, but a necessary prerequisite for Indonesia to achieve meaningful decarbonization across its industrial value chains.

[48] EMBER. (2024). Indonesia's coal mines emit up to eight times more methane pollution than latest official estimates.

Figure 3. Electricity Mix by Country



Source: IEA

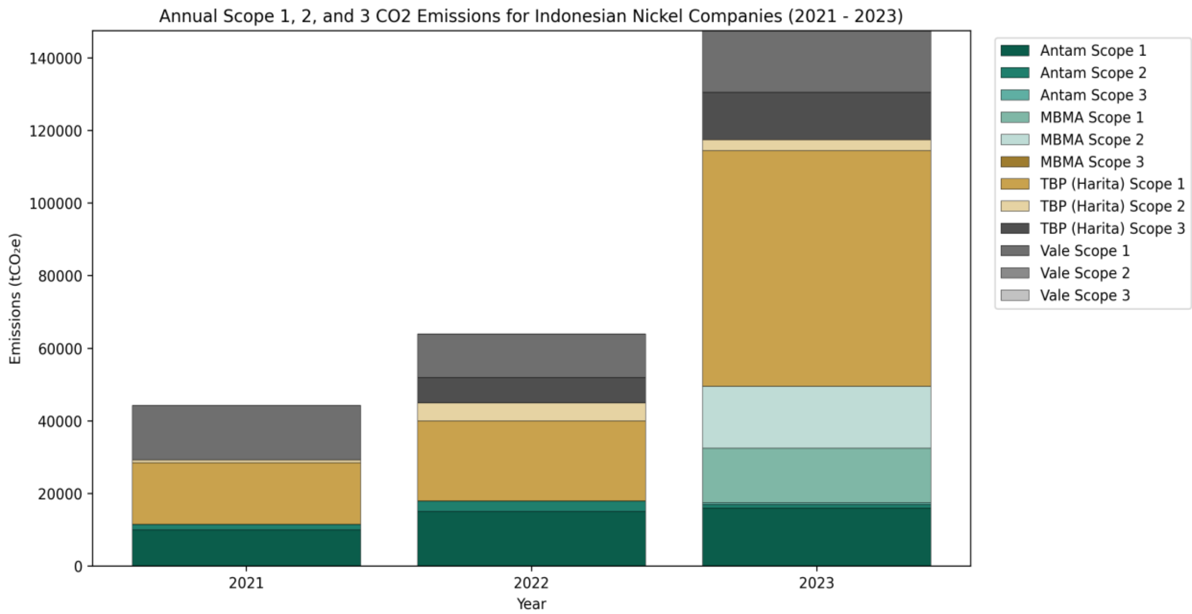
Nevertheless, Indonesia is not alone in its continued reliance on non-renewable energy sources. Comparing the state of Indonesia's energy mix with other countries provide a useful benchmark for assessing Indonesia's industrial and policy competitiveness. A failure to keep pace, especially with regional peers, in energy transition efforts risks constraining market access for Indonesian products, especially as trade partners increasingly integrate decarbonization requirements into trade and investment frameworks, with direct implications for industrial competitiveness. As illustrated in the Figure 3, comparing with more advanced economies such as the United Kingdom, the United States, and Germany, Indonesia remains significantly behind, as evidenced by the more diversified energy mixes and substantially higher shares of renewable energy in those countries. However, most developing countries, or ASEAN peers, in comparison, display a broadly similar composition between renewable and non-renewable energy sources. The divergence lies in the type of non-renewable energy utilized. Indonesia and the Philippines remain heavily dependent on coal and coal-based products, while Thailand relies more on oil products and Malaysia predominantly use natural gas. This comparison suggests that ASEAN countries are starting from a relatively comparable baseline in terms of renewable and non-renewable energy mix. Against this backdrop, Indonesia's future policy choices will be decisive in determining whether the country can maintain industrial competitiveness while aligning with evolving global decarbonization standards.

4.2 Business Perceptions on Greening Value Chain

The continued dominance of coal-fired power plants in Indonesia's electricity mix poses a significant challenge for companies seeking to decarbonize its value chain. The limited scalability and affordability of renewable energy technologies are frequently cited by firms as key constraints on industrial decarbonization efforts.

In the context of energy input for nickel industry, a recent analysis by the Institute for Energy Economics and Financial Analysis (IEEFA) of four major nickel producers, Antam, Merdeka Battery Materials, Trimegah Bangun Persada, and Vale Indonesia, shows that the production of approximately 353,000 tonnes of nickel metal in 2023 generated around 15 million tonnes of greenhouse gas emissions[49]. Higher emissions are largely driven by the continued reliance on coal-fired power for processing activities. Meanwhile firms utilizing hydropower-supported facilities, such as Vale Indonesia, exhibiting significantly lower emissions intensity.

Figure 4. Annual Scope 1, 2, and 3 CO2 Emission for Indonesian Nickel Companies



Source: IEEFA (2024)

Initiatives by several companies to begin using renewable energy as part of their energy sourcing demonstrate growing attention within the industrial sector toward greening their value chains. However, evidence from the CSIS survey suggests that corporate decarbonization efforts remain uneven and largely concentrated in production processes and waste management, while upstream and downstream stages, such as procurement, transportation, and logistics, receive far less attention. The are several main drivers of corporate decarbonization, including compliance with government regulations, the reinforcement of corporate values, and the need to maintain competitiveness in an increasingly sustainability-oriented global market. These findings highlight the central

[49] Peh, G. (2024). Indonesia's Nickel Companies: The Need for Renewable Energy Amid Increasing Production. Institute for Energy Economics and Financial Analysis.

role of policy signals in shaping firm behavior. In addition, ownership structure emerges as a critical factor influencing the depth of decarbonization efforts. Firms with significant foreign ownership, such as joint ventures and wholly foreign-owned enterprises, tend to adopt more advanced and wide-ranging decarbonization measures and are more likely to integrate decarbonization into their long-term business growth strategies. This suggests that international standards and investor expectations or pressures can serve as important transmission channels for accelerating decarbonization, underscoring the potential role in leveraging foreign investment and global partnerships to advance domestic decarbonization objectives.

4.3 Policy and Regulatory Initiatives for Greening Value Chain in Indonesia

As Indonesia seeks to reduce industrial emissions and strengthen the environmental performance of manufacturing, the government has adopted a range of policy instruments that, to varying degrees, support the greening of value chains. This policy orientation is rooted in Indonesia's broader climate and development framework, which articulates decarbonization targets. Key national planning and climate instruments including, the Long-Term National Development Plan (RPJMN 2025 – 2009), the Low Carbon Development Strategy (LCDI), the Second Nationally Determined (NDC), and the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR), largely frame emissions reduction as a macroeconomic and sectoral outcome. Additionally, industrial policy is governed by instruments such as the Industry Development Master Plan (RIPIN) and down streaming frameworks, which continue to shape manufacturing development and value-addition priorities. Within this institutional setting, greening efforts in Indonesia have primarily taken the form of regulatory and standard based measures that align production practices with environmental objectives, rather than comprehensive policies aimed at restructuring industrial value chains.

One of the core instruments guiding greening in manufacturing is the **Standar Industri Hijau (SIH)**, or Green Industry Standard, issued under the Ministry of Industry (*Kementerian Perindustrian*)[50]. The SIH framework provides technical benchmarks for firms to implement practices that enhance **resource efficiency, energy conservation, waste management, and environmental performance** in their operations. SIH is designed to be applied on a **sectoral basis**, with specific standards developed for different industrial categories and accompanied by a certification mechanism through designated Green Industry Certification Bodies (*Lembaga Sertifikasi Industri Hijau*). The intent is to encourage firms to integrate environmental considerations into production processes, positioning the adoption of industry green standards as a measure of corporate sustainability performance. SIH thus operates as an instrument that embeds

[50] Pusat Industri Hijau (2024). Kebijakan Pengembangan Industri Hijau.

environmental criteria within manufacturing operations at the firm and sector level, though it does not explicitly mandate ecological performance across the broader supply chain beyond production processes.

However, as of the most recent implementation, the scope of SIH remains limited to a relatively small number of industrial subsectors, primarily covering selected food processing, cement, fertilizers, chemicals, packaging, paper, oleochemical, and consumer goods industries[51]. Many strategically important and fast-growing sectors such as nickel processing, battery manufacturing, and electric vehicle–related industries are not yet explicitly covered under existing SIH standards. As a result, while SIH represents a concrete regulatory step toward greening industrial production, its current reach across Indonesia's broader industrial value chains remains partial and uneven.

Additionally, in 2025, the Ministry of Industry launched an Industrial Decarbonization Roadmap covering nine energy-intensive sectors – cement, metals (steel and smelters), fertilizers (ammonia), chemicals, pulp and paper, textiles, glass and ceramics, automotive, and food & beverage[52]. This roadmap targets net-zero emissions in these key industries by 2050, a decade earlier than Indonesia's national net-zero goal of 2060. It emphasizes cutting carbon intensity at each stage of production through measures like energy and material efficiency, fuel/feedstock switching to cleaner alternatives, electrification with low-carbon power, and process upgrading, with carbon capture technologies to neutralize any remaining emissions. These interventions focus on reducing emissions at the source rather than relying on offsets. The roadmap's potential impact is significant – it projects a reduction of about 66.5 million tonnes CO_2e by 2035 and nearly 290 million tonnes CO_2e by 2050 in the industrial sectorwri-indonesia.org. To implement this, the government is preparing supporting policies such as an industrial carbon pricing mechanism (Nilai Ekonomi Karbon) and plans to formalize the roadmap through sector-specific regulations by 2026. Strengthening of the Green Industry Standards is also part of this effort, ensuring companies adopt best practices in energy management and emissions control as they grow.

Beyond production-focused instruments, Indonesia has also introduced **supporting regulatory initiatives** related to greening value chain, although their direct relevance for private industrial firms remains limited. One prominent example is the development of **Green Public Procurement (GPP)** and **Sustainable Public Procurement (SPP)** frameworks, which integrate environmental criteria—such as eco-labels and

[51] Balai Besar Standardisasi Pelayanan Jasa Industri Kimia, Farmasi dan Kemasan (2025). Alur Sertifikasi Industri Hijau

[52] Kementerian Perindustrian Republik Indonesia (2025). Peta Jalan Dekarbonisasi 9 Subsektor Industry.

sustainability standards—into **government purchasing decisions**[53]. These initiatives are anchored in the national public procurement framework and promoted through guidelines issued by the National Public Procurement Agency (LKPP) and supporting institutions. However, as emphasized by recent assessments, the scope of GPP in Indonesia is largely confined to **public-sector procurement**, and does not impose binding requirements on private firms to apply green procurement practices across their upstream supply chains (IISD, 2024; Perpres No. 16/2018).

Overall, Indonesia's greening value chain framework is currently anchored in production-focused policies, with regulatory instruments such as the Green Industry Standard and the Industrial Decarbonization Roadmap providing guidance for improving energy efficiency and reducing emissions within manufacturing processes. However, these measures remain uneven in sectoral coverage and are not yet complemented by comprehensive mechanisms governing upstream input sourcing, private-sector green procurement, logistics, or downstream material recovery.

[53] International Institute for Sustainable Development (IISD) (2024). Green Public Procurement in Indonesia

5 EV Development in Indonesia: Assessment of Indonesia's Competitiveness in the region

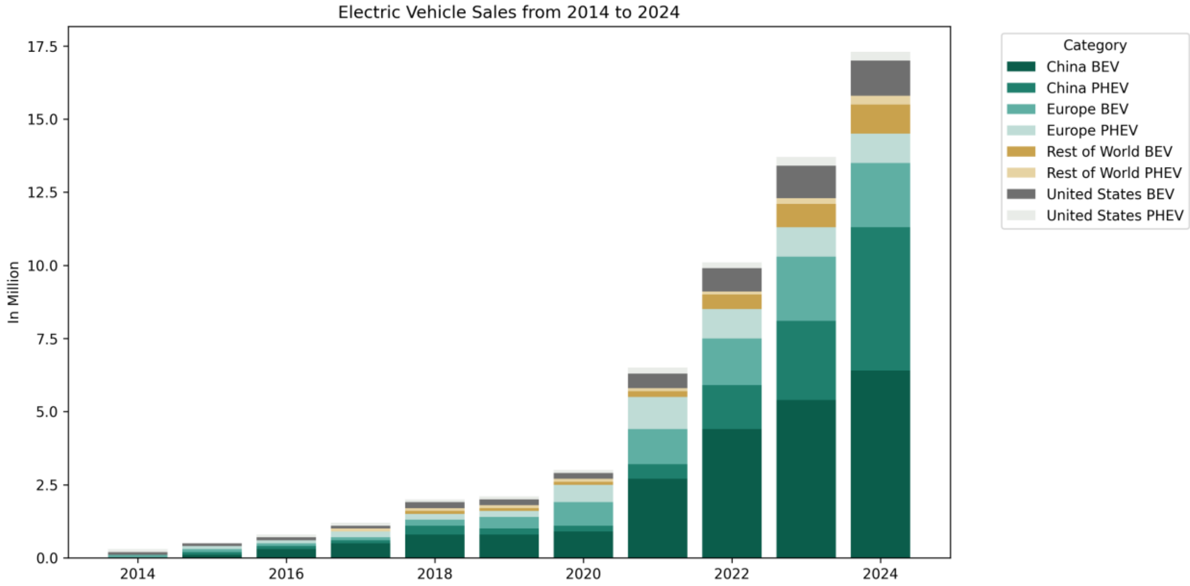
One of the Indonesian government's flagship decarbonization initiatives is the development of the Battery Electric Vehicle (BEV) industry. This strategy is underpinned by two primary policy objectives. First, from an economic and industrial development perspective, the automotive sector is a critical pillar of Indonesia's economy, contributing significantly to GDP and employment. The promotion of the EV industry is therefore intended to safeguard the long-term competitiveness of Indonesia's automotive sector amid a structural shift in global demand toward electric vehicle. Indonesia's large nickel reserves, an essential input for EV batteries, further strengthen the country's comparative advantage and support the government's ambition to move up the global EV value chain.

Second, the BEV strategy is closely linked to Indonesia's climate and energy objectives. BEVs offer the potential for lower lifecycle emissions compared to internal combustion engine (ICE) vehicles, making them a relevant instrument for decarbonizing the transport sector. In parallel, the large-scale adoption of BEVs is expected to reduce Indonesia's dependence on imported oil, thereby enhancing energy security and supporting longer-term energy sufficiency goals.

The decision to prioritize EV industry development in Indonesia is grounded in strong global trends. Over the past ten years, the rapid expansion of the global EV market has significantly reshaped automotive sector market shares. Figure 5 below illustrates how the rapid expansion of BEVs, particularly in China, has been a key driving force behind the accelerating global adoption of electric vehicles. In 2024, global electric car sales exceeded 17 million units, with more than 20 percent of all new cars sold worldwide being electric. The additional 3.5 million EVs sold in 2024 compared to 2023 alone exceeded total global EV sales for the entire year of 2020, underscoring the remarkable pace of growth in the EV market[54].

[54] International Energy Agency (2025). Global EV Outlook 2025.

Figure 5. Electric Vehicle Sales from 2014 to 2024



Source: Bloomberg

This situation creates strong momentum for Indonesia to capitalize on opportunities arising from growing global EV demand. With the world's largest nickel reserves, Indonesia is well positioned to become a hub for battery and EV industry development. Between January and October 2025, nickel-based products were among the five key commodities driving Indonesia's trade balance performance[55]. Not to mention, this successful performance by Indonesia's nickel production is received by only around 85% of the approved production capacity under the Rencana Kerja dan Anggaran Biaya (RKAB) 2025, which was set at 300 million tons[56].

Nickel is a critical input for NMC (nickel-manganese-cobalt) battery components, a type of lithium-ion battery widely used in electric vehicles. Recognizing this potential, Indonesia has long pursued downstreaming policies aimed at increasing the value added of its mineral resources. These efforts were initially introduced under Law No. 4/2009, which mandates domestic processing of mineral ores. However, the downstreaming strategy began to gain stronger traction only after the government introduced substantial incentives for smelter development and imposed restrictions on the direct export of raw nickel ore.

[55] Handayani, L. (2025). BPS Ungkap Nikel Menjadi Salah Satu Komoditas Penyumbang Terbesar Surplus Ekspor 2025. Nikel.co.id.
[56] Purnama, A. Y. R. (2026). Produksi Nikel 2025 Naik ke 2,5 Juta Ton, Serap Ore 300 Juta Ton. Bloomberg Technoz

In addition to incentives in the nickel processing sector, the Government of Indonesia (GoI) has introduced a comprehensive package of fiscal and non-fiscal measures targeting both producers and consumers to accelerate the development of the battery and EV industry. On the supply side, these measures include tax holidays, corporate income tax reductions, and import duty exemptions for capital goods and raw materials. Additional incentives allow firms to deduct up to 300 percent of expenditures related to research and development, technological innovation, and workforce training. On the demand side, the government provides purchase subsidies of up to US$5,130 per electric vehicle, alongside value-added tax (VAT) reductions for battery-based electric cars and buses that meet local content requirements. EVs are also exempt from luxury goods sales tax, transfer tax, and vehicle circulation tax, and are excluded from Jakarta's odd–even traffic policy. To support enabling infrastructure, the government has introduced regulated electricity tariffs for EV charging, including a capped rate for fast chargers and subsidized charging prices. Collectively, these policies are designed to position Indonesia as both a leading domestic market and a global manufacturing hub for EVs.

Despite these efforts, substantial policy challenges remain in aligning EV industrialization with Indonesia's broader decarbonization objectives. First, Indonesia's advantage in nickel's reserve does not automatically translate into comprehensive competitiveness across the entire EV battery value chain. This highlights the need for more targeted industrial policies to strengthen domestic capabilities beyond upstream mineral processing. Second, the carbon intensity of EV battery production remains a significant concern. The continued reliance on coal-fired power plants for nickel processing and battery manufacturing undermines the potential emissions reductions associated with vehicle electrification. Without parallel progress in decarbonizing the power and industrial energy sectors, the EV strategy risks generating limited net climate benefits.

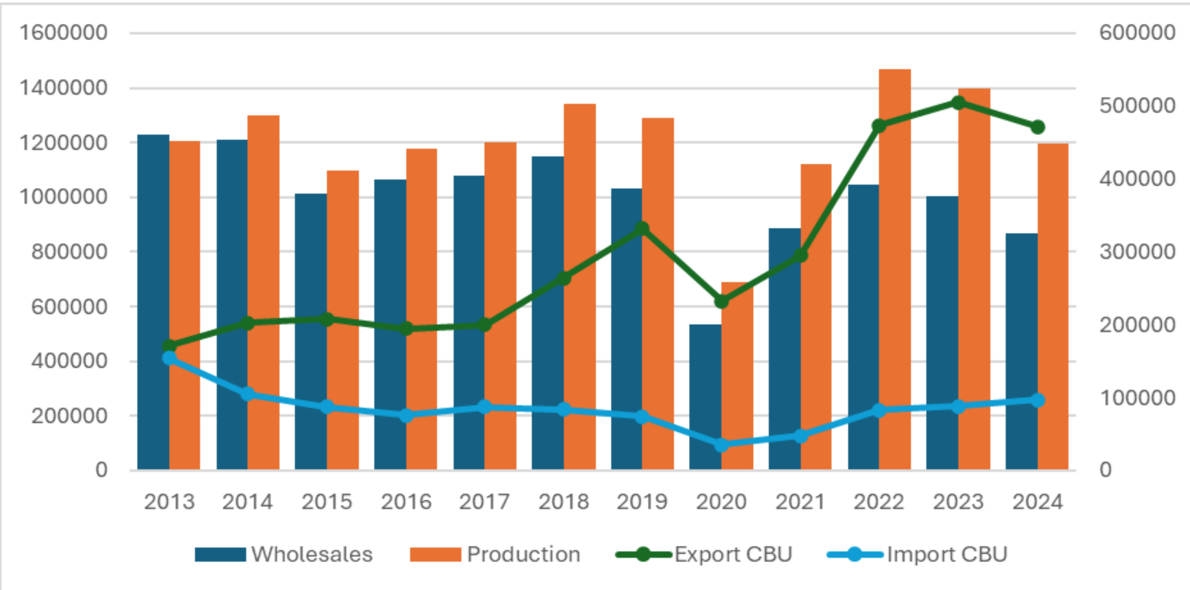
This chapter examines the structure and development of Indonesia's automotive sector as a foundational step in assessing the global competitiveness of the country's automotive industry. It then analyzes Indonesia's comparative advantages in EV value chain in order to assess its industrial competitiveness in the development of the EV industry. The subsequent chapter discusses the implications of greening the EV value chain, with particular attention to its impacts on emissions and public health. By adopting a more targeted industrialization strategy and incorporating life-cycle emissions considerations for EVs and batteries, the development of Indonesia's EV industry can enhance its global competitiveness while simultaneously supporting the country's climate objectives.

5.1 Current Condition of Indonesia's Automotive Sector

The automotive sector plays a significant role in Indonesia's economy. Since 2010, the transport equipment industry has contributed between one to two percent of the total GDP and seven to nine percent of the manufacturing GDP. The Indonesian automotive industry experienced significant development during the 2006-2014 commodity boom period[57] (Negara and Hidayat, 2021). By its peak in 2014, Indonesia's production capacity was able to exceed domestic demand, a trend that is clearly reflected in the data where Production consistently outpaced Wholesales throughout the decade. Although there was a significant decline in 2015 following the end of the commodity boom, production, domestic sales, and car exports continued to increase until 2019.

However, the sector faced a sharp contraction in 2020 due to the pandemic, followed by a strong recovery in 2021 and 2022. During this recovery phase, CBU Exports (gray line) reached a significant peak, nearly doubling the levels seen in 2013. Despite this momentum, a downturn occurred from 2023 to 2024, likely driven by high interest rates and weakened domestic purchasing power. On a positive note, the trade of Completely Built-Up (CBU) vehicles has consistently maintained a surplus over the last ten years. This is evidenced by the widening gap between CBU Exports and CBU Imports (yellow line), confirming Indonesia's strengthening position as a regional manufacturing hub.

Figure 6. Car's Wholesales, Production, Export, and Import in Indonesia (units)



Source: Gaikindo

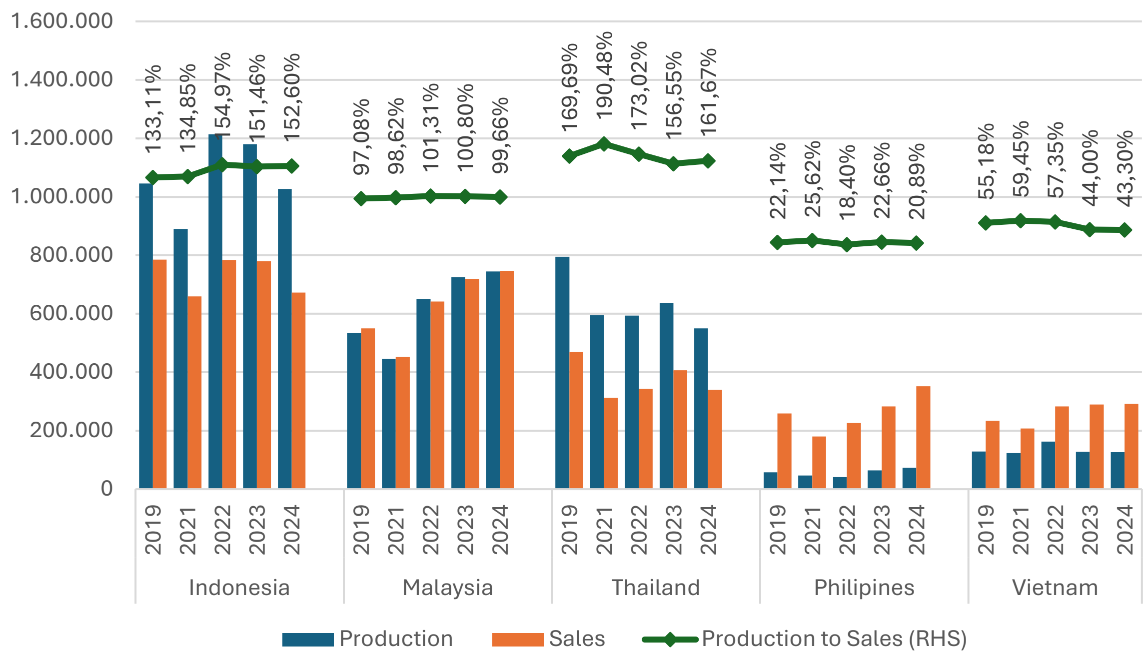
At the regional level, Indonesia has emerged as the largest producer of passenger cars in Southeast Asia. As of 2024, Indonesia's passenger car production exceeded 1 million

[57] Negara, S. D., & Hidayat, A. S. (2021). Indonesia's Automotive Industry: Recent Trends and Challenges. Journal of Southeast Asian Economies.

units, surpassing Malaysia (~700,000 units) and Thailand (>500,000 units). While Indonesia leads in total volume, a deeper look at efficiency shows that only Indonesia and Thailand possess production capacities that significantly exceed domestic demand.

Thailand currently holds the highest Production-to-Sales ratio at 161.67%, compared to Indonesia's 152.60%, indicating that Thailand remains more aggressively export-oriented per unit of domestic sale. In contrast, Malaysia's market is primarily driven by internal consumption, with production meeting 99.66% of domestic sales. Meanwhile, countries like the Philippines and Vietnam remain net importers, with production meeting only 43.30% and 20.89% of their respective domestic demands. Ultimately, this confirms that while Indonesia is the volume leader, it continues to compete closely with Thailand for manufacturing supremacy in the ASEAN region.

Figure 7. Passenger Car Production and Sales (units)



Source: Gaikindo, AAF

Meanwhile, the automotive sector is entering a new era of transformation. In line with global trends and developments in other countries, Indonesia is actively promoting the adoption and production of electric vehicles. This shift is driven not only by environmental objectives, such as reducing emissions, but also economic goals, including attracting foreign investment, and create jobs[58] (Halimatussadiah et al., 2024). With the world's largest nickel reserves, Indonesia has a strong foundation to position itself as a global hub for EV production. Leveraging this strategic advantage, the

[58] Halimatussadiah et al. (2024). Employment impacts of energy transition in Indonesia. LPEM FEB UI Working Papers.

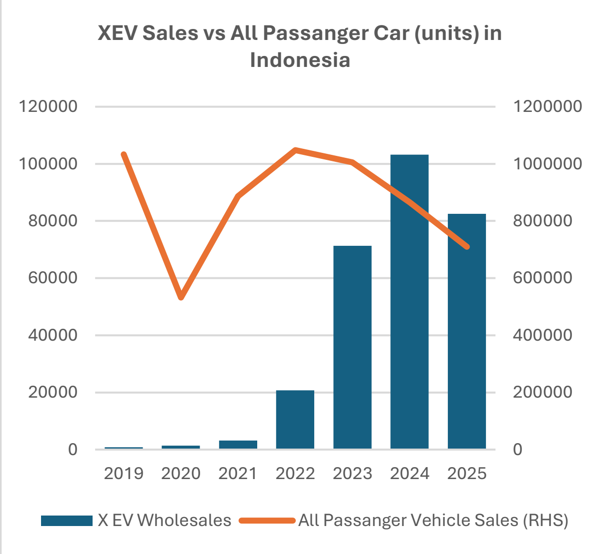
government has introduced a range of policies aimed at accelerating the development of battery-based electric vehicles for road transportation, as part of its broader industrial and energy transition agenda. This includes increasing Local Content Requirement (TKDN) targets, providing fiscal and non-fiscal incentives for industries and users, and developing charging infrastructure. This foundation was updated through Presidential Regulation No. 79 of 2023, which also mandates that manufacturers build factories within Indonesia.

More specifically, the government provides a Value Added Tax (VAT) incentive, where 10% is borne by the government (DTP) as regulated in Ministry of Finance Regulation (PMK) No. 8 of 2024 and continued through PMK No. 12 of 2025. Consequently, consumers only need to pay 1% VAT for units meeting a minimum TKDN of 40%. Additionally, based on PMK No. 9 of 2024 and PMK No. 135 of 2024, the government provides a 100% Luxury Goods Sales Tax (PPnBM) exemption and a 0% import duty for vehicles under certain conditions. At the regional level, in accordance with Law No. 1 of 2022 (HKPD), electric vehicles also enjoy exemptions or minimal rates for Motor Vehicle Tax (PKB) and Vehicle Ownership Transfer Fee (BBNKB). These measures are collectively designed to lower selling prices and make EVs more competitive for the public.

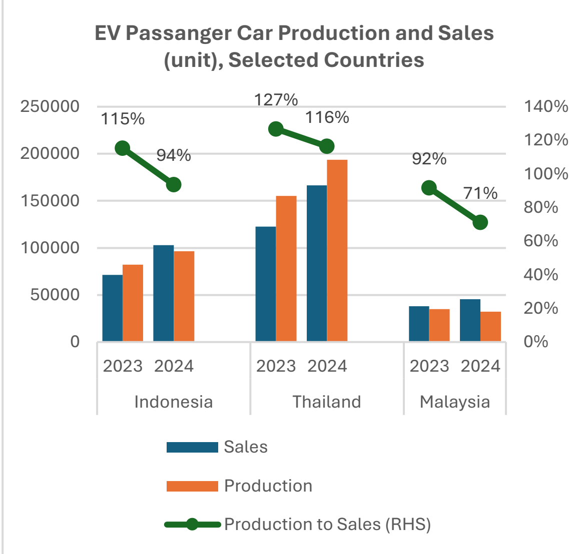
The implementation of various fiscal and non-fiscal incentives has successfully accelerated electric vehicle (EV) adoption within Indonesia. As illustrated in the market data, there has been a remarkable surge in EV sales from 2019 to 2024, growing from a mere 812 units to 103,228 units. The most significant growth trajectory was recorded in 2023, which saw a 245% year-on-year increase as sales jumped from 20,681 units to 71,358 units. A critical observation in this trend is that EV sales continued to climb significantly even as the broader passenger car market experienced a decline. This divergence suggests a clear shift in public preference and a growing consumer transition toward electric mobility despite general market headwinds.

While Indonesia's domestic growth is substantial, it has yet to reach the top position in production and sales at the regional level. In 2024, Indonesia recorded production and sales of 96,482 and 103,091 units respectively, much lower than Thailand, which produced 193,655 units and sold 166,468 units in the same period. Furthermore, Thailand demonstrates a more robust export-ready infrastructure, with production capacity exceeding domestic demand by 127% in 2023 and 116% in 2024. While Indonesia was able to exceed its internal demand in 2023 with a 115% ratio, this figure dropped to 94% in 2024, indicating that production did not keep pace with domestic sales in the most recent year.

Figure 8. XEV and EV Sales and Production in Indonesia



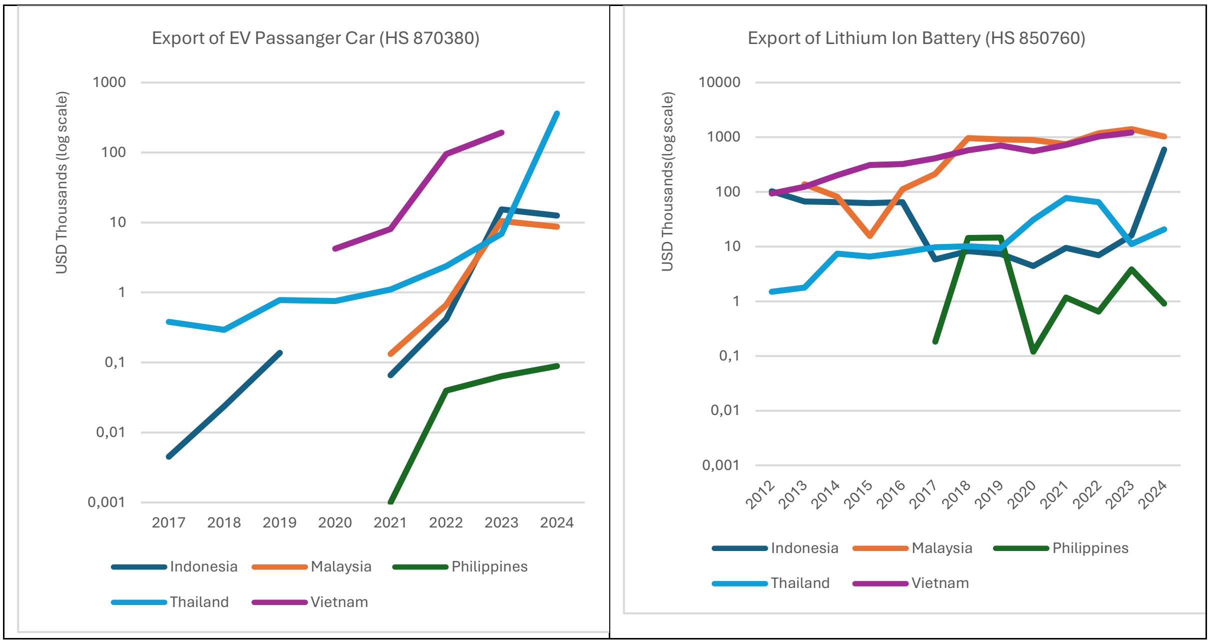
Source: Gaikindo



Source: Gaikindo, AAF

The regional export landscape for lithium-ion batteries (HS 850760) and electric vehicles (HS 870380) reflects these production trends. In 2024, Indonesia's EV exports reached USD 12.5 million, a significant increase from USD 416 thousands in 2021. However, it is considerably lower than Thailand's export of EV USD 361.9 million in 2024 or even Vietnam's export in 2023, which recorded USD 192 million. Regarding the lithium-ion battery sector, Indonesia's exports were USD 596 million in 2024, much higher than the year before which was recorded at USD 16 million. Meanwhile, Thailand's battery exports rose to USD 361.9 million in 2024, and Vietnam's reached USD 192.4 million in 2023. Yet, the figure is much lower than Malaysia's and Vietnam's export for Battery in 2023 which was recorded at USD 1.4 and USD 1.2, respectively. This once again highlights the rapid growth of Indonesia's EV and battery industry. Nevertheless, the country's ambition to position itself as a regional industrial hub remains a distant goal, as Indonesia continues to trail behind several neighbouring countries in the region.

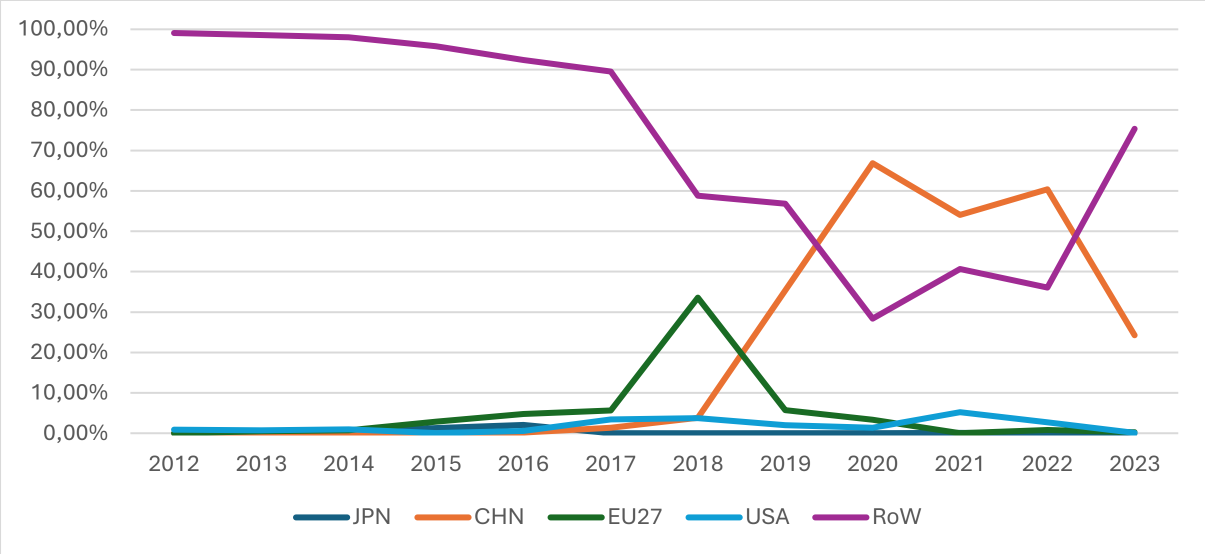
Figure 9. Export of EV Passenger Car and Lithium-ion Battery



Source: WITS

Regarding Indonesia's lithium-ion battery exports by destination, there has been a significant shift in market share toward China. While China's share was close to 0.00% in 2012, it grew substantially to 35.39% in 2019 and reached a peak of 66.86% in 2020. By 2023, China's share stood at 24.29%, remaining considerably higher than other major markets such as the EU27 and the USA, which held shares of 0.26% and 0.06% respectively. This trend underscores China's growing dominance in the global EV market. By contrast, although the market shares of the European Union and the United States saw a temporary uptick, they have since levelled off. This development is particularly important for Indonesia to consider. The country aims to develop NMC-type batteries, which are predominantly used in the EU and US markets. A slowdown or stagnation in demand within these markets could therefore have strategic implications for Indonesia's battery industry ambitions.

Figure 10. Market Share of Indonesia's Li-Ion Battery Exports by Destination



Source: WITS

5.2 Does Indonesia has what it takes to be the hub of EV Production?

To evaluate Indonesia's competitiveness across the Electric Vehicle (EV) value chain, this study employs the Revealed Comparative Advantage (RCA) framework, an empirical measure used to assess a nation's relative export performance. Originally developed by Bela Balassa, the RCA index quantifies whether a country possesses a "revealed" advantage in a specific product by comparing that product's share in the country's total exports to its share in total world trade. An RCA value greater than one suggests that the country is a competitive exporter of that good relative to the global average, while a value less than one indicates a comparative disadvantage. The primary data for this analysis is sourced from the World Integrated Trade Solution (WITS) database.

The analysis begins by establishing a baseline within the established automotive sector, evaluating the RCA of passenger cars (HS 8703) and passenger car components (HS 8708). This initial assessment provides the necessary context to determine whether Indonesia's existing manufacturing infrastructure serves as a robust foundation for the EV transition. From this baseline, the study adopts a comprehensive lifecycle approach, moving into raw material extraction and upstream mineral production. Guided by the critical materials framework established by the Columbia University Center on Global Energy Policy, the analysis quantifies Indonesia's dominance in the supply of essential ores such as nickel and cobalt[59].

The analysis then shifts to the upstream and midstream segments of the value chain, utilizing trade classifications from the USGS ScienceBase-Catalog to assess Indonesia's capacity to refine raw minerals into lithium-ion battery components[60]. It is important to note that these trade codes are primarily aligned with the supply chain structures of the

[59] Columbia University Center on Global Energy Policy (2024). Critical Materials Monitor.
[60] McMahon (2022). Trade Codes Related to the Lithium-Ion Battery Supply Chain. U.S. Geological Survey.

United States, the European Union, and the People's Republic of China, and therefore may not fully capture the entirety of the global value chain. Nevertheless, they provide a useful and robust proxy for evaluating Indonesia's upstream and midstream performance, particularly when compared with downstream manufacturing outputs such as electrolytes and finished lithium-ion batteries.

The RCA analysis employs a two-point comparative approach, evaluating data from 2013 and 2023. This ten-year interval captures significant structural shifts in Indonesia's industrial competitiveness while ensuring methodological alignment with Vietnam, for which the most recent consistent data is available through 2023. Notably, for the electric vehicle (EV) sector, the assessment is confined to the 2017–2023 period, as specific trade classifications for EVs were not established until 2017. The products analysed within this framework are detailed in the table below:

Table 1. Components of Lithium-ion Battery

Segment	Material
Raw Materials	Alumunium (HS 260600)
	Cobalt (HS 260500)
	Iron (HS 2601)
	Lithium (HS 253090)
	Manganese (HS 260200)
	Nickel (HS 260400)
	Phosphorus (HS 2510)
Upstream	Spherical Natural Graphite (HS 250410)
	Spherical Synthetic Graphite ,Synthetic Graphite Powder, Colloidal Suspension (HS 380190)
	Intermediate Cobalt Products (HS 810520)
	Electrolytic Manganese Metal Powder (HS 811100)
Midstream	Cobalt Tetroxide (HS 282200)
	1. Lithium Cobalt Oxide; Lithium Iron Phosphate; Lithium Nickel Cobalt Aluminum Oxide (HS 284190)
	2. Lithium Cobalt Oxide; Lithium Iron Phosphate; Lithium Nickel Cobalt Aluminum Oxide (HS 284290)
	Nickel Cobalt Aluminum Composite Hydroxide (Precursor); Nickel Cobalt Manganese Composite Hydroxide; (Precursor); Nickel Cobalt Manganese Composite Hydroxide (Precursor) (HS 285300)
	Electrolytic Manganese Dioxide (HS 282010)
	Manganese Sulfate (HS 283329)
	Mixed Metal Hydroxide (HS 382490)
	Lithium Hydroxide (HS 282520)
	Lithium Chloride (HS 282739)
	Lithium Hexafluorophosphate (HS 282690)

Segment	Material
Downstream	Electrolyte (HS 382490)
	General Battery (HS 8507)
	Li-Ion Battery (HS 850760)

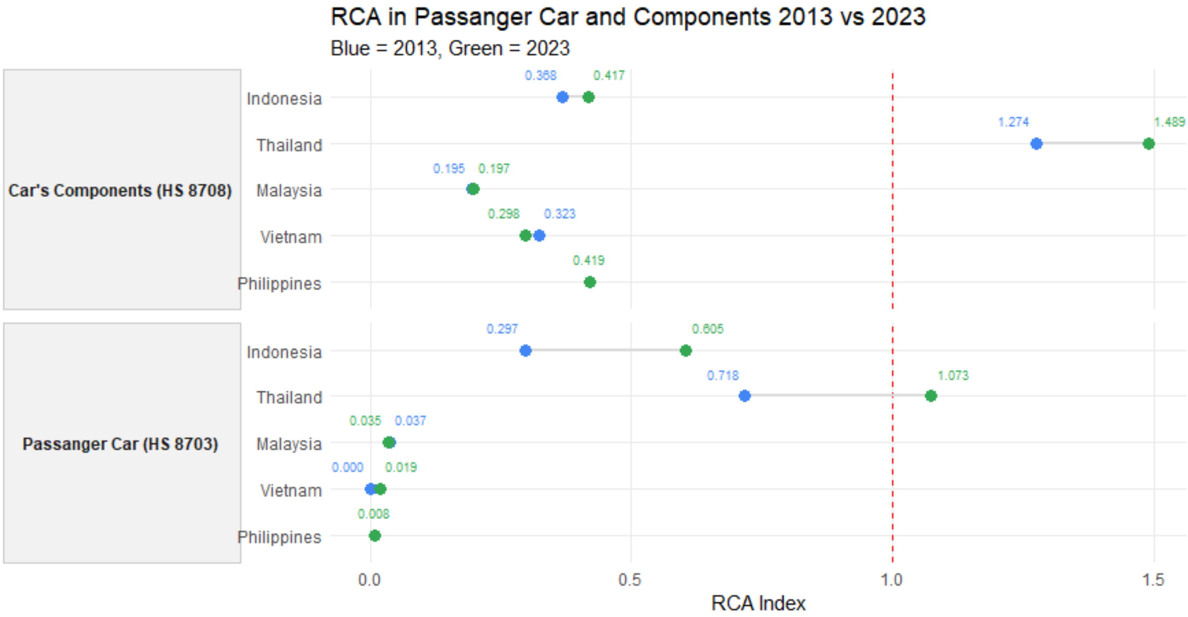
Source: Global Energy Policy (2024) and McMahon (2022)

5.2.1 Passanger Vehicle and EV

Looking at the competitiveness level in the region, the data shows that Thailand is the dominant regional leader in the automotive sector, maintaining a significant comparative advantage in both passenger cars and car components. Over the ten-year period, Thailand notably strengthened its position, with its RCA for passenger cars rising from 0.72 to 1.07, signalling its transition into a specialized global exporter. In contrast, Indonesia has emerged as a rising competitor in the finished vehicle market; while its advantage in components grew modestly, its RCA for passenger cars saw a dramatic increase from 0.30 to 0.60, doubling its comparative strength and closing the gap with Thailand. Although Indonesia ranks second, this does not necessarily indicate strong competitiveness in its automotive and components industry. An RCA value below 1 suggests that Indonesia’s automotive and components sector lacks a comparative advantage and remains insufficiently competitive in the global market.

The remaining countries, Malaysia, Vietnam, and the Philippines, show a distinct specialization in the "Car's Components" segment rather than finished vehicles. Vietnam, despite a slight decline in component RCA (from 0.32 to 0.30), saw its passenger car RCA surge from near-zero to 0.019, indicating the very early stages of a developing domestic export industry.

Figure 11. RCA in Passenger Car and Components 2013 vs 2023

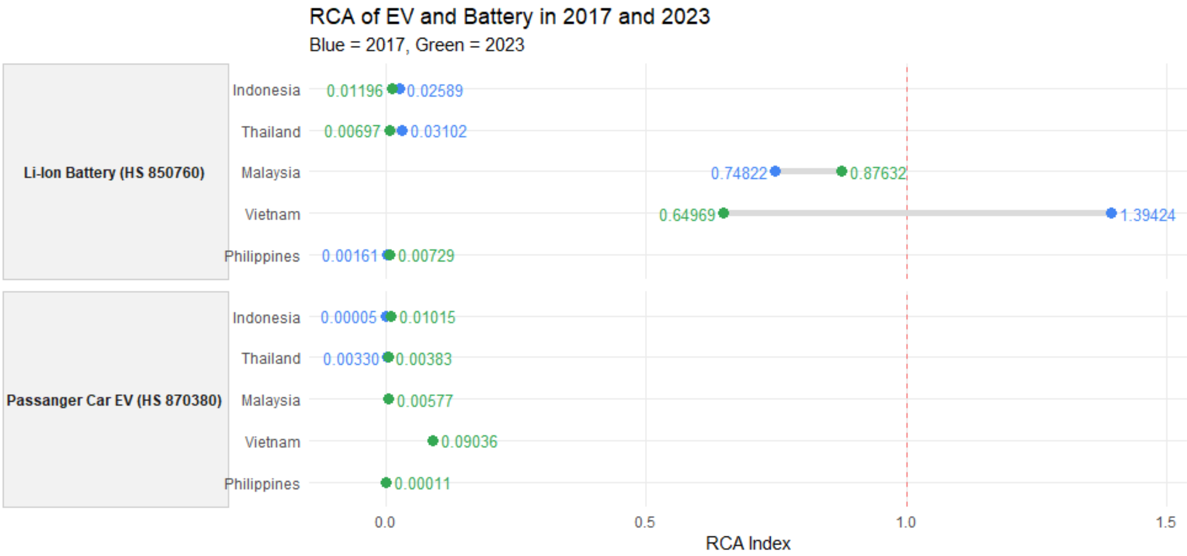


Source: Authors' calculation

Meanwhile related to EV, Indonesia has demonstrated a sharp divergence in its EV export. In the Passenger Car EV (HS 870380) segment, Indonesia's RCA grew from a a very low point in 2017 to 0.01 in 2023. Conversely, its competitiveness in the Li-Ion Battery (HS 850760) sector declined, with the RCA falling from 0.026 to 0.012 during the same period. This development raises an important question: what factors are driving the decline in comparative advantage in the battery sector, especially at a time when the EV industry is expanding rapidly? One plausible explanation is the surge in domestic demand for batteries, fuelled by the growth of Indonesia's EV industry. However, given that domestic battery production capacity remains limited, rising internal demand may strain supply and reduce export availability. As a result, Indonesia's competitiveness in the global battery market may weaken despite the broader expansion of the EV sector.

Regionally, Vietnam initially led both categories, establishing the highest Passenger Car EV RCA in the group at 0.09 by 2023. While its Li-Ion Battery RCA declined from a dominant 1.39 in 2017 to 0.65 in 2023, it remained a primary regional competitor until 2024 data became unavailable. The decline in Vietnam's battery RCA is likewise an interesting development. Using a similar hypothesis, this trend may reflect a shift in battery supply toward meeting growing domestic demand, particularly to support the expansion of its own EV and battery industries. Meanwhile, only Malaysia demonstrated consistent growth in battery competitiveness, with its RCA rising from 0.75 in 2017 to 0.88 in 2023, although its EV car presence remained marginal at 0.006.

Figure 12. RCA of EV and Battery in 2017 vs 2023



Source: Authors' calculation

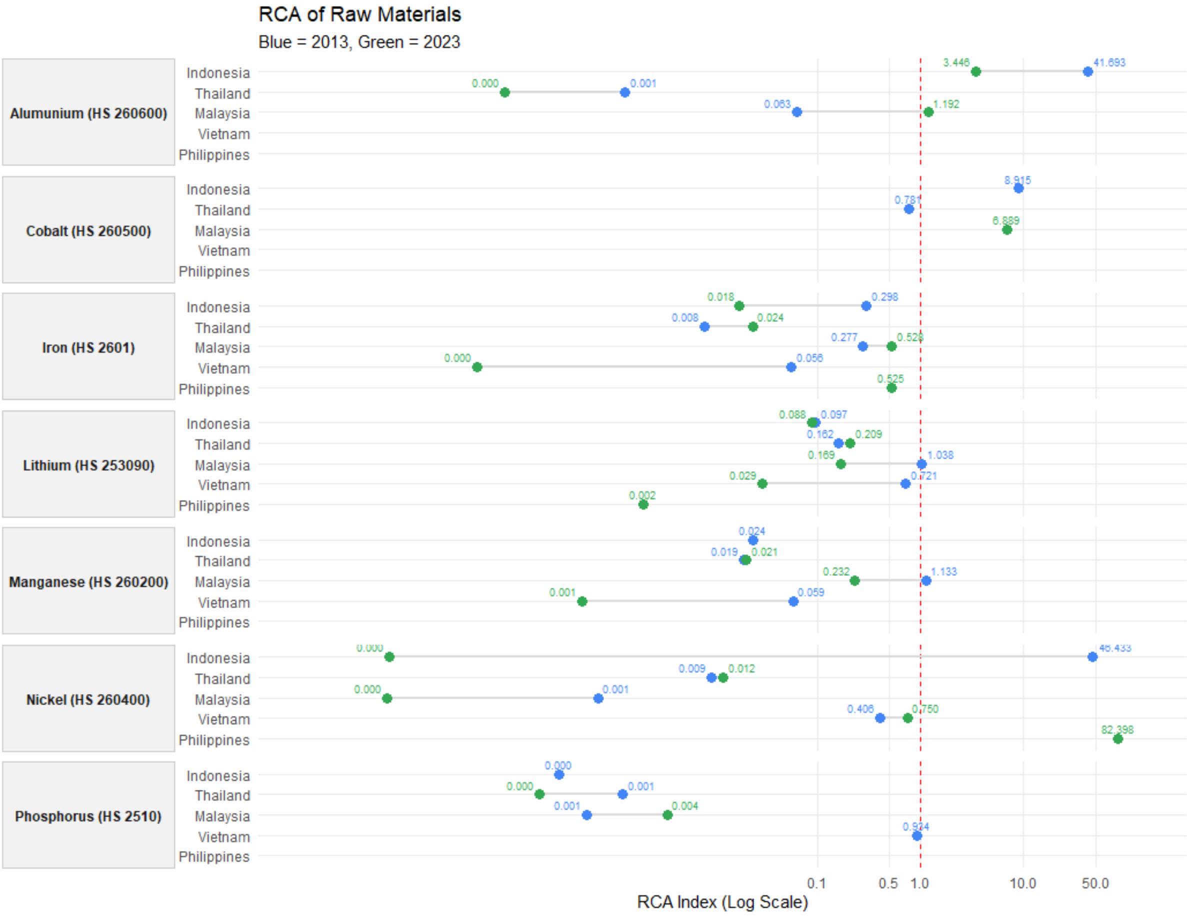
5.2.2 Battery

a. Raw Material

The regional data for raw material exports indicates a significant strategic shift, as most nations have experienced a sharp decline in their comparative advantage for unprocessed minerals to prioritize downstream industrialization. Indonesia presents the most drastic example of this transition; its Nickel (HS 260400) RCA plummeted from a globally dominant 46.43 in 2013 to less than 0.001 by 2023. Similarly, Indonesia's Cobalt (HS 260500) competitiveness, which stood at a strong RCA of 8.91 in 2013, vanished entirely by 2023, while its Aluminum (HS 260600) RCA fell from 41.69 to 3.44. This outcome is expected, given that Indonesia has imposed an export ban on raw materials and requires that these materials be processed domestically before they can be exported.

This trend of diminishing raw material export strength is observable across other regional players as they pivot toward higher value-added segments. Malaysia saw its RCA for Lithium (HS 253090) drop from 1.03 in 2013 to 0.17 in 2023, while its Manganese (HS 260200) advantage eroded from 1.13 to 0.23. Vietnam also recorded a significant contraction in its Lithium, falling from 0.72 to 0.029 during the same period. While Thailand maintained a generally low presence in raw mineral exports, its Cobalt RCA of 0.78 in 2013 also dropped to unrecorded levels by 2023. In contrast, the Philippines remains an outlier in the region, significantly increasing its comparative advantage in raw Nickel to an RCA of 82.39 in 2023. This development illustrates how many countries are adopting a similar strategy, prioritizing the use of their raw materials for domestic battery production rather than exporting them. Such a trend signals a broader shift in the global value chain, with countries increasingly focusing on strengthening domestic processing and manufacturing capabilities.

Figure 13. RCA of Raw Materials for Battery



Source: Authors' calculation

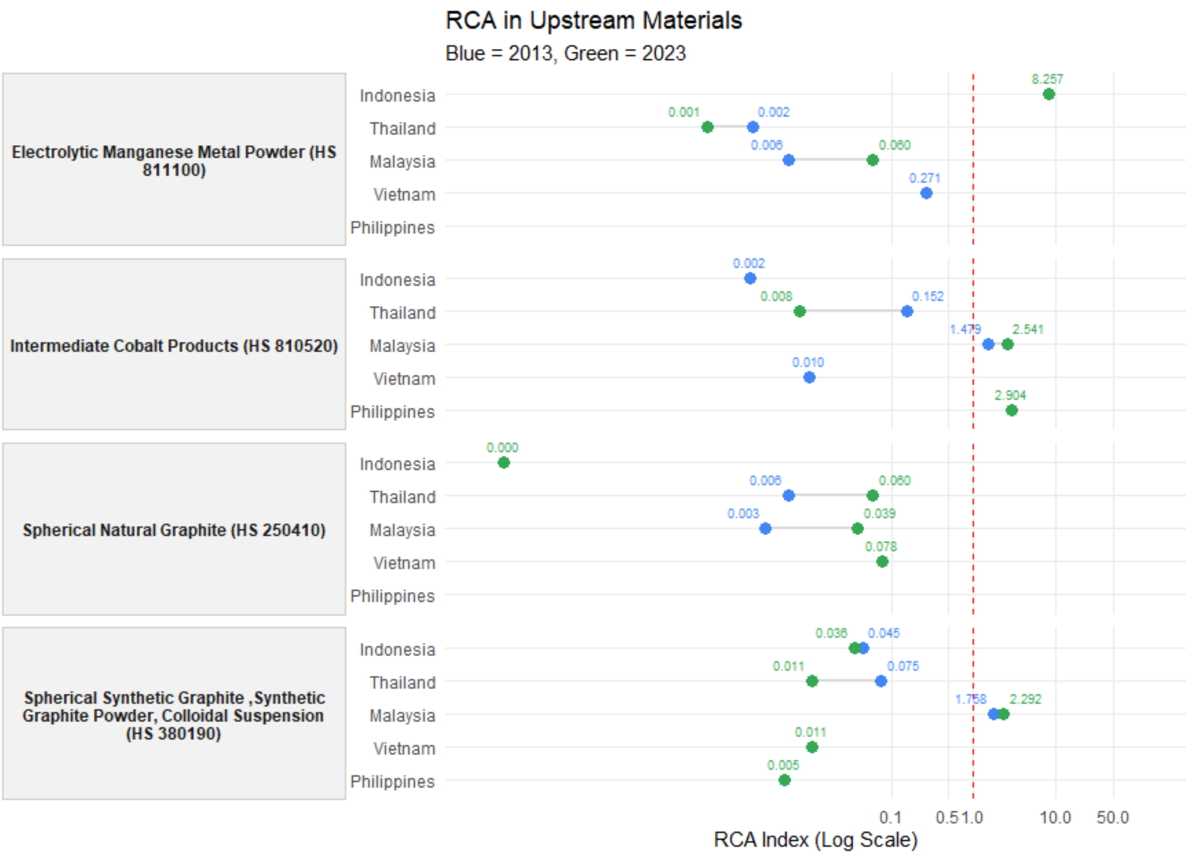
b. Upstream and Midstream

In the upstream sector, Indonesia's transition toward advanced chemical processing is characterized by extreme specialization rather than a diversified industrial shift. As of 2023, Indonesia has established a definitive comparative advantage in Electrolytic Manganese Metal Powder (HS 811100) with a commanding RCA of 8.26, marking a massive leap from its non-existent export status in 2013. However, this success is isolated; Indonesia's RCA in Spherical Synthetic Graphite (HS 380110) fell from 0.045 to 0.036, and its already negligible presence in Intermediate Cobalt Products (HS 810520) effectively vanished. This upstream gap is further highlighted by the Philippines, which holds a significant advantage in cobalt intermediates with a strong RCA of 2.90.

This pattern of narrow specialization continues into the midstream segment, where the policy of restricting raw material exports has not yet translated into widespread competitiveness across refined products. Indonesia achieved a definitive advantage in Manganese Sulfate (HS 283329), with its RCA surging from less t to 1.01, and saw Mixed

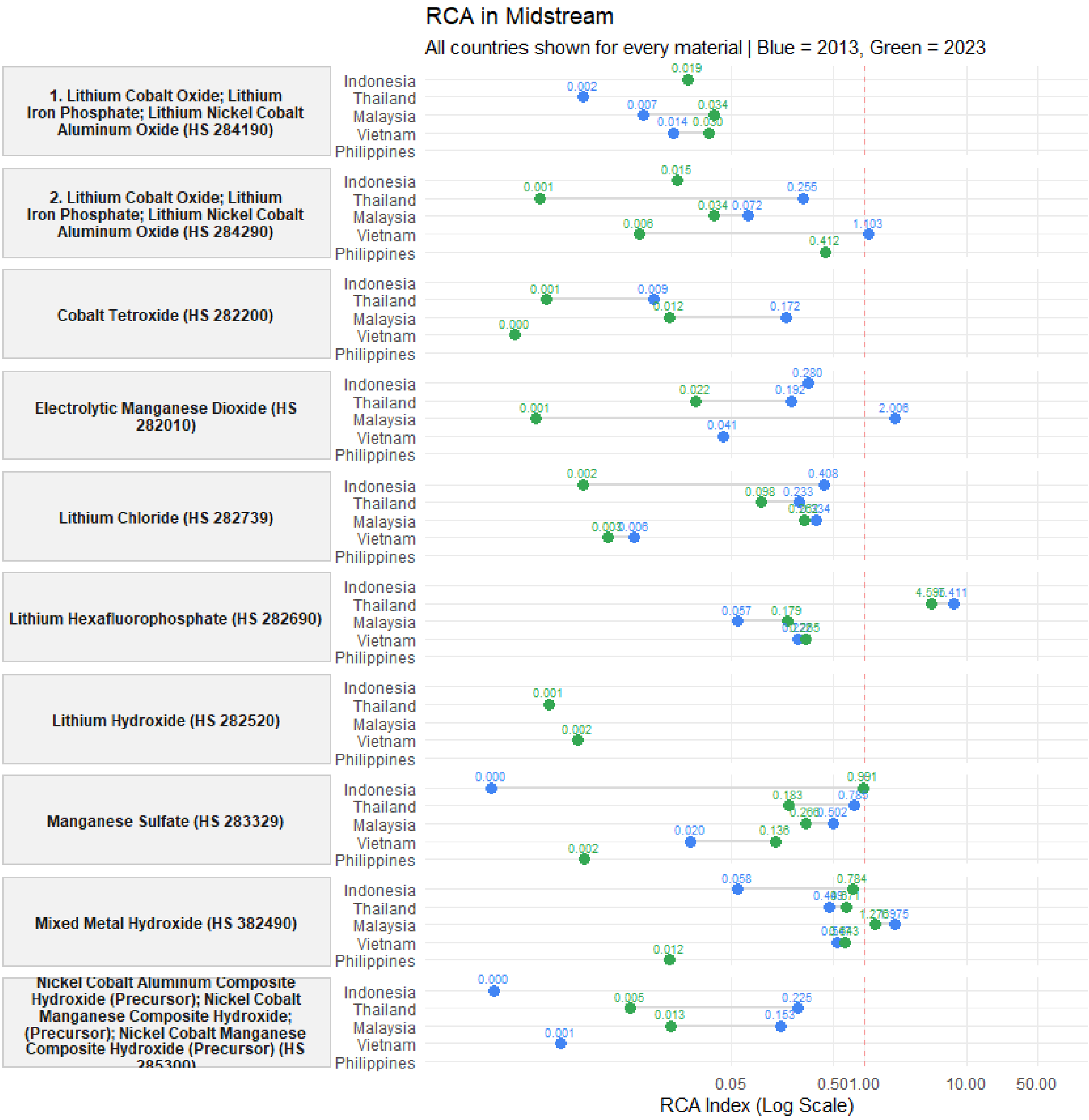
Metal Hydroxide (HS 382490) rise from 0.060 to 0.820. Aside from these manganese and nickel-based precursors, other midstream indicators remain weak or in decline. For instance, Lithium Chloride (HS 282739) saw its RCA collapse from 0.41 to 0.0018. Regionally, Indonesia still trails behind Thailand's extreme dominance in electrolyte salts (Lithium Hexafluorophosphate RCA 4.92) and Malaysia's established lead in Mixed Metal Hydroxides (RCA 1.33). These data points suggest that while Indonesia is successfully developing specific niches, the broader midstream and upstream ecosystems have yet to show a comprehensive increase in export competitiveness following the reduction of raw material exports.

Figure 14. RCA in Upstream Materials



Source: Authors' calculation

Figure 15. RCA in Midstream



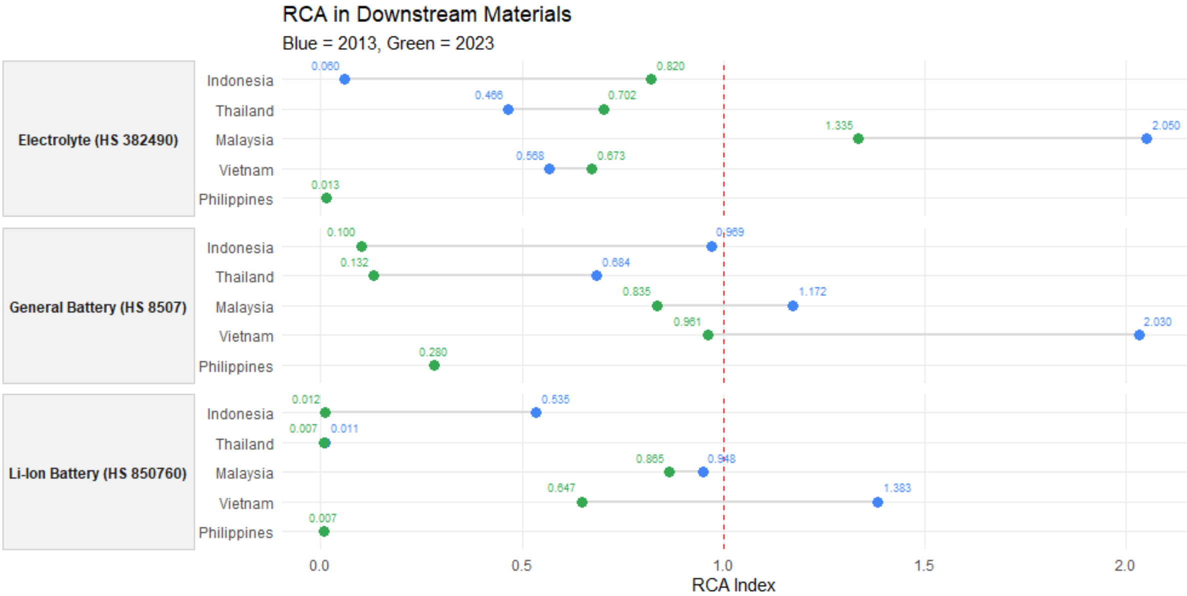
Source: Authors' calculation

c. Downstream

Despite the strategic focus on industrialization, Indonesia's downstream EV competitiveness has largely declined across several key segments. Aside from Electrolytes (HS 382490), which saw its RCA rise from 0.060 in 2013 to 0.820 in 2023, other downstream indicators show a lack of sustained growth. The Li-Ion Battery (HS 850760) RCA fell from 0.535 in 2013 to 0.012 in 2023, and while it recovered to 0.465 in 2024, it remains below its 2013 levels. Similarly, the General Battery (HS 8507) category dropped significantly from 0.968 to 0.100 during the same period.

This downward trend in the lead-up to 2024 was also observed regionally. Vietnam's battery RCA declined from 1.39 in 2017 to 0.650 in 2023, and Malaysia's fell from 0.876 to 0.641 between 2023 and 2024. Furthermore, Indonesia's Passenger Car EV (HS 870380) RCA remains marginal at 0.0085 as of 2024. These data points indicate that outside of specific chemical components, Indonesia's downstream export performance has yet to show a broad-based improvement relative to its 2013 baseline.

Figure 16. RCA in Downstream Materials



Source: Authors' calculation

The increasing competitiveness in the Passenger Car EV (HS 870380) segment across Thailand, Vietnam, and Indonesia indicates a broader regional ambition to establish independent, integrated EV ecosystems. Thailand's EV car RCA exploded from 0.0038 in 2023 to 0.203 in 2024, while Vietnam reached 0.090 in 2023 and Indonesia grew from a negligible less than 0.0001 in 2017 to 0.0085 in 2024. Meanwhile, despite its strategic ambitions, Indonesia's export performance remains behind its regional peers in both the conventional automotive and electric vehicle (EV) sectors. In the passenger car market, Indonesia continues to trail Thailand, while in the specific EV segment, it lags behind both Thailand and Vietnam.

Indonesia's downstreaming strategy has resulted in a loss of comparative advantage in raw materials. Yet, paradoxically, it has not translated into a stronger comparative advantage in subsequent stages of the battery value chain, whether upstream, midstream, or downstream. One key reason is that nickel downstreaming policies have largely been oriented toward the steel industry rather than battery-grade processing. The technologies and capabilities required to convert nickel into battery components remain underutilized. This misalignment between industrial ambition and actual industrial upgrading has made Indonesia's aspiration to become a regional leader in the EV and battery industry increasingly challenging.

At the same time, it is important to acknowledge that Indonesia does not hold a comparative advantage across all critical inputs and components necessary for battery production. For this reason, greater trade openness and deeper regional integration should be incorporated into Indonesia's industrial development strategy. A more strategic mapping of which sectors offer comparative advantage, and which are better sourced through international trade, would provide a more realistic pathway for EV and battery industrialization.

Such a shift is also essential to prevent fragmented industrial development across Southeast Asia. As countries such as Thailand and Vietnam pursue their own domestic EV ecosystem strategies, there is a risk of "scattered specialization," where overlapping ambitions lead to inefficiencies and duplication. By adopting a more open and cooperative trade approach, Indonesia can help facilitate a more coordinated regional production network. This would reduce industrial fragmentation and allow each country's specialization to complement one another, ultimately strengthening a more integrated and competitive Southeast Asian EV supply chain.

5.3 Other Challenges in EV's Development

As discussed in the previous sub-chapter, Indonesia does not possess strong comparative advantages across all components required for battery and EV production. However, this limitation is only part of the broader challenge. Beyond gaps in comparative advantage, several structural mismatches need to be addressed if Indonesia is to successfully develop a sustainable and competitive EV industry.

The first mismatch relates to both the scale and the composition of Indonesia's nickel reserves. According to the Ministry of Energy and Mineral Resources (ESDM), Indonesia's total nickel reserves amount to approximately 698 million tons—an amount estimated to support domestic refining capacity for only seven to eight years. From a long-term industrial strategy perspective, this relatively limited reserve horizon raises concerns about sustainability, particularly if Indonesia aims to position itself as a regional hub for battery and EV production.

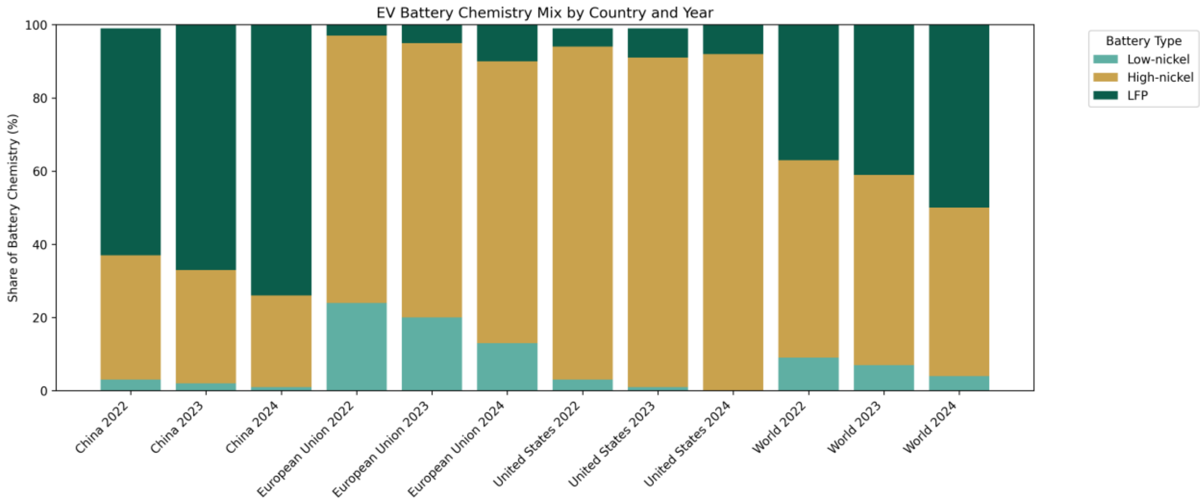
Equally important is the issue of nickel type. Around 65 percent of Indonesia's nickel output is better suited for stainless steel production rather than battery-grade materials[61]. This creates a misalignment between existing downstreaming policies—

[61] Tenggara Strategics (2025). Path to Indonesia's 8% Growth: Leveraging Nickel-Based EVs for Energy Security.

originally designed to maximize value added in mineral processing—and the strategic objective of developing a battery-focused EV ecosystem. At the same time, High Pressure Acid Leach (HPAL) technology, which is required to process lower-grade nickel into battery-grade inputs, remains underutilized. As a result, the transition from a steel-oriented downstream industry to a battery-oriented one has not yet been fully realized.

The second mismatch concerns the evolving dynamics of global market demand. Given its nickel endowment, Indonesia's battery strategy has largely emphasized Nickel Manganese Cobalt (NMC) batteries, which offer higher energy density and have traditionally been favored in markets such as the European Union and the United States. However, global demand patterns are shifting. In recent years, Lithium Iron Phosphate (LFP) batteries have gained significant market share, particularly driven by China's rapid expansion in LFP-based EV production. As illustrated in Figure 17 below, the cost advantage of LFP batteries has made EVs more affordable, accelerating adoption worldwide.

Figure 17. EV Battery Chemistry Mix by Country

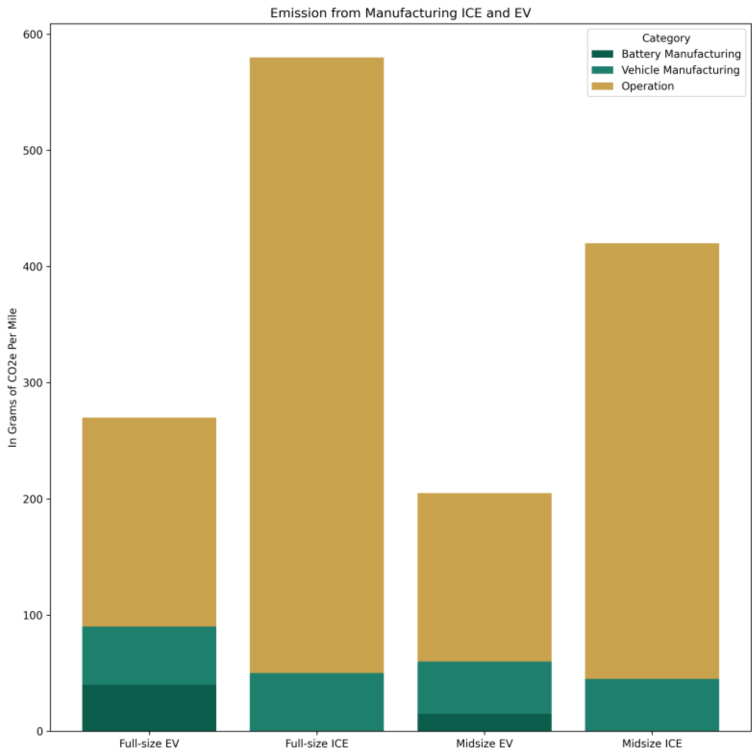


Source: IEA

This market shift creates a strategic dilemma for Indonesia. On the one hand, Indonesia's strong comparative advantage in nickel suggests that prioritizing the development of NMC batteries would be economically efficient. On the other hand, NMC batteries may gradually lose their competitiveness in the global market if they are unable to match the lower prices of LFP batteries. Relying exclusively on NMC battery development could therefore jeopardize Indonesia's ambition to become a regional battery production hub. Rather than focusing solely on NMC technology, the government should begin crafting a more diversified strategy—one that leverages Indonesia's comparative advantages while also exploring opportunities in other emerging battery technologies.

The third issue relates to a potential mismatch between EV development and Indonesia's broader decarbonization agenda. It is important to emphasize that BEVs do not automatically result in lower carbon emissions compared to internal combustion engine vehicles (ICEVs). From a manufacturing perspective, BEVs tend to generate higher emissions, primarily due to battery production (see Figure 18 below). According to data from the Union of Concerned Scientists, manufacturing a mid-size BEV with a range of approximately 84 miles produces slightly more than one additional ton of CO_2 compared to manufacturing a similar ICE vehicle. For a full-size BEV with a longer range of around 265 miles, the larger battery increases emissions by roughly six additional tons. On average, this translates into approximately 15 percent higher emissions for mid-size BEVs and about 68 percent higher emissions for full-size, long-range BEVs relative to ICE vehicle production. However, the emissions profile changes when evaluated across the full life cycle. Although BEVs are more emissions-intensive at the manufacturing stage, they generally produce significantly lower emissions during the use phase due to the absence of tailpipe emissions. As a result, over their lifetime, BEVs tend to have a lower overall carbon footprint—provided that the electricity used for charging is increasingly sourced from cleaner energy.

Figure 18. Emission from Manufacturing ICEV and BEV

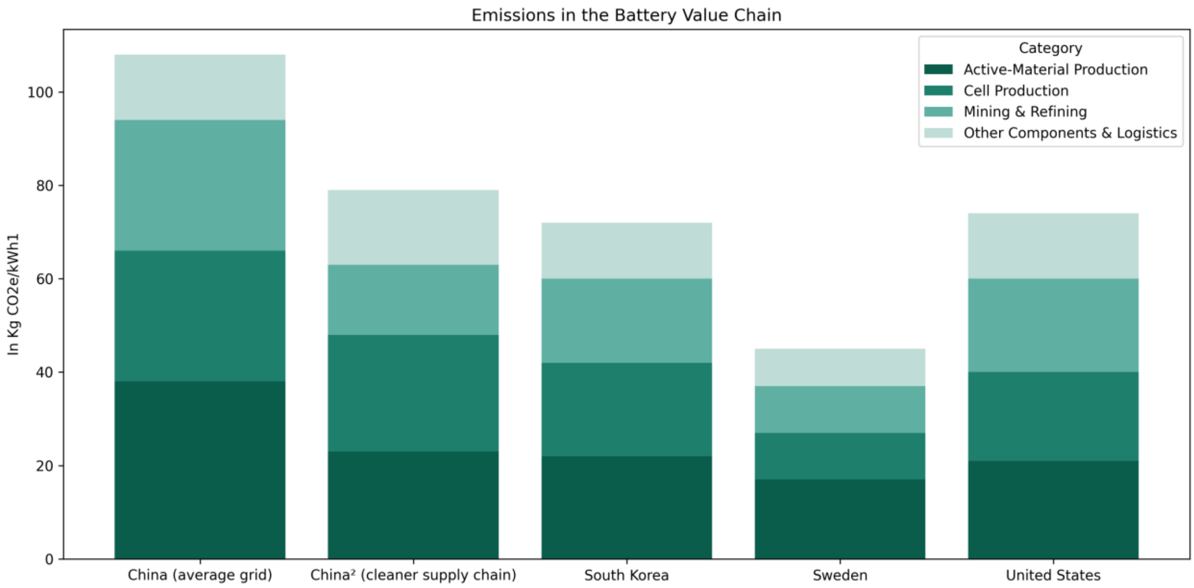


Source: Union of Concerned Scientists

Higher emissions associated with EVs at the manufacturing stage stem primarily from the additional materials required for battery production, which involve extensive mining and processing activities. The level of emissions generated at this stage depends on both the type and volume of materials extracted, as well as the energy intensity of refining and processing. As illustrated in Figure 18 below, there are significant cross-country differences in emissions from battery manufacturing. These differences are largely driven by variations in national energy mixes and energy efficiency levels, which directly shape the emission intensity of battery production.

For Indonesia, this creates a structural issue. While EV development is intended to support the country's broader decarbonization agenda, Indonesia's heavy reliance on coal-fired power plants in its energy mix, as discussed in the previous chapter, means that domestic battery manufacturing is likely to remain carbon-intensive. As a result, Indonesia's ambition to meet its NDC targets and achieve net-zero emissions cannot rely solely on scaling up the EV industry. A parallel and accelerated transition toward renewable energy is essential. Strengthening renewable energy deployment would help reduce the carbon intensity of battery production and ensure that EV development effectively contributes to Indonesia's long-term decarbonization objectives.

Figure 19. Emissions in the Battery Value Chain



Source: McKinsey

Another major challenge in EV development concerns waste management. In Indonesia, Presidential Regulation No. 55/2019 classifies EV battery waste as hazardous, meaning that any activities related to its handling, storage, transportation, or processing require official permits. Lithium-ion batteries, which contain flammable electrolytes, demand specialized and careful treatment. In addition, improper disposal poses significant environmental risks, as battery waste can release heavy metals and toxic substances into surrounding ecosystems. Therefore, repairing, remanufacturing, repurposing, and recycling used batteries are not merely desirable options, they are essential practices that should be systematically enforced for all EV battery manufacturers.

More broadly, decarbonization across the entire value chain, from mining and raw material extraction to battery manufacturing and end-of-life waste management, must be integrated into Indonesia's EV and battery development framework. Ensuring low-carbon practices at every stage of the value chain would help align industrial development objectives with Indonesia's broader climate commitments. At the same time, external initiatives such as the Global Battery Alliance (GBA) Battery Passport are raising sustainability and traceability standards across the global battery industry. These standards increasingly function as de facto market access requirements, particularly in the European Union. Given that key markets for NMC batteries are concentrated in the EU and the United States, Indonesia must comply with evolving international sustainability benchmarks. Without such compliance, Indonesia risks losing access to strategic export markets and undermining the competitiveness of its domestic battery industry. Accordingly, strengthening international cooperation and securing technical assistance to meet global standards should become one of a policy priority to not only support Indonesia's decarbonization agenda but also reinforce its broader industrialization strategy and long-term competitiveness.

6. Assessment of Greener EV Value Chain: Environmental, Social and Economic Benefits of Greening EV Value Chain

Electric vehicles (EVs) are promoted as a key mitigation option within Indonesia's climate mitigation strategy for the transportation sector (SNDC, 2025). While EVs are often considered a low-carbon alternative during the use phase, their environmental impacts vary across different life-cycle stages, ranging from raw material extraction, battery production, vehicle manufacturing, to end-of-life management. To capture these overall impacts, this study applies Life Cycle Assessment (LCA), a standardized methodology for evaluating potential impacts of a product or process throughout its life cycle.

LCA has been widely applied in previous studies to assess the environmental impacts of EVs, including comparisons between internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs)[62], regional comparisons of BEV-related impacts[63], and evaluations of different lithium-ion battery technologies, such as nickel–manganese–cobalt (NMC) and lithium iron phosphate (LFP) batteries [64]. By adopting this approach, this study aims to evaluates the impacts of two product systems: NMC622 batteries produced in Indonesia, reflecting national policies on nickel downstreaming, and BEVs equipped with LFP batteries imported from China, which currently dominate the Indonesian EV market.

The assessment of the NMC battery product system aims to quantify the environmental impacts of NMC battery production under different electricity supply scenarios over the 2023-2034 period. In addition, it evaluates the potential emission reductions achievable through alternative technology pathways.

For the BEV product system, the assessment focuses on quantifying the life-cycle environmental impacts of BEVs during their operational lifetime and comparing these impacts with those of ICEVs in Indonesia. Furthermore, a regional comparison of LFP-

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[62] Champeecharoensuk, T., Saisirirat, P., Chollacoop, N., Vithean, K., Thapmanee, K., Silva, K., Champeecharoensuk, A. (2025). Global warming potential and environmental impacts of electric vehicles and batteries in Association of Southeast Asian Nations (ASEAN). Energy for Sustainable Development, 86.
[63] Aryan, Y., C K, A., Dikshit, A.K. et al. (2025). Comparative life cycle assessment of battery electric vehicles in developing countries under current and future electricity mix scenarios. Discov Sustain, 6(675).
[64] Scrucca, F., Presciutti, A., Baldinelli, G., Barberio, G., Postrioti, L., & Karaca, C. (2025). Life cycle assessment of Li-ion batteries for electric vehicles: A review focused on the production phase impact. Journal of Power Sources, 639.

based BEVs operated in neighboring countries, namely Thailand and Vietnam, is conducted to provide insights under different electricity generation pathways.

Life cycle inventory data regarding material, energy, emissions, and waste associated with both product systems are primarily obtained from the ecoinvent database version 3.11. When relevant data are unavailable in the database, supplementary information is sourced from official documents and available studies. The impact from each product system then being assessed using openLCA software version 2.5.0, applying the ReCiPe 2016 impact assessment method at midpoint (H) levels of indicators[65].

The impact categories considered in this study are grouped into two main categories: environmental impacts and human health impacts. Environmental impacts include climate change and eco-toxicity, while human impacts cover human toxicity (carcinogenic and non-carcinogenic) and fine particulate matter formation ($PM_{2.5}$). These impact categories have been widely used in previous life cycle assessments of EV batteries and are considered relevant for capturing key environmental and health implications of battery and vehicle production[66].

Climate change impact represents the total greenhouse gas (GHG) emissions associated with a product system, expressed as carbon dioxide equivalent (CO_2-eq). This indicator combines emissions from different gases, such as methane and nitrous oxide, based on their global warming potential. In the context of EVs, GHG emissions are closely linked to electricity source used during vehicle operation and to energy-intensive processes in battery production. Examining this indicator helps illustrate how electricity supply and battery production shape the overall climate profile of EVs.

Ecotoxicity and human toxicity impact capture the potential harmful effects of substances released to the environment. Ecotoxicity reflects impacts on ecosystems resulting from emissions to freshwater, marine, and terrestrial (industrial soil) environments, while human toxicity represents the increased risk of cancer and non-cancer diseases due to exposure to toxic substances. In life cycle assessment, both impacts are expressed in 1,4-dichlorobenzene equivalents (1,4-DCB). Both impacts are relevant for EV and battery production, as these processes involve intensive use of metals and minerals that may cause toxic effects when released into the environment and exposed to human population.

[65] Impact indicators at an intermediate stage of the damage pathway, prior to final damage to human health or ecosystems.
[66] Swamy, V. M. M., & Vidyasagar, S. (2025). Analyzing the Environmental Burden of Electric Vehicle Batteries: A Life Cycle Assessment Synthesis. Journal of Information Systems Engineering and Management, 10(32s).

To better understand the necessity of a cleaner energy mix in Indonesia, this section will also analyze the health impacts and costs that NMC battery production has on humans. As mentioned above, NMC battery production potentially influences human exposure toward PM2.5 and human toxins (carcinogenic and non-carcinogenic).

Fine particulate matter (PM2.5) represents very small airborne particles (with a diameter of less than 2.5 μm) formed either directly (primary aerosols) or indirectly from precursor gases such as SO_2. Exposure to PM2.5 is associated with adverse human health effects, as these particles can penetrate deep into the lungs when inhaled. Direct association of PM2.5 on the respiratory tract includes airway inflammation, decreased lung function, and increased risk of respiratory tract infections and chronic respiratory diseases[67]. Over prolonged exposure, PM2.5 can also exacerbate other diseases such as tuberculosis; alarming for Indonesia since it shouldered 10% of tuberculosis globally in 2024[68]. In this study, PM2.5 formation is assessed to capture air pollution arising from energy use and raw material extraction in NMC battery production, as well as to examine potential differences in air pollution impacts between BEVs and ICEVs during vehicle operation.

Exposure to carcinogens is linked to increased cancer rates, neurological damage, and developmental disorders over time[69]. Non-carcinogens, mainly from other heavy metals such as As, Hg, Pb, Co, and Mn, may also cause an array of adverse effects on the nervous system when present in excess[70].

The results from the climate change impact are further used to compare the carbon footprint of EV batteries and vehicles in Indonesia with those in other countries, providing insights into the competitiveness of Indonesian battery production in global markets. In addition, the estimated $PM_{2.5}$, human toxicity, and associated damage to human health are further valuated to derive indicative health costs using conversion factors. This approach allows the analysis to extend beyond environmental impacts and highlight the potential health and economic implications of battery and EV production.

To complement the life-cycle evidence presented in earlier sections, this study introduces an economy-wide simulation to quantify how "greening the EV value chain" translates into macroeconomic, sectoral, and trade outcomes. The logic is

[67] Krismanuel, H., & Tjhin, P. (2025). The association between PM2.5 level and respiratory tract infections among children: A cross-sectional study. AIMS public health, 12(4), 1084–1114.

[68] World Health Organization. (2025). Global tuberculosis report 2025. Geneva: World Health Organization.

[69] Dimowo, B. O., Gbadebo, A. M., taiwo, A. M., Sojinu, O. S., & Dimowo, M. O. (2025). Carcinogenic and non-carcinogenic health risk assessment of heavy metals in water from selected oil pollution-prone communities in the Niger delta region. Journal of Trace Elements and Minerals, 14.

[70] Fahimah, N., Salami, I. R. S., Oginawati, K., & Mubiarto, H. (2024). Appraisal of pollution levels and non-carcinogenic health risks associated with the emergence of heavy metals in Indonesian community water for sanitation, hygiene, and consumption. Emerging Contaminants, 10(3).

straightforward: even if an LCA shows that a cleaner electricity mix can reduce the carbon footprint and health damages associated with battery production, the feasibility and durability of that transition ultimately depend on whether it supports growth, maintains industrial competitiveness, and manages adjustment costs across upstream and downstream activities. For this reason, the analysis applies a CGE-based simulation framework that projects the economy to 2034, the end-year of the RUPTL target planning horizon, before introducing policy shocks that represent alternative decarbonization pathways.

6.1 Environmental and Health Impact Assessment of NMC622 Battery

There are three scenarios assessed in the study of NMC622 battery product system. The analysis focuses on two main stages: nickel material extraction and battery pack production[71]. In current practice, nickel smelters in Indonesia typically rely on a combination of captive coal power plants and on-grid electricity. This industrial condition is adopted as the baseline configuration in this study.

The first scenario evaluates the effect of national electricity mix transition on battery production emissions while maintaining existing captive power usage[72]. In this scenario, on-grid electricity follows the RE Base and ARED pathways outlined in RUPTL 2025-2034, whereas the share of captive coal power remains unchanged. This scenario isolates the impact of national electricity policy on battery production emissions and has not yet addressed the emissions associated with captive coal power.

The second scenario introduces reductions in captive coal use in nickel processing. This scenario aims to assess the potential emission reductions achievable through decreasing reliance on captive coal power while increasing grid electricity use, while the combined share of other sources (hydropower and natural gas) is held constant at 10%.

The third scenario evaluates the combined effects of electricity transition and technological substitution in nickel processing. This scenario considers increased adoption of HPAL, which is generally associated with lower carbon intensity than RKEF. However, HPAL application is typically limited to limonite ores. Within Indonesia's laterite nickel deposits, limonite and saprolite has an approximate ratio of 1:2[73], so the maximum feasible share of HPAL is assumed to be 33%. Accordingly, for each captive coal reduction configuration, HPAL shares are increased from the baseline value of 10% to

[71] See Appendix System Boundary
[72] See Appendix Energy Generation Mix of Nickel Industries in Indonesia
[73] Kementerian Perencanaan Pembangunan Nasional/Bappenas & WRI Indonesia. (2025). Peta Jalan Dekarbonisasi Industri Nikel Indonesia.

20% and up to 33%. Increases in HPAL are assumed to directly replace RKEF processing, such that their combined share remains constant at 100%.

To understand the health impacts, this analysis uses disability-adjusted life years or DALYs, one of the endpoint results of LCA. This measure is used to illustrate years of healthy life lost to premature death and disability[74]. DALYs are made up of two components, which are years of life lost (YLL) or premature mortality, and years lived with disability (YLD) or time lived with illness or other conditions. DALYs are often used in quantifying cost-effectiveness comparison between health interventions. LCA endpoint results in the form of DALY have considered the fate, exposure, and toxicity of these pollutants[75]. DALYs are measured as proportions of a year, where 1.0 equals 1 year of life lost. The number may be multiplied by 365.25 to show the number of days lost.

The DALY values will be converted to health costs using the WHO-CHOICE method. This method involves multiplying the DALY by Indonesia's GDP per capita. In 2025, Indonesia's GDP per capita is approximately USD 5,400[76]. Multiplication by GDP per capita aims to show the cost of unproductivity (how much an individual contributes to the economy times how many years are lost due to the scenario). Though this method is criticized due to the lack of accountability for other factors that may influence health interventions, around 1/3 of cost-effectiveness studies are still based on this method. As research on battery-specific health costs in Indonesia are still limited, this method is still able to give a proxy of societal welfare loss due to premature death and/or sickness.

Scenario 1: Electricity Mix Transition (On-Grid)
The life cycle impact assessment (LCIA) results for NMC622 battery production, scaled by the projected annual battery production capacity, are presented in Figure 20. Ecotoxicity, human toxicity, and particulate matter impacts are largely localized, as they mainly affect communities and ecosystems surrounding battery and upstream material production sites.

The results show a steady increase in both environmental and human impacts over time, primarily driven by the planned expansion of battery production capacity under Indonesian government targets, which aim to reach up to 250 GWh of battery cell and

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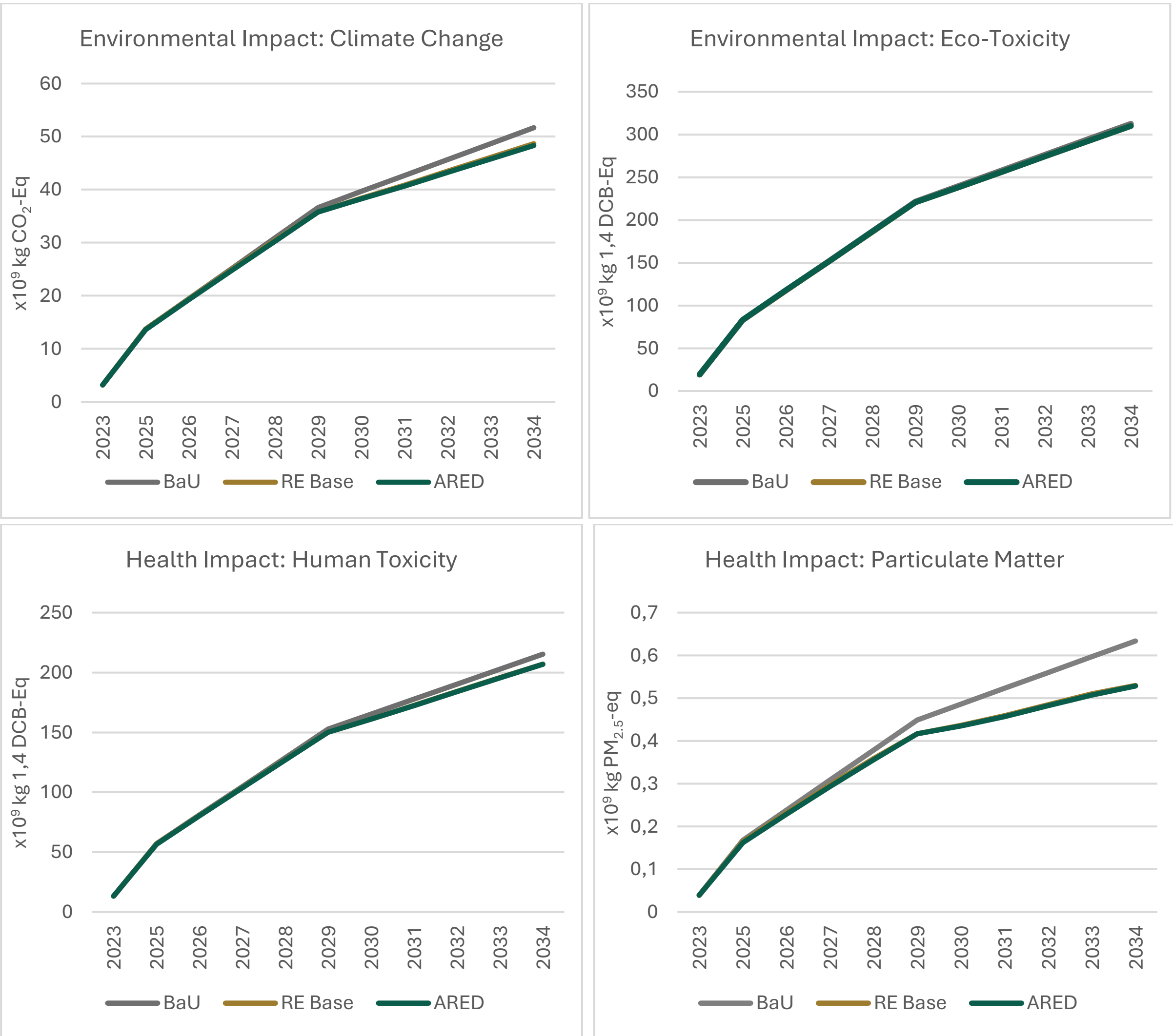
[74] Institute for Health Metrics and Evaluation (IHME). (2025). Global Burden of Disease 2023:Findings from the GBD 2023 Study. Seattle, WA: IHME.
[75] Huijbregts, M. A. J., Steinmann, Z. J. N., Elshout, P. M. F., Stam, G., Verones, F., Vieira, M. D. M., Hollander, A., Zijp, M., & Van Zelm, R. (2016). ReCiPe2016: A harmonized life cycle impact assessment method at midpoint and endpoint level. RIVM Report 2016-0104. Bilthoven, The Netherlands: National Institute for Public Health and the Environment.
[76] IMF. 2025. World Economic Outlook, October 2025. Washington, DC: International Monetary Fund. ©IMF.

pack production by 2039-2040[77]. Across all impact categories, the business-as-usual (BaU) scenario consistently results in the highest impacts.

Transitioning on-grid electricity towards RE Base and ARED scenarios leads to only modest reductions, with less than 7% for climate change and human toxicity impacts, even less than 1% for ecotoxicity impacts. A more noticeable contrast is observed for fine particulate matter formation, where reductions of up to 16% are achieved under both RE Base and ARED scenarios. These limited improvements reflect the continued dominance of coal in the national electricity mix target, which remains close to half of total generation by 2034. The difference between the RE Base and ARED scenarios is also marginal, reflecting the relatively small divergence in their projected clean energy shares.

Figure 20. Total impacts generated from NMC622 battery production



Source: Authors calculation

[77] Tenggara Strategics. (2025). Path to Indonesia's 8% growth: Leveraging Nickel-based EVs for Energy Security. https://tenggara.id/project/leveraging-nickel-based-evs-for-energy-security

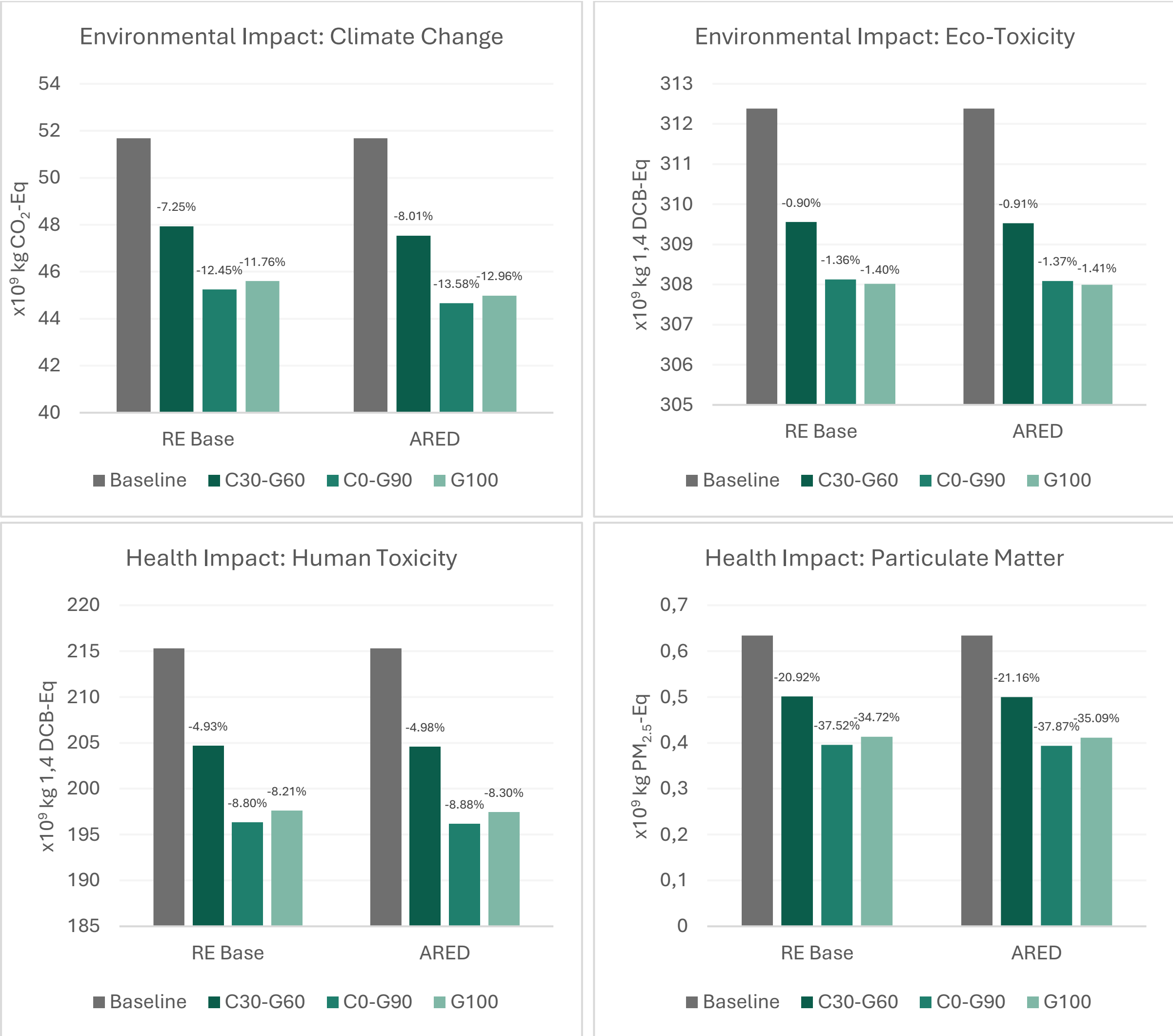
These results indicate that decarbonizing on-grid electricity alone is insufficient to substantially reduce the overall impacts of NMC622 battery production, as emissions from captive coal power plants remain unaddressed. This highlights the need for more ambitious strategies that extend beyond on-grid electricity transition.

Scenario 2: Reduction of Captive Coal Power

The impact assessment results for the captive coal reduction scenarios are illustrated in Figure 21. This scenario results reported for C30–G60, C0–G90, and G100 configurations to represent the upper and lower bounds of captive coal configurations, with all impacts compared to the 2034 BaU baseline.

Compared to Scenario 1, reductions in captive coal use result in substantially larger impact reductions across all impact categories. The trends are consistent across configurations, that decreasing captive coal use and substituting it with on-grid electricity leads to lower impacts. Among all configurations, the complete phase-out of captive coal while retaining a residual share of other sources (C0–G90) yields the lowest impacts. Ecotoxicity, however, shows minimal response to changes in electricity supply, suggesting that this impact is largely driven by upstream material extraction and processing rather than electricity generation.

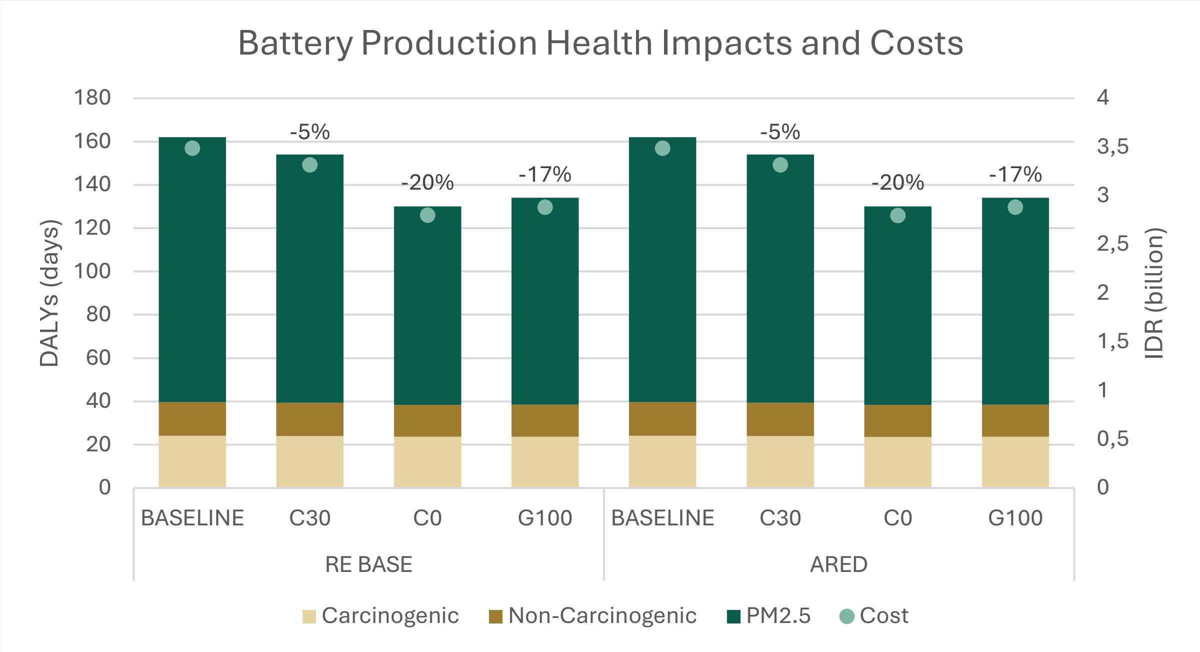
Figure 21. The Impacts of Captive Coal Power Reduction



Source: Authors' calculation

Notably, a full transition to on-grid electricity (G100) does not result in the maximum reduction. This suggests that while eliminating captive coal is crucial, reliance solely on on-grid electricity, without maintaining a share for other cleaner energy sources, may limit the achievable reductions. Overall, these findings emphasize that phasing out captive coal power is a key lever for reducing the environmental impacts of NMC622 battery production. Moreover, a diversified electricity supply that combines cleaner on-grid electricity with other clean energy sources may offer a more effective reduction than full dependence on the grid alone.

Figure 22. Battery Production Health Impacts and Costs



Source: Authors' calculation

Figure 22 presents the human health impacts expressed as days of healthy life lost (DALYs in days) across the RE Base and ARED scenarios under different grid and captive generation configurations. Across all scenarios, $PM_{2.5}$ exposure constitutes the dominant source of health burden, with baseline conditions resulting in approximately 122 days of healthy life lost per individual. The $PM_{2.5}$ levels decrease the most in the C0 scenario compared to baseline (20%). Health impacts from toxic substances are considerably smaller in magnitude. Carcinogenic effects range from approximately 23.6 to 24.1 days per individual, while non-carcinogenic effects range from about 14.7 to 15.6 days.

Given that the direct impacts of battery production primarily affect workers within the sector, health impacts are scaled by a factor of 100,000, corresponding to the estimated size of Indonesia's nickel downstreaming workforce. Baseline estimates show that total health costs amount to IDR 3.5 trillion. Through the C0 scenario, health costs could decrease IDR 690 billion or 20%. In 2025, GDP attributable to downstreaming activities (basic metals and metal ores) is estimated at USD approximately IDR 268.5 billion. Health costs for the battery production sector amount to around 1.3% of the sector's GDP.

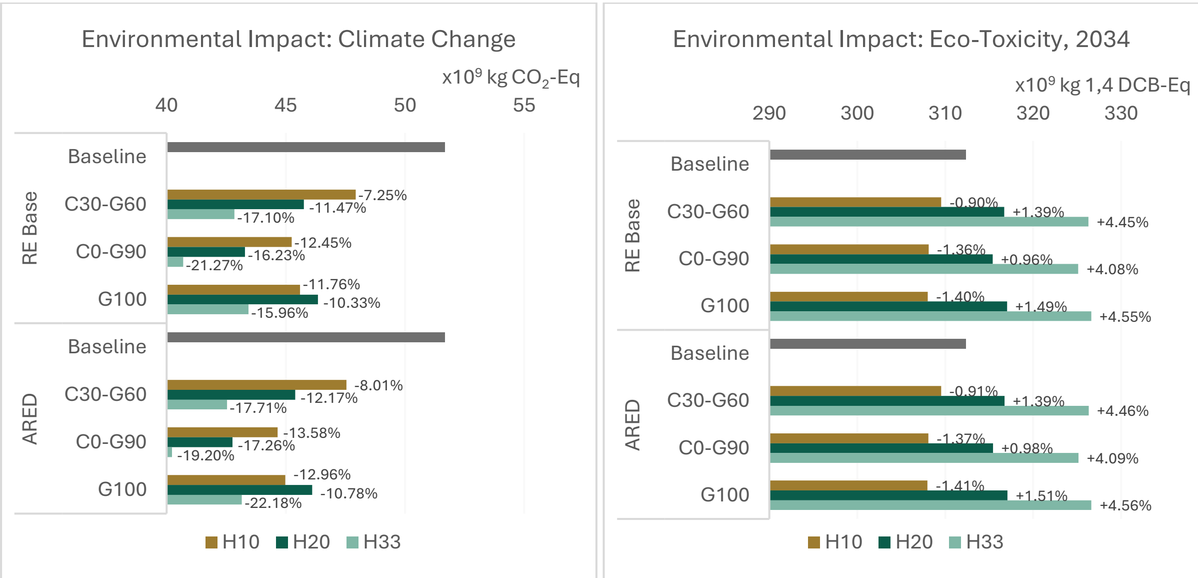
Scenario 3: Increased Adoption of HPAL

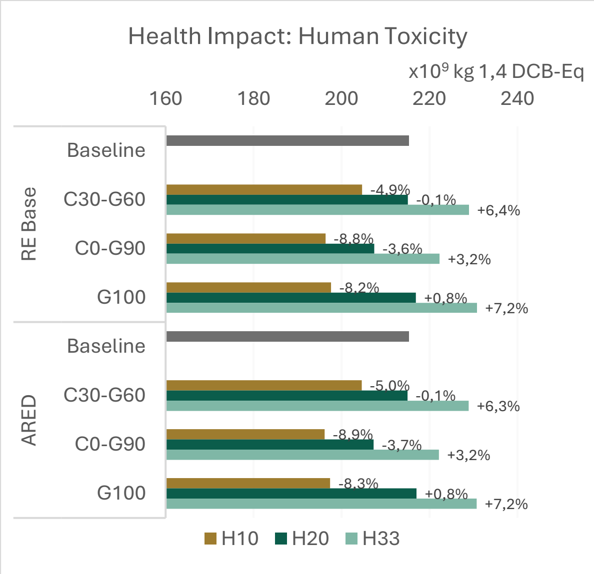
The results of the technology transition scenario, focusing on increased adoption of HPAL, are presented in Figure 23. The H10 configuration, representing a 10% HPAL share, reflects existing condition which is also used in Scenarios 1 and 2.

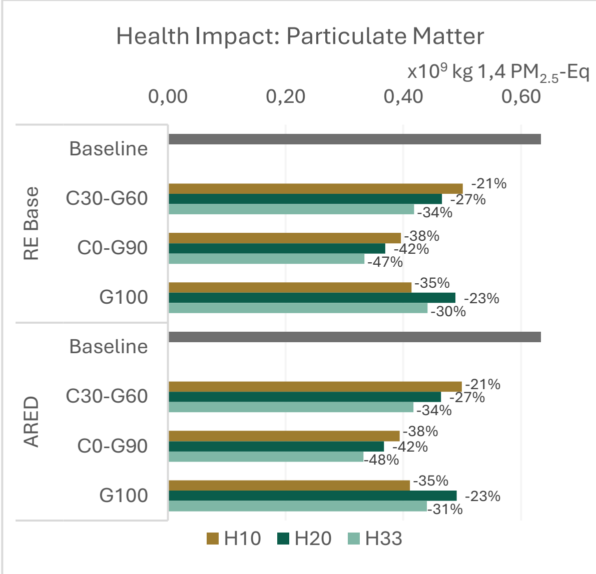
For climate change and particulate matter impacts, increasing the share of HPAL leads to notable reductions relative to the 2034 BaU baseline. The largest reductions are achieved under the maximum feasible HPAL share of 33%. In contrast, ecotoxicity and human toxicity exhibit an opposite trend, with higher HPAL shares leading to increased toxicity impacts across all configurations. Notably, these increases exceed even the 2034 BaU baseline.

The increase in toxicity impacts is primarily associated with the substantially larger volume of tailings generated by HPAL facilities compared to RKEF operations. It intensifies localized environmental and human health risks at surrounding nickel processing sites. These findings highlight that while HPAL adoption can contribute to climate and air pollution mitigation, its expansion without adequate tailing management may exacerbate toxicity-related impacts.

Figure 23. Impacts of an Increase in HPAL Use



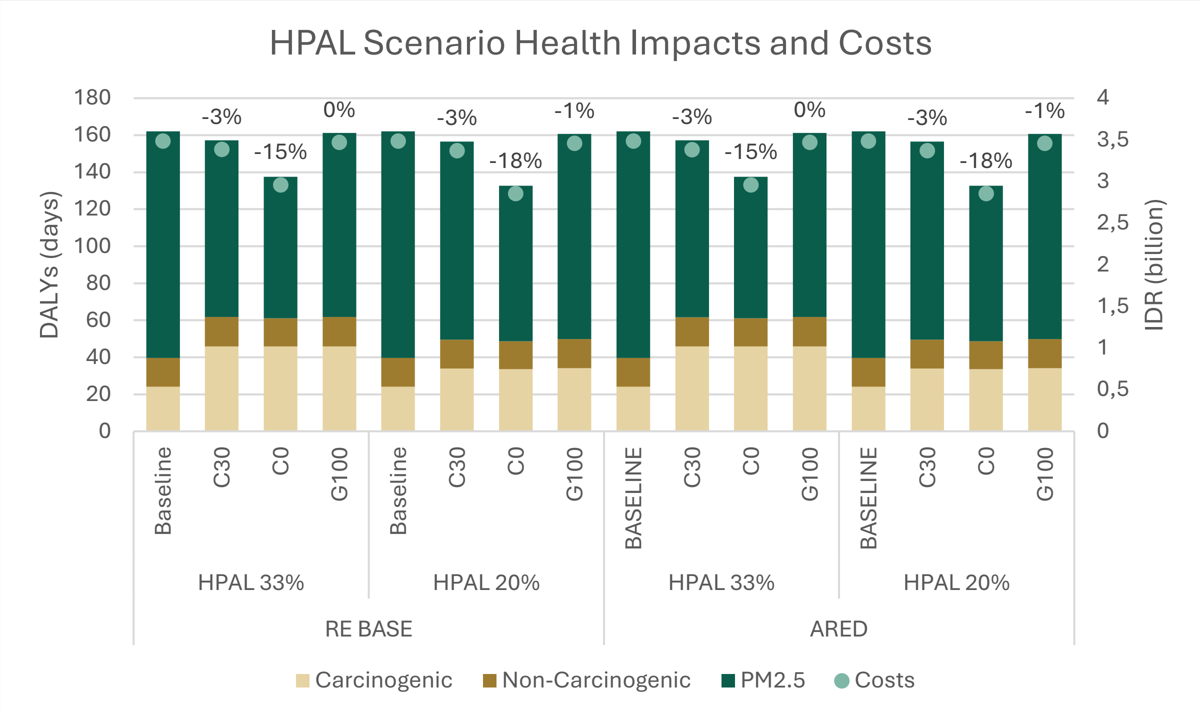




Source: Authors' calculation

Across all assessed scenarios, the largest reduction in climate change impact is achieved under the combination of C0–G90 with a 33% share of HPAL facilities. Under this scenario, total greenhouse gas emissions are reduced by 21.27% (RE Base) and 22.18% (ARED) compared to the BaU scenario in the same year (2034). This configuration also improves the emission intensity, reducing it from 318.5 kg CO_2-eq/kWh in 2023 (baseline) to approximately 248–250 kg CO_2-eq/kWh in 2034. Despite this improvement, the carbon emission intensity remains significantly higher than that of batteries produced in other major producing regions, such as EU and China, where values typically range between 64-109 kg CO_2-eq/kWh (T&E, 2023). This comparison highlights the significant gap that Indonesian battery production must close to remain competitive in global market.

Figure 24. HPAL Scenario Health Impacts and Costs



Source: Authors' calculation

Figure 24 presents the human health impacts, expressed as days of healthy life lost (DALYs in days), under the HPAL scenario across RE Base and ARED pathways, differentiated by HPAL penetration levels (33% and 20%) and power supply configurations (C30, C0, and G100). $PM_{2}{\cdot}_{5}$ exposure remains the dominant contributor to health impacts across all configurations, with impacts ranging from approximately 76 to 111 days of healthy life lost. Total health costs are most effectively reduced through the C0 scenario with HPAL 20%, however this is due to PM2.5 portions making up the greater portion of costs. HPAL usage does not significantly reduce health costs when compared to baseline without HPAL.

As stated above, higher use of HPAL does not necessarily result in better toxin count. Carcinogenic impacts are notably higher under HPAL 33% (around 46 days) compared to HPAL 20% (approximately 34 days), indicating a strong sensitivity of toxic health impacts to HPAL production intensity. Overall carcinogen levels increase by 90% in the HPAL 33% scenario and around 40% for the HPAL 20% scenario. A paper observed similar results, where higher HPAL usage bears a higher burden of carcinogenic human toxicity[78]. Groundwater contamination from metal leaching in HPAL tailings management is a source of concern and uncertainty for human toxicity and ecotoxicity. Non-carcinogenic impacts are smaller in magnitude, ranging from about 15 to 16 days, Considering the

[78] Roy, Sophia & Moustafa, Hossam & Vaidya, Ketan & Harvey, Jean-Philippe & Fradette, Louis. (2025). Improving process granularity of life cycle inventories for battery grade nickel. npj Materials Sustainability. 3. 10.1038/s44296-025-00059-7.

trade-off, it is recommended to take the middle ground of lower HPAL count to reduce carcinogens, while PM2.5 numbers can be mitigated through other routes such as increasing RE in the energy mix and phasing out captive coal.
The estimated cancer-related health burden associated with the baseline HPAL scenario amounts to approximately 12,320 DALYs after scaling to an assumed workforce of 100,000 workers. When placed in context, this figure is modest relative to Indonesia's overall cancer burden: DALY-based burden priorities among Indonesian men include lung cancer (298,980 DALYs), liver cancer (60,367 DALYs), and nasopharyngeal cancer (46,185 DALYs), while among women the leading burdens are lung cancer (34,119 DALYs), cervical cancer (9,213 DALYs), and pancreatic cancer (5,433 DALYs)[79]. In total, cancers attributable to smoking alone account for an estimated 638,682 DALYs nationally. While not directly comparable in terms of exposure pathways or affected populations, this comparison illustrates that the cancer-related health impacts associated with HPAL operations are small in absolute terms at the national level, yet potentially significant for the directly exposed workforce.

The analysis yields several policy-relevant implications. First, coal-based electricity remains a major contributor to environmental and human impacts. Transitioning away from coal-based power, both captive and on-grid, towards cleaner energy sources offers substantial potential for impact reduction. Moreover, diversifying electricity sources at the raw material extraction, which are still heavily dependent on captive coal power plants, yields larger reductions than relying solely on improvements in the national electricity mix.

Second, the adoption of lower-carbon processing technologies, such as HPAL, for upstream nickel processing can further reduce climate change and air pollution impacts. However, this transition is associated with an increased risk of ecotoxicity and human toxicity due to the substantially larger volumes of tailings generated by HPAL compared to RKEF. Therefore, any expansion of HPAL capacity must be accompanied by robust tailings and environmental management strategies to avoid shifting environmental burdens from one impact category to another.

Taken together, these findings suggest that achieving a low-carbon NMC622 battery industry in Indonesia requires an integrated decarbonization strategy that addresses both energy supply and processing technology. Such an approach is essential not only to ensure that batteries promoted as climate solutions deliver genuine environmental benefits, but also to enhance the competitiveness of Indonesian battery products in an increasingly carbon-conscious global market. Without ambitious decarbonization

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[79] Kristina, S. A., Endarti, D., Sendjaya, N., & Pramestuty, O. (2016). Estimating the Burden of Cancers Attributable to Smoking Using Disability Adjusted Life Years in Indonesia. Asian Pacific journal of cancer prevention : APJCP, 17(3), 1577–1581.

efforts, there is a risk that environmental burdens are merely relocated rather than reduced, potentially undermining both climate objectives and long-term economic opportunities.

6.2 Environmental and Health Impact Assessment of BEV Adoption (LFP)

This section provides an integrated assessment of the environmental and public-health implications of Indonesia's BEV pathway, structured to three assessment scenarios.
First, we evaluate the life-cycle environmental impact of BEV relative to ICEV under current Indonesian conditions, capturing emissions and ecotoxicity across the production, use, and end-of-life phases. This comparison shows whether BEVs deliver net environmental benefits in a context where electricity characterized by a coal-dominated electricity system and emission-intensive industrial processes, showing the trade-offs between higher production impacts and lower operational emissions.

Secondly, we assess human-health impacts, focusing on air-pollution and human toxicity indicators from ICEV usage and the corresponding health benefits and cost savings from a transition to BEVs. By linking life-cycle environmental results with avoided PM2.5 and toxicity exposures, our analysis underscores that electrification is not only a climate and industrial strategy, but also a public health intervention with potentially substantial societal benefits for Indonesia's urban population.

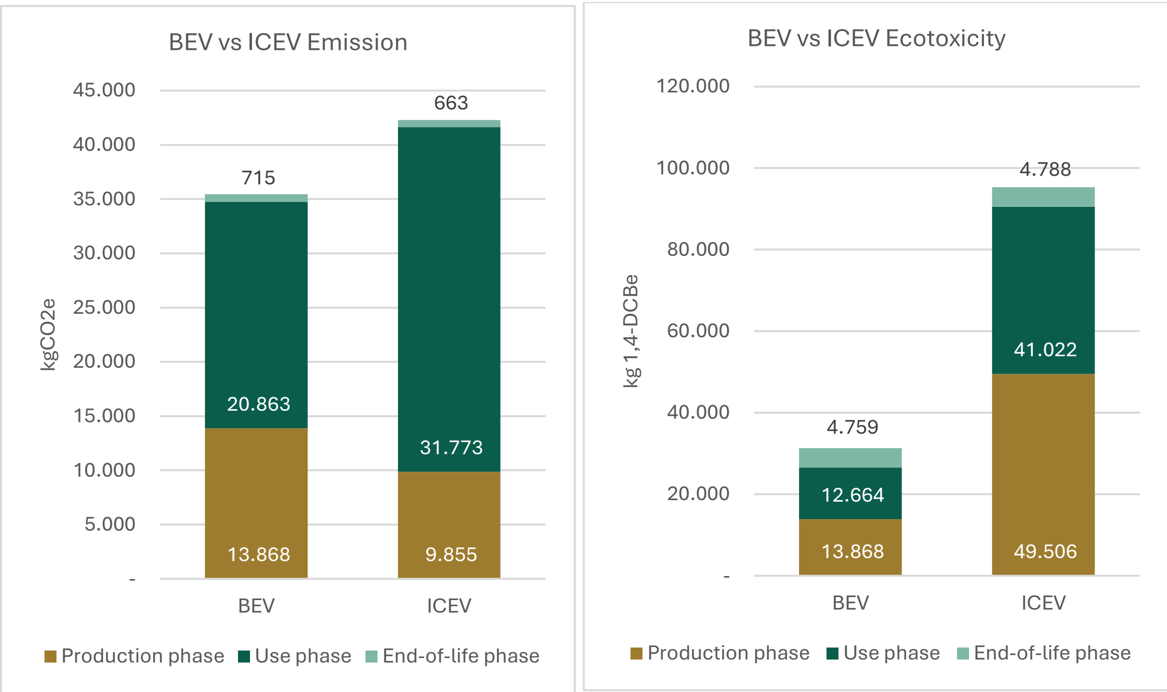
Lastly, we compare the calculation of BEV environmental impact with two other Southeast Asian countries, Thailand and Vietnam. This cross-country analysis evaluates Indonesia's current green competitiveness in BEV manufacturing and examines how differences in power-sector trajectories and manufacturing capacity result overall BEV environmental life-cycle impacts. Two electricity mix scenarios are assessed in these scenarios. The business-as-usual (BaU) scenario reflects the current electricity generation mix in 2023, while the 'greener' scenario represents alternative pathways with increased mix of renewable electricity sources over the period 2025-2035 in three countries[80]. The greener scenario assumes a vehicle produced in 2025 and assumes a vehicle lifetime of ten years, capturing the effects of power sector transitions on BEV impacts.

Life-Cycle Environmental Impact Assessment of BEV and ICEV in Indonesia

[80] Electricity generation projections are based on the Electricity Supply Business Plan (RUPTL) 2025–2034 for Indonesia, the Vietnam Electricity Development Plan (Decision No. 768/QĐ-TTg), and the Thailand Power Development Plan 2016–2035.

The results for both greenhouse gas emissions and ecotoxicity indicate that BEV perform better than ICEV across the full life cycle. For climate impacts, outcomes remain highly sensitive to the use phase, reflecting the carbon intensity of Indonesia's electricity mix, while ecotoxicity impacts are dominated by production processes. End-of-life contributions are comparatively small for both indicators, although BEV shows slightly higher end-of-life impacts due to the treatment of battery components.

Figure 25. BEV vs ICEV Environmental Impact



Source: Author's Calculation

In terms of total life-cycle emissions, BEV generates 35.4 tCO_2e, compared with 42.3 tCO_2e for ICEV. Meaning that shifting from ICEV to BEV corresponding to a 16% emission reduction. BEV clearly 'greener' during the use phase, despite continued reliance on a coal-dominated electricity grid, which accounts for 59% of total BEV emissions. By contrast, ICEV shows substantially higher use-phase emissions (79% of their total life-cycle emissions) driven by fuel production and direct combustion. Although BEV production remains more emission-intensive, particularly due to battery manufacturing, this disadvantage is outweighed by lower operational emissions over the vehicle lifetime.

Ecotoxicity results show an even clearer contrast, where ICEV ecotoxicity impacts are 3 times higher than BEV, largely due to production-phase processes, which even higher than the overall BEV lifecycle. This finding underscores the importance of cleaner manufacturing pathways for ICEV, material substitution, and fuel supply chains.

From a system-level perspective, scaling these results to one million BEVs, in line with the Ministry of Industry's production targets[81], yield an estimated 6.8 million tCO_2e reduction, equivalent to approximately 4% of total transport sector emissions in 2023. This highlights the potential emission reduction even under current grid conditions, while reinforcing the need for parallel progress in electricity decarbonization and greener industrial production phase.

Human Health Benefits of BEVs in Comparison with ICEVs

The health impact of ICEVs compared to BEVs all lie in the burden of pollution that ICEVs produce when in use. Compared to BEVs, which are virtually zero, this section aims to illustrate the amount of pollution that can be mitigated through use of BEVs.

The PM2.5 impact of ICEV reflects the fine particulate matter emitted directly from fuel combustion and formed in the atmosphere during the use phase. Although 0.98 kg per vehicle may appear small, PM2.5 is considered as the most health-damaging air pollutant, due to its ability to penetrate deep into the lungs and enter the bloodstream.

Table 2 Estimated Health Impact and Savings from BEV Adoption

Variable	**Impact (1 million vehicles)**	**Health Impact: DALYs (years)**	**Health Cost (billion)**	**Estimated Health Savings**
PM2.5	983 tCO2e	618	IDR 53.4	
Carcinogenic	4,032 t1,4-DCBe	13.4	IDR 1.2	
Non-carcinogenic	108,801 t1,4-DCBe	24.8	IDR 2.1	
TOTAL			IDR 56.7	0.03% of national health budget

Source: Authors

The table presents the estimated human health impacts associated with emissions from one million ICEVs, expressed in disability-adjusted life years (DALYs) and their health cost equivalents. These numbers have been scaled to one million vehicles, as targeted by Ministry of Industry of EV by 2035[82]. Fine particulate matter ($PM_{2.5}$) accounts for the largest health burden, resulting in approximately 618 DALYs, corresponding to an

[81] Minister of Industry Regulation Number 6 of 2022 concerning Specifications, Development Roadmap, and Provisions for Calculating the Domestic Component Level Value of Battery-Based Electric Motor Vehicles (Battery Electric Vehicles).

[82] Minister of Industry Regulation Number 6 of 2022 concerning Specifications, Development Roadmap, and Provisions for Calculating the Domestic Component Level Value of Battery-Based Electric Motor Vehicles (Battery Electric Vehicles).

estimated welfare loss of IDR 53 billion when valued using Indonesia's GDP per capita. Health impacts from toxic substances are substantially smaller in magnitude, with carcinogenic emissions contributing 13.4 DALYs (IDR 1 billion) and non-carcinogenic emissions contributing 24.8 DALYs (IDR 2 billion). When the total health costs (IDR 56.7 billion) are compared to the Indonesia's 2025 health budget (IDR 218 trillion), the potential health savings amount to approximately 0.03% of the total health budget. Overall, the results indicate that $PM_{2.5}$ exposure dominates the health burden from vehicular emissions.

It is known that high levels of PM2.5 can exacerbate lower acute respiratory infections. When viewed against Indonesia's overall burden of lower acute respiratory infections, which are estimated at 98.7 million DALYs[83] (approximately IDR 7.760 trillion), the 618 DALYs attributable to $PM_{2.5}$ (IDR 53 billion) emissions from one million ICEVs appear modest (around 0.7% of the total). Nevertheless, the 618 DALYs means more years lived, especially for vulnerable urban populations at a disproportionate health risk for transportation emissions. In Jakarta, where the transport sector contributes an estimated 20–40% of ambient $PM_{2.5}$ concentrations[84], policies that accelerate EV adoption offer a tangible solution for reducing urban air pollution.

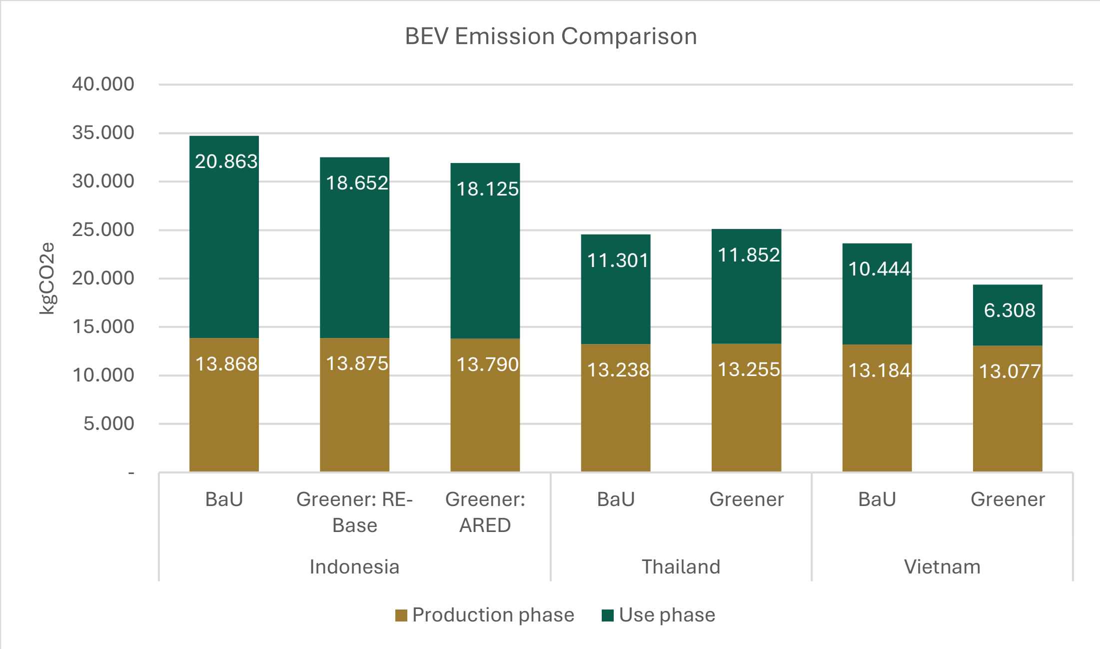
Comparative Environmental Impacts Assessment of BEVs in Indonesia and Selected Southeast Asian Countries

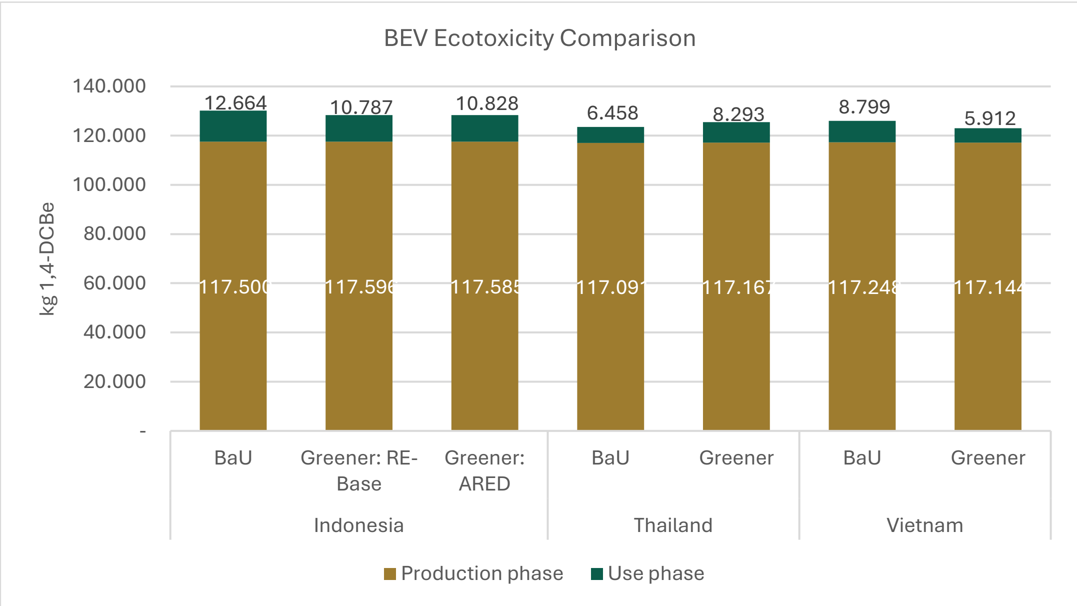
The assessment result shows that Indonesia the highest total life-cycle environmental impacts for BEVs among the three countries. In addition, the result shows that Indonesia is the highest production-phase emission intensity for BEVs, indicating comparatively lower green competitiveness in BEV manufacturing relative to neighboring countries.

In general, the production phase dominates BEV life-cycle environmental impacts across countries and impact categories, approximately 13 (tCO_2e) and 210-220 (t 1,4-DCB-eq) per vehicle over its lifetime, with only marginal variation between countries. An exception is observed for greenhouse gas emissions in Indonesia, where the use phase becomes the dominant contributor due to the high carbon intensity of electricity generation from coal. In contrast, ecotoxicity impacts remain dominated by the production phase in all countries, with use-phase contributions playing only a minor role.

[83] Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2023 (GBD 2023). Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2025.
[84] Vital strategies. (2020). Identifying the Main Sources of Air Pollution in Jakarta: A Source Apportionment Study.

Figure 26. BEV Environmental Impact Comparison between Indonesia, Thailand, and Vietnam





Source: Author’s Calculation

Within the production phase, battery manufacturing is the single largest contributor, accounting for approximately 36-38% of total life-cycle emission, reflecting the energy- and material-intensive nature of battery cell production. The vehicle assembly process contributes a relatively small share, approximately 5-10%, while the remaining production emissions are associated with vehicle body and component manufacturing, including materials such as steel and aluminum. As a result, although a substantial portion of production-phase impacts is geographically externalized through LFP battery imports from China, production emissions also partially reflect domestic industrial processes related to vehicle assembly and component manufacturing.

The differences between countries for the emission intensity are driven almost entirely by the use phase, reflecting national electricity grid mixes. Indonesia shows the highest use-phase emission due to its coal-intensive electricity system. Even under the greener electricity scenario (RE-Base and ARED), the emission reduced only by 11-13%, indicating the grid decarbonization delivers limited emission reduction impact. Thailand shows intermediate values with increased of emission slightly by 5% under the national electricity plan scenario. This increase attributed to a higher percentage of coal use in the electricity mix plan. On the other hand, Vietnam shows the lowest use-phase emissions and the highest relative reduction (40%) compared to BaU scenario, showing a more substantial shift towards low-carbon electricity scenario.

In contrast to emission intensity, use-phase ecotoxicity contributes only a minimal share to total life cycle ecotoxicity, which remains overwhelmingly dominated by production-related processes. Although use-phase ecotoxicity varies with electricity generation mixes, while being highest in Indonesia and lowest in Vietnam, these differences do not affect significantly to overall ecotoxicity impact.

The results indicate that strategies to improve the environmental performance of BEVs must extend beyond electricity-grid decarbonization and address production-phase impacts. In the Indonesian context, this implies a need to strengthen green competitiveness in BEV manufacturing, as current production-phase emission intensity remains higher than that of neighboring countries. At the national level, policies should prioritize improvements in domestic manufacturing processes, including energy-efficiency standards for vehicle assembly plants, greater use of low-carbon materials in vehicle body and component production, and incentives for manufacturers to adopt cleaner industrial energy sources.

Given Indonesia's ambition to position itself as a regional EV and battery hub, complementary industrial and environmental policies are critical to avoid locking in carbon- and toxicity-intensive production pathways. Beyond national policies, measures such as battery sustainability standards, extended producer responsibility, and investment in battery reuse and recycling infrastructure, are necessary to ensure that BEV deployment generate substantial reductions in environmental impacts rather than shifting environmental burdens across geographical borders.

6.3 Economic Impact on Greening the Value Chain

As discussed earlier, greening the EV value chain offers substantial environmental and health benefits. Reductions in carbon emissions would help Indonesia meet its Nationally Determined Contribution (NDC) targets, while improved air quality could enhance labor productivity and reduce public healthcare expenditures. However, these environmental gains are not without economic costs. Greening the value chain entails trade-offs that policymakers must carefully navigate. This section therefore assesses the scale of the economic implications associated with efforts to green Indonesia's EV value chain.

To examine these impacts, this study conducts ex-ante simulations using the GTAP-E-Power model to evaluate the economy-wide effects of decarbonization measures in Indonesia. The Global Trade Analysis Project (GTAP) model is a computable general equilibrium (CGE) framework widely used to assess the impacts of external shocks and policy interventions, while accounting for inter-sectoral and international linkages. We use the GTAP database version 11c in this model, which covers the year 2017. We modified the sectors into 29 and regions/countries into 9. In addition, using the GTAP-E-Power model is more relevant to this research, as it extends the standard GTAP model by incorporating emissions variables and detailed electricity-sector dynamics, making it particularly suitable for analysing climate-related policies. For a more detailed discussion on the methodology, see Appendix.

The scenarios employed in this study were designed as follows. First, we projected the aggregated GTAP-E-Power database to 2034, the year-end RUPTL target. As a pre-experiment procedure, we use shocks to the capital stock, labor force, population, and GDP for all regions through 2034. This approach treats those variables as exogenous under modified closure. This method is common among the GTAP articles (Banaszewska et al., 2025; Higashi et al., 2022; Burfisher, 2021) to address the limitation of the latest GTAP database, which consists of 2017 macroeconomic datasets. Thus, running this pre-experiment procedure is expected to yield macroeconomic indicators for the year we intended to analyze, 2034. The forecast for the aforementioned macroeconomic variables is based on variables comes from the SSP2 scenario by Fontagne et al. (2022).

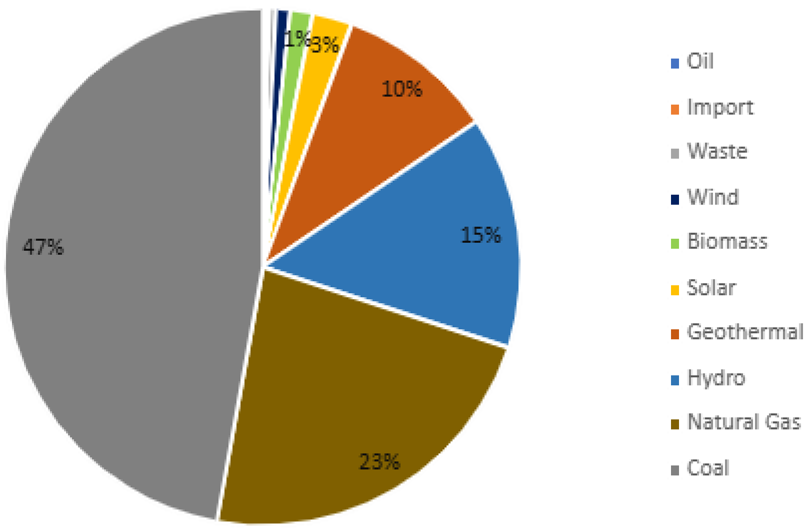
After running that pre-experiment, we run a baseline experiment by reverting the closure to the standard, so that the capital stock, labor force, population, and GDP become endogenous. However, we use the output productivity change (*aoreg*), the result of the pre-experiment procedure, as our exogenous variables. This replicates what Banaszewska (2025) and Burfisher (2021) did in their article and book, allowing the baseline to better inform macroeconomic conditions in the year of interest.

Using this baseline, this study develops two policy scenarios to see the impact of a greener value chain in Indonesia as discussed below:

Scenario 1: Electricity Mix Transition (On-Grid)

This scenario assesses the economic impact of changes in Indonesia's electricity mix as outlined in the RUPTL 2025–2034, aligning with **Scenario 1** in subchapter 6.1. The input used in this study is the electricity mix in 2034 based on the RE Base scenario in the RUPTL 2025–2034, as shown in Figure 27. In this scenario, Indonesia is projected to have a larger share of renewable energy of 29.7% in 2034 compared to its current share of 15.75% in 2025 (IESR, 2026). By increasing renewable energy on the grid, the value chain of nickel-battery-electric vehicles will have greener pathways. On the other hand, there might be economic consequences.

Figure 27 Electricity Mix Plan in 2034 Based on RUPTL



Source: RUPTL 2025 – 2034

The electricity mix was defined by modifying the outputs of Indonesia's electricity sectors. Under an adjusted closure in GTAP, the output of the shocked sector (qo) was treated as exogenous and swapped with its technical productivity (aoall). On top of the baseline shock, the output productivity change, we employed a shock to the electricity mix output in Figure 27 for the shocked sector. Using this approach, we can force the output of electricity generation output share to meet the 2034 target electricity mix based on the RE Base scenario in RUPTL.

The limitations of this setup are that the change in the electricity mix is exclusive to Indonesia. Other regions and countries in the model will change their electricity mix. Thus, the model does not consider the development of the electricity mix or other factors outside Indonesia, aside from the output productivity of other countries and regions.

Scenario 2: Emissions Trading Systems

The second scenario evaluates the introduction of an Emissions Trading System (ETS) as a core decarbonization instrument in Indonesia. In this scenario, progressively tighter emission allowances for firms serve as the operational mechanism for ETS implementation. We follow the Indonesian Second Nationally Determined Contributions (SNDC), under which, in 2034, Indonesia reduces total emissions by 20.08% relative to its actual absolute emissions in 2017 (GTAP database 11c baseline year). The introduction of ETS in Indonesia provides a market mechanism for the economy to adjust to green technology, for example, by encouraging green HPAL (Scenario 3 in subchapter 6.1) or other available low-carbon technology in the market.

We treat the reduction in total emissions from SNDC as a reduction of the emissions quota (gco2q) in Indonesia. With an adjusted closure in GTAP where the carbon tax rate (rctaxb) is a power of emissions purchases (pemp[85]). Then, we swapped the power of emissions with the emissions quota (gco2q) to treat the latter variable as exogenous, while carbon tax and power emissions purchases as endogenous. This approach results in the use of a quota-based market mechanism, also known as a cap-and-trade or emissions trading system. We also conduct a sensitivity analysis, reducing the emissions quota by 50% to show the direction of the economic variables in a more ambitious ETS setup.

The limitation of this scenario is similar to Scenario 1, in which the shock is applied exclusively to Indonesia, without accounting for other countries' and regions' efforts to pursue their NDC targets.

Macroeconomic outcomes: growth effects and "no-tradeoff" conditions

The simulation results suggest that the electricity mix transition under the RUPTL is associated with an increase in Indonesia's GDP by approximately 0.74 percent by 2034 relative to the baseline (2017). The planned expansion of renewable energy capacity emerges as the primary driver of this positive outcome. The channels that rationalize the positive growth outcome are consistent with the narrative of a green industrial push:

- **Investment and infrastructure spillovers**: renewable deployment and transmission upgrades stimulate demand for capital goods and supporting manufacturing.
- **Productivity and cost stabilization**: a more diversified power mix can reduce exposure to fossil price volatility and improve system efficiency over time.

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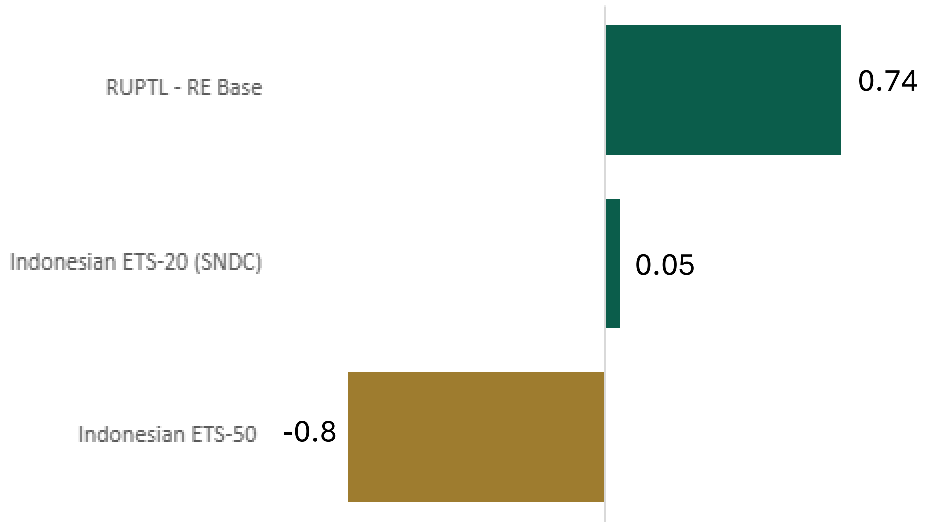
[85] Power of emissions purchases (pemp) is defined as the difference between aggregate emissions in an economy (gco2t) and quota emissions (gco2q)

- **Industrial upgrading**: sectors linked to electrification and transport technology benefit from higher demand and factor reallocation.

This finding indicates that transitioning toward renewable energy does not necessarily constitute an economic trade-off.

Meanwhile, the ETS scenario presents more nuanced results. A 20 percent reduction in emission allowances still yields a positive GDP impact of 0.05% relative to the baseline. This small positive outcome is economically intuitive because ETS imposes compliance costs and reallocations away from emissions-intensive activities. The net effect depends on whether the economy's medium-run efficiency gains and investment responses outweigh near-term adjustment costs. In that sense, ETS-20 can be interpreted as a manageable constraint that nudges retooling without materially depressing aggregate output, while tighter caps (as shown by the sensitivity case in the draft) risk pushing adjustment costs high enough to outweigh growth benefits. A more stringent 50 percent reduction in emission allowances leads to a GDP contraction of approximately 0.8 percent by 2034 compared to the baseline, reflecting the higher adjustment burden placed on firms. In other words, the results suggest that a tighter target of quota emissions in a short period might induce negative effects to growth.

Figure 28. Economic Growth Results from Simulations

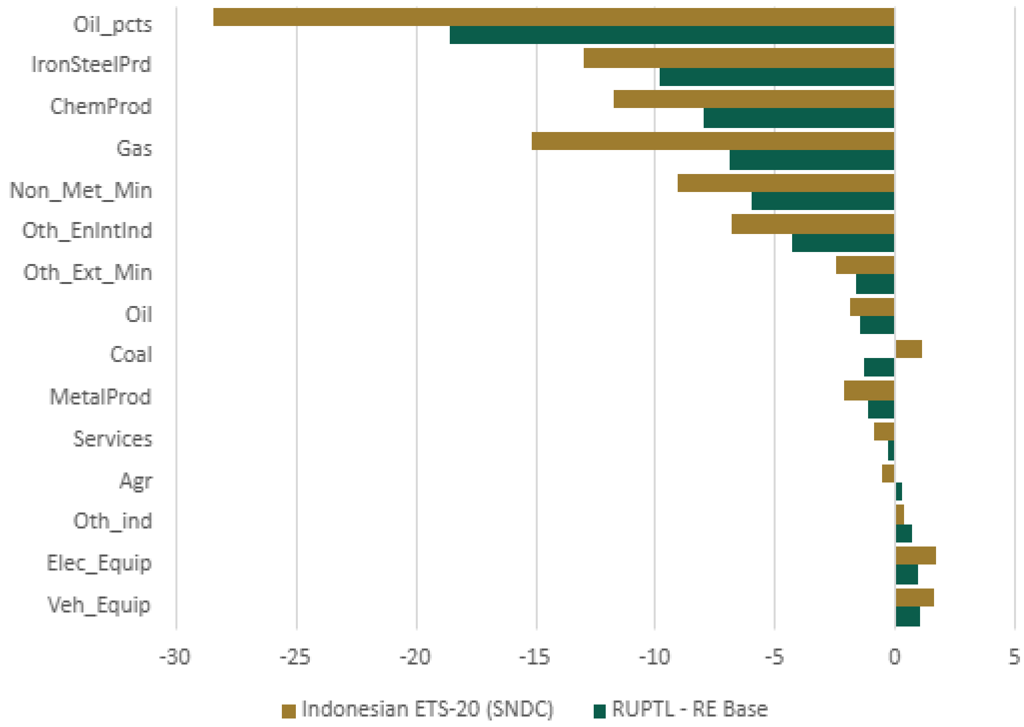


Source: Author's estimation

Sectoral output changes: where the value chain expands, and where pressures concentrate

Figure 28 provides the clearest picture of structural transformation. Across both scenarios, the output effects reveal a consistent pattern: downstream electrification-linked manufacturing grows, while fossil fuels and emissions-intensive upstream industries contract, with the contraction larger under ETS-20.

Figure 29. Sectoral Output Change from Simulations



Source: Author's estimation

1. Downstream segments: EV- and electrification-linked industries expand

Two sectors directly associated with the EV industrial ecosystem show positive output changes in both scenarios:

- **Vehicle equipment**: +1.04 (RUPTL – RE Base) → +1.67 (ETS-20)
- **Electrical equipment and electronics**: +1.00 (RUPTL – RE Base) → +1.71 (ETS-20)

This outcome is important for greening the nickel-battery-EV value chain. It suggests that policies which improve the carbon profile of electricity and introduce stronger decarbonization incentives do not suppress the downstream manufacturing base. Instead, they are associated with incremental expansion in transport equipment and electrical equipment. Interpreted in value-chain terms, this is consistent with a shift toward:

- greater demand for **power electronics, motors, control systems, charging equipment**, and grid components (Electrical equipments and electronics), and
- higher activity in **vehicle assembly and components** (Vehicle equipment), even if export outcomes differ by destination (discussed below).

The fact that gains are *larger under ETS-20* suggests that a carbon constraint can accelerate reallocation toward sectors that are either (i) less emissions-intensive per unit of value added, or (ii) positioned to benefit from an electrification-driven investment cycle.

2. Upstream and materials: emissions-intensive inputs contract, creating a competitiveness challenge for the EV chain

The sectors that are typically materials- and energy-intensive, and therefore critical upstream inputs for EV and battery supply chains, show declines in both scenarios, with deeper contractions under ETS-20:

- **IronSteelPrd**: -9.78 → -12.97
- **ChemProd**: -7.92 → -11.73
- **Non_Met_Min**: -5.97 → -9.06
- **Oth_EnIntInd**: -4.25 → -6.77
- **MetalProd**: -1.13 → -2.11

This result is central to the greening value chain discussion: the EV value chain remains tightly linked to carbon-intensive upstream production, and a generic decarbonization push can create transitional pressure precisely in the sectors that supply critical intermediate goods (steel, chemicals, minerals, fabricated metals). The implication is not that Indonesia should accept upstream shrinkage as an objective; rather, it indicates that industrial decarbonization must be engineered, not assumed.

Economically, these declines can be read as a combination of:

- higher effective costs for emissions-intensive production under ETS,
- factor reallocation (capital and labor) toward expanding sectors (vehicle/electrical equipment),
- and demand-side shifts as the economy changes its composition under the new energy and emissions constraints.

This means that the success of a greener EV value chain depends on whether upstream industries can decarbonize without losing scale, through clean power procurement, process upgrades, efficiency, and (where relevant) low-carbon fuel switching, so the downstream EV buildout is not constrained by a weakened domestic input base.

3. Energy sectors: oil and gas contracts sharply, coal behaves differently across scenarios

Energy-sector results are directionally consistent with a greening transition, especially for oil products:

- **Oil_pcts**: -18.55 → -28.43
- **Oil**: -1.45 → -1.85
- **Gas**: -6.87 → -15.14

The deeper decline in gas under ETS-20 signals that the cap (and resulting carbon price) creates stronger pressure on fossil-based activity overall. This reinforces the point from earlier chapters: without addressing the energy basis of industrial production, it is difficult to meaningfully green the full supply chain.

One notable (and policy-relevant) exception is Coal, which falls slightly in Scenario 1 (-1.24) but rises in Scenario 2 (+1.17). This does not mean coal becomes "green"; instead, it likely reflects model reallocation and substitution effects (including trade and relative price adjustments) that can occur when the constraint is implemented in a stylized way across the economy. Substantively, this result underlines a design lesson: ETS coverage and complementary measures matter. If coal-related activity is not effectively constrained across relevant segments (power and industrial use), or if substitution pathways are left open, some emissions-intensive activities can persist or relocate even as other fossil sectors contract. Aside from that, these results might also be because of the limitation of the shock, might also be because of the limitation of the shock where the ETS is exclusively only in Indonesia, but not in other countries. It encourages the production of coal for export to countries where coal is still being consumed excessively.

Export impacts: how greening changes trade patterns across major partner markets

The export change results shown in Table 3 indicate that greening policies can reshape where Indonesia's upstream and downstream products are absorbed internationally. Interpreting the export table as percentage changes by destination, two key insights emerge.

Table 3. Change of export from Indonesia by destination from simulations

	RUPTL - RE Base							Indonesian ETS-20 (SNDC)						
Export to	Japan	China	Rep Korea	India	US	SEAsia	EU28	Japan	China	Rep Korea	India	US	SEAsia	EU28
Oth_Ext_Min	-0.54	-0.73	-0.74	-0.79	-0.77	-0.71	-0.74	22	13.62	9.16	4.12	-3.68	3.39	11.29
IronSteelPrd	4.94	8.34	7.51	6.7	7.36	8.22	6.21	63.58	-31.83	-7.14	72.18	1.6	-31.99	29.54

MetalProd	2.87	2.29	2.25	1.74	2.02	2.1	2.25	-98.73	-11.27	-17.72	60.49	-1.89	-2.53	-24.43
Non_Met_Min	2.93	1.88	2.05	1.66	1.99	2.01	1.91	-125.43	-14.96	3.75	57.32	2.75	-16.49	12.57
ChemProd	0.28	0.32	0.28	0.3	0.32	0.33	0.33	105.67	19.25	38.61	68.84	23.04	-3.65	38.22
Oth_EnIntInd	4.52	3.55	3.68	3.35	4.08	4.24	4.17	-74.11	13.72	9.99	51.8	-7.45	-30.04	-29.09
Elec_Equip	1.68	1.19	1.1	1.03	1.19	1.11	1.24	-130.07	8.56	-7.13	9.03	-47.16	-2.55	-35.01
Veh_Equip	-1.64	-1.4	-1.38	-1.29	-1.48	-1.36	-1.5	-12.76	7.08	25.32	27.23	11.48	-11.15	5.57
Oth_ind	-3.72	-2.34	-2.28	-2.09	-2.77	-2.3	-2.68	-168.46	-45.36	-27.55	-16.88	-60.99	-44.93	-56.64

Source: Author's estimation

1. Scenario 1 (RUPTL – RE Base): modest trade rebalancing; exports of materials rise, while vehicle equipment exports soften

Under RUPTL – RE Base, export changes are generally moderate (mostly within a few percentage points) and show:

- **Increases** for key materials and intermediates:
  - **IronSteelPrd** rises broadly across all listed markets (roughly +5% to +8%).
  - **MetalProd** and **Non_Met_Min** also rise (around +2% on average).
  - **ChemProd** shows a small positive change (~+0.3%).
- **Declines** for:
  - **Veh_Equip** (around -1.3% to -1.6% across markets),
  - **Oth_ind** (roughly -2% to -4%).

For the EV value chain, the interpretation is nuanced. Even though Veh_Equip output increases domestically (+1.04), exports of Veh_Equip decline slightly, suggesting the output increase may be absorbed domestically (e.g., meeting domestic demand for vehicles/components as the value chain develops), while export competitiveness is not yet strong enough to translate into export expansion. This pattern is consistent with an economy at an early-to-middle stage of downstreaming that suggests domestic value addition increases, but export upgrading requires additional productivity and scale improvements.

2. Scenario 2 (ETS-20): strong reorientation—India emerges as a major growth destination; some markets show sharp contractions in selected products

ETS-20 produces much more heterogeneous export changes, including very large positive and negative percentage swings in some bilateral flows. These extreme values should be interpreted carefully (large percentage changes can occur when baseline trade volumes are small), but the directionality still conveys strategic implications.

A key pattern is that India shows consistently strong increases across many sectors:

- **IronSteelPrd** to India: +72.18
- **MetalProd** to India: +60.49
- **Non_Met_Min** to India: +57.32
- **ChemProd** to India: +68.84
- **Oth_EnIntInd** to India: +51.8
- **Veh_Equip** to India: +27.23
- **Elec_Equip** to India: +9.03

By contrast, several flows to other markets fall sharply for certain products (e.g., very large negative changes to Japan for MetalProd, Non_Met_Min, Elec_Equip, and Oth_ind). The economic reading is that ETS-20 reshapes relative prices and production patterns in ways that can redirect trade toward markets where demand conditions, supply-chain complementarities, or relative competitiveness align more favorably.

For the greening the value chain framing, the implication is strategic:

- If Indonesia's goal is to expand EV-related exports into markets with stringent green procurement and embodied-emissions expectations, then domestic ETS alone is not sufficient. It must be paired with measurable decarbonization of upstream inputs and robust MRV/traceability systems.
- At the same time, the results indicate a near-term opportunity to deepen production network integration with fast-growing markets (notably India), which could support scale-up and learning. It provided that this scaling is aligned with the decarbonization pathway so that competitiveness is not undermined later when embodied-carbon constraints tighten globally.

7 Recommendation and Way Forward

Decarbonizing the supply chain is a crucial policy strategy for helping Indonesia achieve the targets set out in its NDC and Net Zero Emissions (NZE) commitment for 2060. Beyond supporting climate objectives, supply chain decarbonization can also generate substantial socio-economic benefits. It should therefore be framed not merely as an environmental obligation, but as an opportunity to foster clean industrial development and strengthen Indonesia's long-term industrial transformation.

One of Indonesia's flagship initiatives to achieve both climate and industrial goals is the development of battery-based electric vehicles (EVs). However, despite the implementation of nickel downstreaming policies, the expected progress in lithium-ion battery and EV manufacturing has yet to materialize. At the same time, carbon-intensive nickel processing and Indonesia's coal-dominated electricity mix risk undermining emission reduction efforts in these sectors. As a result, industrial expansion in batteries and EVs may deliver only limited decarbonization benefits. Moreover, if Indonesia's EV products fail to meet increasingly stringent environmental standards, particularly in the European market, the country may face future constraints on market access.

In light of these challenges, three strategic policy priorities should guide the development of a more sustainable battery and EV industry.

1. Strengthen Downstreaming and Industrial Strategy by Incorporating Indonesia's Competitiveness Level

Indonesia's ambition to become a regional hub for battery and EV production deserves recognition. However, historically, Indonesia's automotive and component industries have lagged behind regional competitors such as Thailand. If Indonesia aims to leapfrog into a leading position in the EV sector, it is also important draw lessons from the development trajectory of the regional automotive industry.

While Indonesia's abundant nickel reserves provide a strong foundation for domestic industrial development, the export ban policy has reduced the competitiveness of raw materials without sufficiently strengthening midstream and downstream capabilities. As a result, Indonesia's battery and EV competitiveness currently trails even behind Vietnam, a country with more limited raw material reserves.

This gap reflects a fundamental mismatch between the downstreaming agenda and the actual needs of the battery and EV industries. A comprehensive roadmap, covering the entire value chain from mineral processing to EV production, is therefore urgently needed. Such a roadmap should be supported by targeted incentives, clear performance benchmarks, and regular policy evaluation to minimize misalignment. For example, incentives for advancing HPAL technology development should be integrated into the broader industrial strategy.

Another critical issue is the disconnect between domestic industrial planning and global battery market trends. Without close alignment with evolving technological and market developments, Indonesia risks building a heavily subsidized industry that struggles to compete globally. Greater trade openness and deeper regional integration should therefore be incorporated into Indonesia's EV strategy. Rather than relying solely on domestic resource endowments, Indonesia must position itself within global lithium-ion technology trends. Enhanced international cooperation could also reduce industrial fragmentation in Southeast Asia and improve regional efficiency, thereby supporting domestic EV development.

2. Optimizing Supply Chain Decarbonization for Environmental, Social and Economic Sustainability

It is important to recognize that developing the battery and EV industry does not automatically guarantee meaningful emission reductions. Indonesia's electricity mix, which remains heavily dependent on coal-fired power plants, renders industrial production carbon-intensive across the value chain.

This Research finds that greening the electricity grid represents one of the most effective strategies for lowering emissions. Increased adoption of HPAL technology can further reduce carbon intensity. Together, these measures should be prioritized to ensure that Indonesia's battery and EV industries become significantly less carbon-intensive.

However, the current electricity transition pathway outlined in the RUPTL appears insufficiently ambitious. Under existing projections, Indonesia's EV industry would still generate higher emissions than neighbouring countries such as Thailand and Vietnam. This disparity weakens Indonesia's competitiveness not only in industrial performance but also in its ambition to lead in green manufacturing. A more aggressive decarbonization strategy is therefore essential to enhance Indonesia's regional position.

Nevertheless, higher decarbonization ambition entails social and economic trade-offs. For example, while HPAL technology may reduce emissions, it can also produce higher levels of toxic by-products, potentially affecting public health. Companies adopting this technology must therefore be required to implement strict environmental safeguards, including toxin filtration and proper waste management systems, to prevent negative community impacts.

From an economic standpoint, emission reduction policies, such as those envisioned under the SNDC scenario, may generate short-term economic contraction due to emission allowance mechanisms. Energy-intensive sectors, particularly upstream materials and energy industries, are likely to bear the greatest burden. These trade-offs are unavoidable. However, they should not deter supply chain decarbonization efforts. On the contrary, the long-term competitiveness of Indonesia's battery and EV industries depends fundamentally on successful upstream decarbonization. Without it, Indonesia risks losing both market competitiveness and momentum toward achieving its NDC commitments.

3. Accelerating ESG Adoption through Market and Financial Pressure

Supply chain decarbonization is increasingly linked to both environmental performance and economic competitiveness. Instruments such as the Battery Passport in the EV sector demonstrate how international standards are reshaping global value chains. For Indonesia, compliance with emerging international standards is critical to maintaining access to global markets. This is particularly important given Indonesia's strategic focus on producing NMC-type batteries, for which the European Union represents a key export destination. As more countries adopt similar environmental standards, failure to comply could significantly undermine Indonesia's industrial competitiveness.

Beyond regulatory requirements, voluntary pressure from investors and financial institutions is becoming increasingly influential. ESG-based investment criteria and financial conditionalities can accelerate industry-wide compliance with international standards. Stronger investor engagement can therefore help expedite supply chain decarbonization while enhancing the global competitiveness of Indonesia's battery and EV industries.

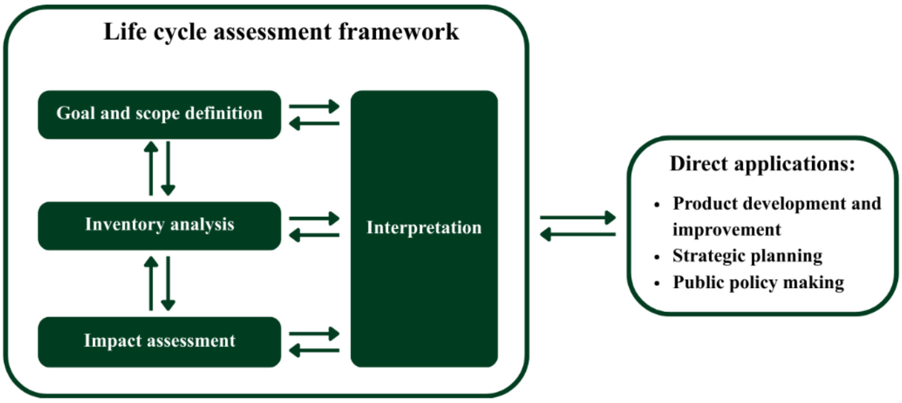
Appendix I. Global Policy Instruments to shape Greener Value Chain Economies

Policy Instrument (Short Summary)	**Scope**	**Voluntary/Mandatory**
Paris Agreement (2015) – Landmark global climate treaty under the UNFCCC aiming to limit warming to well below 2°C (pursuing 1.5°C); *legally binding* on 195 countries[1]. Parties submit national targets (NDCs) on a 5-year cycle and must report progress.	**International**	**Mandatory** (binding treaty for signatories)
EU Emissions Trading System (EU ETS) – Cap-and-trade carbon market launched 2005; requires power plants, factories, airlines, etc. in EU to **pay for their CO_2 emissions** by surrendering allowances[2]. Covers ~40% of EU emissions; cap declines annually to drive reductions.	**Regional (EU)**	**Mandatory** (for regulated entities)
EU Carbon Border Adjustment Mechanism (CBAM) – EU measure (phased 2023–25, full from 2026) imposing a carbon price on **carbon-intensive imports** (e.g. steel, cement, aluminum, fertilizers, electricity, etc.) so their cost reflects CO_2 emissions[3]. Aims to prevent carbon leakage and encourage cleaner production abroad.	**Regional (EU)** (Global trade impact)	**Mandatory** (for importers, after transitional phase)
CORSIA (Aviation Offsetting) – *Carbon Offsetting and Reduction Scheme for International Aviation* under ICAO. First global sector-wide carbon market scheme[4]; aims for **carbon-neutral growth** of aviation from 2020. Started 2021 with a **voluntary** pilot phase; becomes **mandatory** for most international flights from 2027[5].	**International**	*Voluntary* (2021–26); **Mandatory** (from 2027)
IMO Maritime Emissions Rules – The International Maritime Organization's regulations to decarbonize shipping. Since 2013 new ships must meet efficiency design standards (EEDI); since 2023, **all large ships must calculate an efficiency index (EEXI) and annual carbon intensity (CII)** and improve if ratings are poor[6]. In 2023 IMO adopted a strategy for **net-zero shipping by 2050** with interim CO_2 reduction targets[7].	**International**	**Mandatory** (under MARPOL for member states' ships)
China National ETS – National emissions trading system launched in 2021, now **world's largest carbon market**. Initially covers ~2,200 power plants (over 4 billion tons CO_2, ~40% of China's emissions) with plans to expand to steel, cement, etc.[8]. Companies must surrender allowances for emissions; currently free allocations with intensity benchmarks.	**National (China)**	**Mandatory** (compliance market)
India Perform, Achieve and Trade (PAT) – Energy-efficiency **cap-and-trade** program (started 2012) for large industrial energy users. Sets specific energy reduction targets for each firm and issues tradable Energy Saving Certificates (ESCerts) for over-achievement[9]. Has covered hundreds of plants across 13 sectors, achieving notable energy savings in early cycles.	**National (India)**	**Mandatory** (targets for designated industries; trade in credits)
South Africa Carbon Tax – **Carbon pricing law** effective June 2019 as a phased tax on fuel combustion, industrial processes and fugitive emissions[10]. Initial tax rate R120/ton CO_2 (about $8) with annual increases; generous allowances (60–95% emissions exempt) in Phase 1 yield an effective rate of R6–48 to ease transition[11]. Higher carbon price levels are planned by 2030 and 2050.	**National (S. Africa)**	**Mandatory** (tax with phased implementation)
Indonesia Carbon Pricing (NEK) – Indonesia's *Nilai Ekonomi Karbon* framework introduced a pilot **emissions trading system** in 2023 for the power sector. Covers 99+ coal power plants (≥25 MW), setting intensity-based emissions caps and trading of allowances[12]. A **carbon tax** will	**National (Indonesia)**	**Mandatory** (ETS compliance, with carbon tax enforcement)

function as a floor price/penalty for non-compliance[13]. An official carbon exchange (IDX Carbon) launched in 2023 to facilitate trading.		
U.S. Inflation Reduction Act (2022) – U.S. climate law investing **$369 billion** in clean energy and decarbonization via tax credits, grants and loans[14]. It is the largest climate investment in U.S. history, funding renewable energy, EVs, decarbonizing industry, agriculture, etc. The policy relies on **market incentives** (not penalties), aiming to cut U.S. emissions ~40% by 2030.	**National (USA)**	**Voluntary** (incentive-based; companies opt in for credits)
EU Deforestation-Free Supply Chain Regulation (2023) – New EU law banning the import or sale of key commodities (beef, soy, palm oil, coffee, cocoa, timber, rubber, etc.) if they were produced on land deforested after 2020[15]. Firms must perform due diligence and provide **verifiable proof** that products are deforestation-free, or face fines up to 4% of turnover. Aims to eliminate deforestation from EU supply chains, with compliance required by end of 2024.	**Regional (EU)**	**Mandatory** (due diligence law)
German Supply Chain Due Diligence Act (2023) – National law requiring large German companies (≥3,000 employees, and ≥1,000 from 2024) to identify and address **human rights and environmental risks** throughout their supply chains[16]. Companies must implement risk management, audits and corrective measures to prevent issues like child labor or severe pollution (e.g. mercury, hazardous waste) at suppliers[17]. Non-compliance can lead to fines.	**National (Germany)**	**Mandatory** (due diligence obligations)
Science Based Targets initiative (SBTi) – Global voluntary program launched in 2015 that helps companies set greenhouse gas reduction targets aligned with climate science and the Paris Agreement[18][19]. Companies commit to specific emissions cuts (e.g. 50% by 2030, net-zero by 2050) which are independently validated as "science-based." Widely adopted by hundreds of major firms (especially to green their value chains), but participation is self-initiated.	**International**	**Voluntary** (corporate commitment)
Task Force on Climate-related Financial Disclosures (TCFD) – Framework created by the G20's Financial Stability Board in 2015 for **voluntary climate risk disclosure** in financial filings[20]. Provides standardized recommendations for companies to report climate-related risks and opportunities (governance, strategy, risk management, metrics & targets). TCFD-aligned reporting has become a *de facto* global standard, now **widely adopted** and being integrated into mandatory disclosure rules in the UK, EU, Japan, etc.	**International**	**Voluntary** (in origin; becoming mandatory in some jurisdictions)

Sources: The information above was compiled from official publications and reports as cited. Each policy's summary and status (international/national, voluntary/mandatory) are based on the latest available

Appendix II. Life Cycle Assessment Framework (ISO 14040, ISO14044)



Appendix III Functional Unit of The Product Systems

Product System	**Functional Unit**
NMC622 battery	1 kWh
BEV	1 unit vehicle

Appendix IV Specifications of the BEV assessed in the study

Parameter	**Unit**	**Value**
Model	-	Air Wuling
Weight	kg	1,160
Average lifetime	years	10
Average annual usage	km	10,000

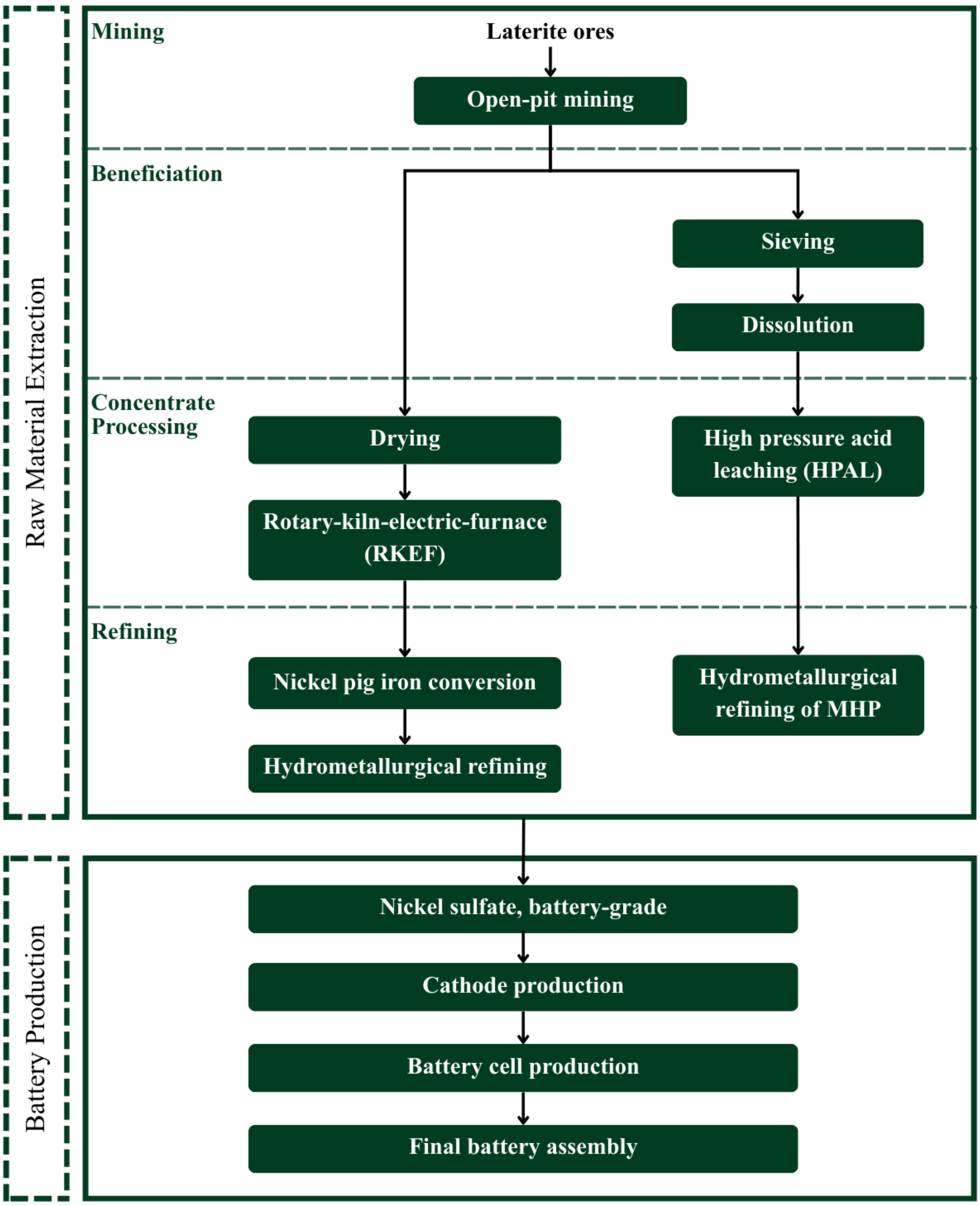
Sources: Wuling and Veza et al. (2023)

Appendix V Battery Specifications

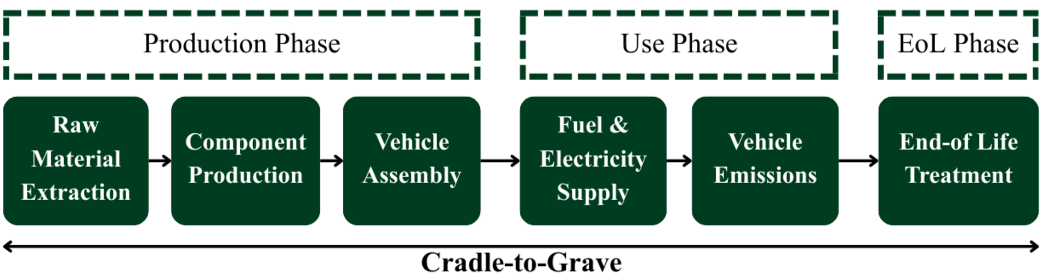
Parameter	**Unit**	**Value**
Gross pack energy	kWh	23.5
Number of cells	Unit	140
Voltage of cells	V	3.6
Electric charge	Ah	4.6
Specific energy	kWh/kg	0.155

Source: ecoinvent 3.11

Appendix VI System Boundary



Appendix VII. System Boundary of NMC622 Battery Product System



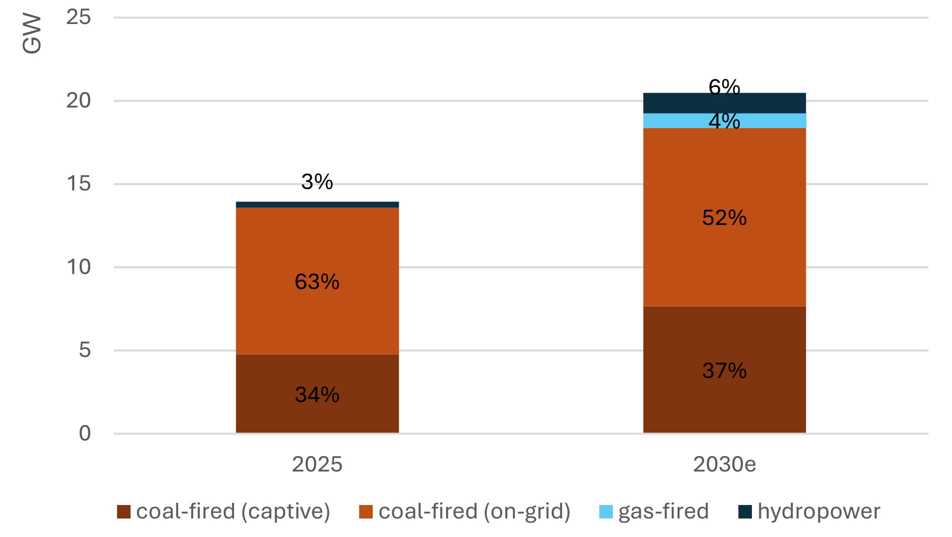
Appendix VIII. System Boundary of BEV Product System

Appendix IX Life Cycle Inventory Data Adjustments

Life cycle inventory data for both stages are primarily sourced from ecoinvent version 3.11, with several adjustments are applied to better reflect the Indonesian context.

Aspect	**Baseline dataset/ assumption**	**Adjustment**	**Source**	**Justification**
Nickel extraction process	The ecoinvent 3.11 database provides a single global inventory for nickel sulfate production, aggregating multiple production routes (sulfide and laterite ores).	Nickel sulfate production is modelled using only RKEF and HPAL routes.	Roy et al. (2025)	To reflect Indonesian nickel production, which relies on laterite ores.
Electricity mix (baseline year)	Default electricity mixes in ecoinvent 3.11	Electricity mix for the baseline year is aligned with country-specific shares reported in IEA (2023).	IEA (2023)	To represent current national electricity mix more accurately.
Electricity mix (target)	Default electricity mixes in ecoinvent 3.11	Electricity mix trajectories for Indonesia, Vietnam, and Thailand over 2025–2034 are applied.	Indonesia: RUPTL 2025–2034; Thailand: Power Development Plan; Vietnam: Revised PDP8 (Decision No. 768/QD-TTg).	To reflect electricity transitions in future scenarios.

Appendix X Energy Generation Mix of Nickel Industries in Indonesia



Notes: e = estimated

Appendix XI. Energy generation mix used by nickel smelters in Indonesia (CSIS analysis based on data from the RMI, 2025)

Configurations of Scenario 2 NMC Battery

Configurations	**Share of Energy (%)**		
	Captive Coal	**On-Grid**	**Other**
Baseline	37	52	10
C30-G60	30	60	10
C0-G90	0	90	10
G100	0	100	0

Configurations of Scenario 3 NMC Battery

Configurations	**Share of Processing Technology (%)**	
	HPAL	**RKEF**
H10 (baseline)	10	90
H20	20	80
H33	33	67