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Sustainability of Nickel Mining in the Development of the Electric Vehicle Industry in ASEAN

Economic Research Institute
for ASEAN and East Asia

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List of Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
BAU	Business-as-usual
BEV	Battery electric vehicle
CAM	Cathode active material
CO_2	Carbon dioxide
EU	European Union
EV	Electric vehicle
FAME	Fatty acid methyl ester
HEV	Hybrid electric vehicle
HPAL	High-pressure acid leaching
ICE	Internal combustion engine
IEA	International Energy Agency
JORC	Joint Ore Reserves Committee
LCA	Life cycle assessment
LCC	Life cycle costing
LIB	Lithium-ion battery
MHP	Mixed hydroxide precipitate
MSP	Mixed sulphide precipitate
NCA	Nickel cobalt aluminium
NMC	Nickel manganese cobalt
NPI	Nickel pig iron
pCAM	Precursor cathode active material
PHEV	Plug-in hybrid electric vehicle
PSA	Philippine Statistics Authority
RKEF	Rotary-kiln electric furnace
WTO	World Trade Organization

Executive Summary

Nickel is a critical mineral for the global energy transition, with electric vehicle (EV) batteries projected to account for about 60% of global nickel demand by 2040. Southeast Asia – particularly Indonesia and the Philippines – hosts some of the world's largest laterite nickel reserves, positioning the region as a strategic hub for EV battery production. This study evaluates the sustainability of nickel supply, reserve resilience, and the carbon footprint of nickel sulphate hexahydrate ($NiSO_4 \cdot 6H_2O$), a key precursor in lithium-ion batteries (LIBs), to assess ASEAN's role in transport decarbonisation.

The analysis combines supply–demand modelling, reserve depletion assessment, and life cycle analysis (LCA) with life cycle costing (LCC), using international databases, policy documents, industry reports, and high-resolution supply chain data. Two EV adoption scenarios are examined: Hybrid Electric Vehicle (HEV) Bridge and Battery Electric Vehicle (BEV) Ambitious, reflecting varied ASEAN market trajectories.

Findings show Indonesia's nickel downstreaming policies have successfully attracted major foreign investments – particularly from China – while generating environmental, social, and trade-related concerns. Supply projections suggest domestic $NiSO_4 \cdot 6H_2O$ availability could reach 0.8 Mt annually from operating HPAL facilities, 1.5 Mt with those under construction, and 2.7 Mt if all planned capacity comes online. On the demand side, ASEAN EV sales are expected to reach 2 million units by 2040 under the HEV Bridge scenario and 3.5 million units under the BEV Ambitious scenario, with BEVs comprising 62%–78% of sales. BEVs are especially nickel-intensive, requiring up to nine times more $NiSO_4 \cdot 6H_2O$ per unit than plug-in hybrids and fifteen times more than HEVs.

Balancing supply and demand, modelling suggests that eight HPAL facilities (1.3 Mt capacity) could meet ASEAN's projected 2040 demand of 0.5–1.0 Mt, leaving a 0.3–0.8 Mt surplus for export. However, with 27 HPAL facilities (2.4 Mt capacity), reserves may face depletion by 2038 unless new exploration and resource conversion efforts are intensified. This underscores the need for strategic reserve management and sustainable mining practices to ensure long-term supply security.

Environmentally, producing 1 kg of $NiSO_4 \cdot 6H_2O$ currently emits about 8 kg CO_2-equivalent, mainly from the HPAL process. Decarbonisation options – such as using biodiesel in mining, integrating renewable energy in processing, and sourcing low-carbon sodium hydroxide – could cut emissions by up to 54%, with renewable energy providing the largest reductions. LCC results show these strategies raise operating costs by only 8%–12%, making low-carbon production economically feasible.

Overall, ASEAN's nickel mining and processing sectors are central to global EV growth and climate goals. Yet, challenges remain: resource depletion risks, socio-environmental impacts, and energy-intensive processing. Addressing these requires responsible mining, midstream–downstream integration, renewable energy adoption, and stronger governance to ensure nickel contributes sustainably to the energy transition.

Chapter 1

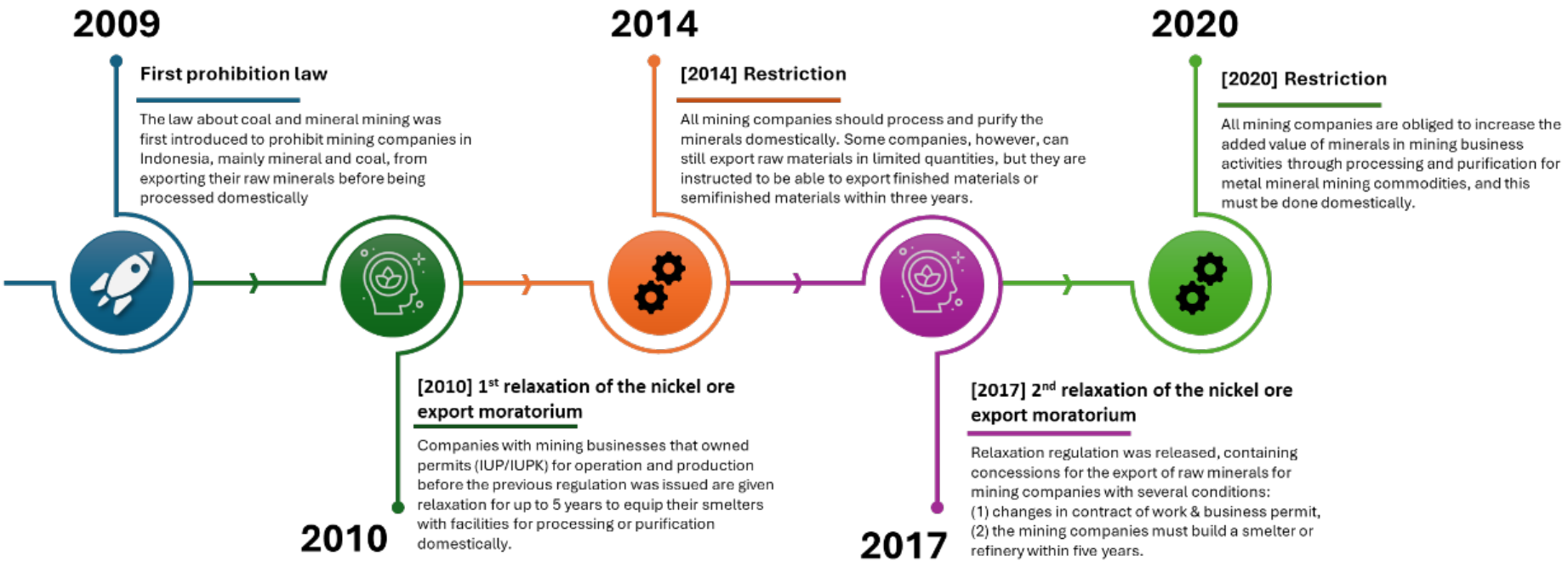
Indonesia's Nickel Downstreaming: Policies, Impact, and Challenges

1.1. The Strategic Move Towards Nickel Downstreaming

Indonesia is the world's top producer of nickel, accounting for 37% of global supply in 2021 (U.S. Geological Survey, 2022). Across the country, massive nickel industrial parks are being built to process nickel ore into compounds for industrial uses. Although nickel has historically been used primarily to make stainless steel, its use in renewable energy technologies, such as in batteries for electric vehicles (EVs), has led to a sharp increase in demand in recent years. For EVs specifically, it is anticipated that the demand for nickel will increase by around 60% globally by 2040 (Leotaud, 2021).

Recognising the increased demand for nickel around the world, in 2020, the Government of Indonesia banned the export of nickel ore to encourage domestic processing. Furthermore, by promoting nickel downstreaming, the Indonesian government seeks to enhance the added value of nickel ore, attract investment, and generate employment opportunities (Lahadalia et al., 2024). The Mining Law of the Republic of Indonesia Number 4 of 2009, which was passed at least 10 years prior, reiterated the prohibition on Indonesian mineral exports. The ban was initially supposed to take effect immediately, but it was postponed twice, in 2014 and 2017. In January 2020, a final decision to ban all exports of nickel ore was put into effect after a few disagreements. In order to protect the nation's vital nickel feedstock, the exporting of nickel with a grade of less than 1.7% was explicitly banned, and the prohibition went into force on 1 January 2020 (Figure 1.1).

Figure 1.1. Nickel Ore Export Ban History in Indonesia



Source: Authors, modified from Pandyaswargo et al. (2021).

The government's decision to outright ban the export of nickel ore resulted in a surge in investment in the construction of smelters and other downstream processing operations. Under the 2015 Minister of Finance Regulation, pioneer industries – such as nickel processing – qualify for a 10%–100% income tax reduction for 5–15 years, extendable to 20 years for investments over Rp1 trillion. As of 2020, there were 11 smelters, 4 work contracts, and 292 mining license holders (MEMR, 2020). To encourage investments in downstream industries like nickel processing, Finance Regulation No. 130 of 2020 was introduced. This regulation grants a tax holiday, cutting corporate income tax by 50% for a period of five years (Lahadalia et al., 2024). These measures have incentivised investments in nickel industrialisation. The number of smelters doubled in 2021 compared to 2015 (Pahlevi, 2022). By 2024, 30 nickel smelters were expected to be operational, according to official projections (Media Nikel Indonesia, 2022).

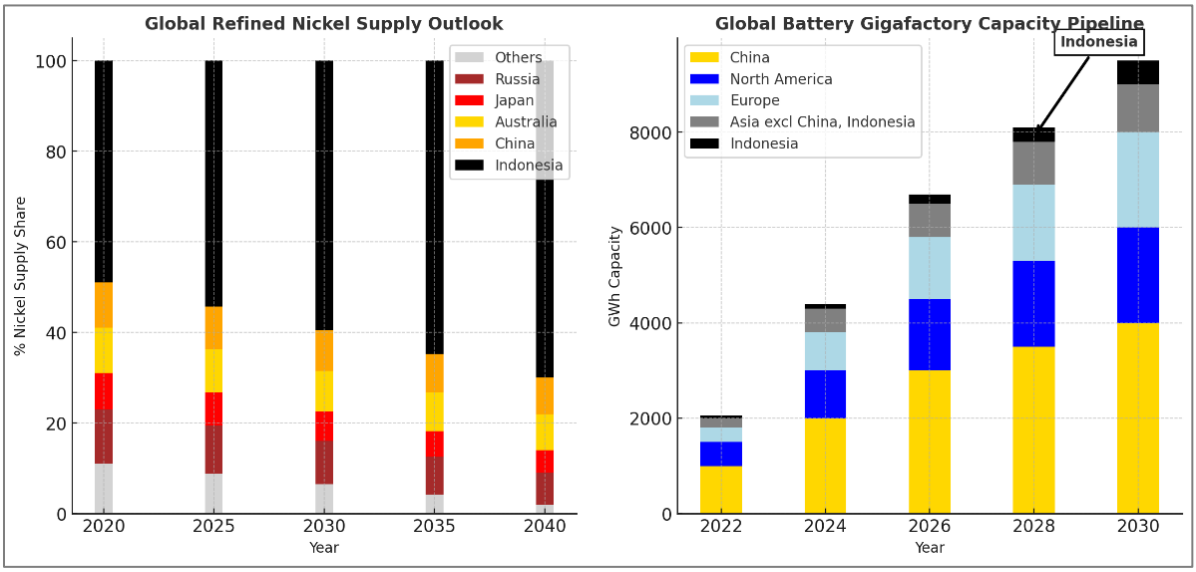
1.2. Political Economy of Nickel Downstreaming

Resource nationalism – defined as state intervention in natural resource industries such as nickel mining (Khalil and Brougel, 2025) – in Indonesia's nickel sector is strongly shaped by the rise of electric vehicles (EVs). A competitive investment climate for battery-based EVs is the goal of both Government Regulation (PP) No. 28 of 2021 on the Implementation of the Industrial Sector and Presidential Regulation (Perpres) No. 79 of 2023 on the Acceleration of the Battery-Based Electric Motor Vehicle (BEV) Program for Road Transportation (President of the Republic of Indonesia, 2023; Ministry of Industry of the Republic of Indonesia, 2021). Starting in 2019, these rules require a progressive rise in the domestic component level for batteries, including nickel. The estimated demand for nickel as a raw material for batteries, particularly the NMC 811 battery type, will continue to rise in light of the quantitative goal of developing the battery-based electric motor vehicle industry for four-wheel vehicles to reach 400,000 units in 2025 and 1.76 million units for two-wheel vehicles (Ministry of Industry of the Republic of Indonesia, 2021; Sutrisno, 2023).

According to Adhiguna (2024), although EV investments in Indonesia have increased significantly due to the entry of big firms like BYD and Tesla into the domestic EV industry, the country's adoption of EVs is still modest. Prior to 2020, the majority of nickel ore processing in Indonesia was focused on producing ferronickel and nickel pig iron (NPI), which are used as raw materials to make stainless steel, rather than batteries (Soelistijo, 2013; Sutrisno, 2023). As shown in Figure 1.2, Indonesia has become the largest refined nickel supplier in the world, and its refined nickel supply share is expected to reach nearly 75% of the world's total refined nickel supply by 2050. However, Indonesia's share of global battery production will remain low, although it is expected to increase towards 2050.

Since 2017, China has been Indonesia's largest nickel importer, driven by its massive stainless steel production needs (OEC, n.d.; Fahalmesta, 2022). The Belt and Road Initiative (BRI), introduced in 2013, is one of the main measures promoting this. The BRI initiative facilitates investment in Indonesia's nickel sector, leveraging China's surplus industrial capacity and financial capital (Sangadji and Ginting, 2023).

Figure 1.2. Indonesia's Nickel Supply versus Battery Pipeline



GWh = gigawatt hour.
Source: Adhiguna (2024).

In addition to BRI, to strengthen its nickel industry and attract foreign investors, the Indonesian government has implemented various strategic policies. One key measure was the issuance of INPRES No. 1 of 2016, which required ministries and subnational governmental agencies to take actions within their mandates to support national strategic projects, including nickel downstreaming (INPRES, 2016). This directive was later amended three times – through Presidential Regulation No. 58 of 2017, No. 56 of 2018, and No. 109 of 2020 – to further streamline processes and accelerate the development of nickel smelters (Perpres, 2017; Perpres, 2018; Perpres, 2020).

Whilst Indonesia argues that its nickel export ban is essential for developing the domestic EV ecosystem, the policy has faced opposition from developed economies such as the European Union (EU), which relies on Indonesian nickel imports (Krustiyati et al., 2022). In 2019, the EU filed a lawsuit against Indonesia at the World Trade Organization (WTO), claiming that the export restrictions violated international trade laws (Winona, 2022). The case was based on WTO Article XI of the General Agreement on Tariffs and Trade (GATT) 1994, which prohibits quantitative export restrictions (WTO, n.d.). According to estimates, the ban could put over 200,000 jobs in the EU's stainless-steel industry at risk (Krustiyati et al., 2022). In October 2022, the WTO ruled against Indonesia, but the

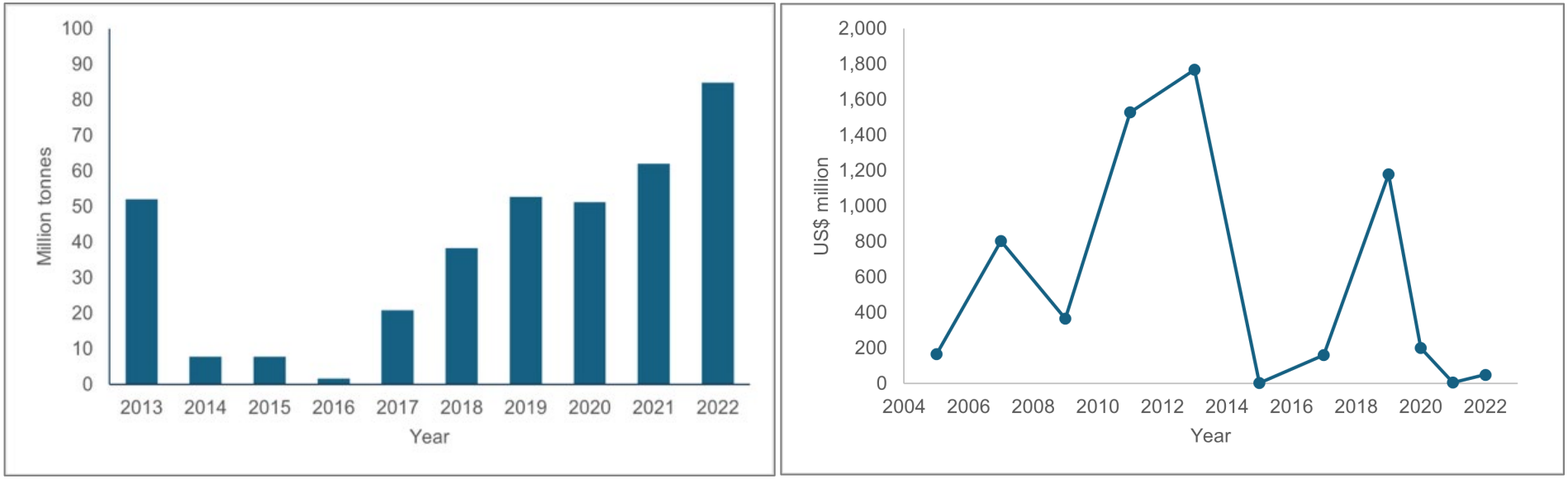
country appealed the decision in November 2022, allowing it to maintain the export ban whilst the appeal process is ongoing.

1.3. Trade-offs of the Nickel Downstreaming Policy

Indonesia's nickel downstreaming policy is promoted to enhance economic growth and public welfare. However, the government's decision to ban nickel ore exports has sparked various political and socio-economic responses. When the ban was initially introduced in 2014, Indonesia's nickel production dropped sharply between 2013 and 2015 due to the country's insufficient processing capacity to support its industrialisation goals (see Figure 1.3 (left)) (Lokadata, n.d.). Nickel ore exports resumed in 2017 but were banned again in January 2020. Ahead of the ban, there was a surge in nickel production and exports in 2019 (Ahdiat, 2023). The 2020 export restriction led to a dramatic 368% year-over-year increase in nickel production, driving the expansion of domestic smelters and increasing the output of value-added products like ferronickel (Dewi et al., 2023). From 2020 onwards, ferronickel emerged as a major contributor to Indonesia's nickel product exports, and it is anticipated to grow even more in the years to come (Dewi et al., 2023).

However, despite rising production volumes, Indonesia's nickel trade value has not increased proportionally. From 2020 to 2022, the trade value declined compared to previous years, mainly due to the country's continued reliance on exporting intermediate products like ferronickel rather than higher-value finished goods, such as battery components (see Figure 1.3 (right)).

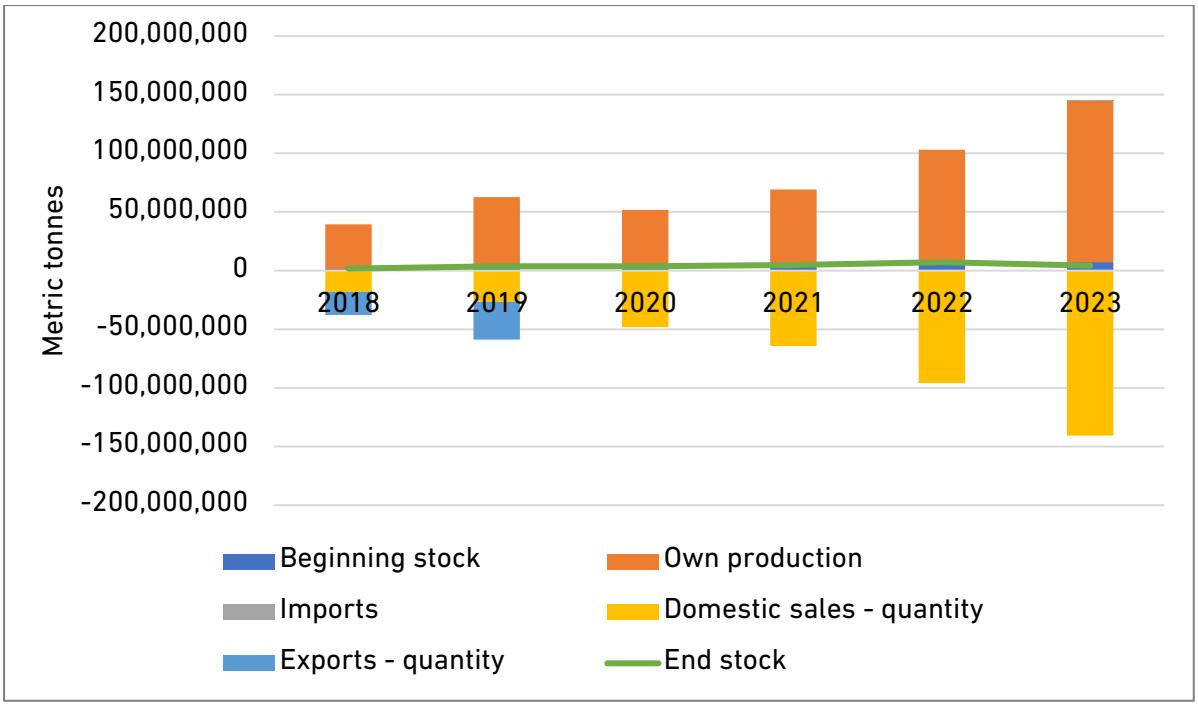
Figure 1.3. Indonesia's Nickel Production (left) and Export Value of Indonesia's Nickel Products (right)



Source: Authors, modified from Lokadata, (n.d.) and MEMR (2020)

The ban on nickel ore exports completely eliminated exports of the ore by 2020 (see Figure 1.4). Starting from 2020, almost all of the nickel ore produced, growing from around 48 million metric tonnes of nickel ore in that year to almost 138 million metric tonnes by 2023, has been absorbed by domestic demand for further refining and processing to become higher-value nickel products.

Figure 1.4. Nickel Ore Production and Usage in Indonesia



Source: Authors, adapted from BPS (2023).

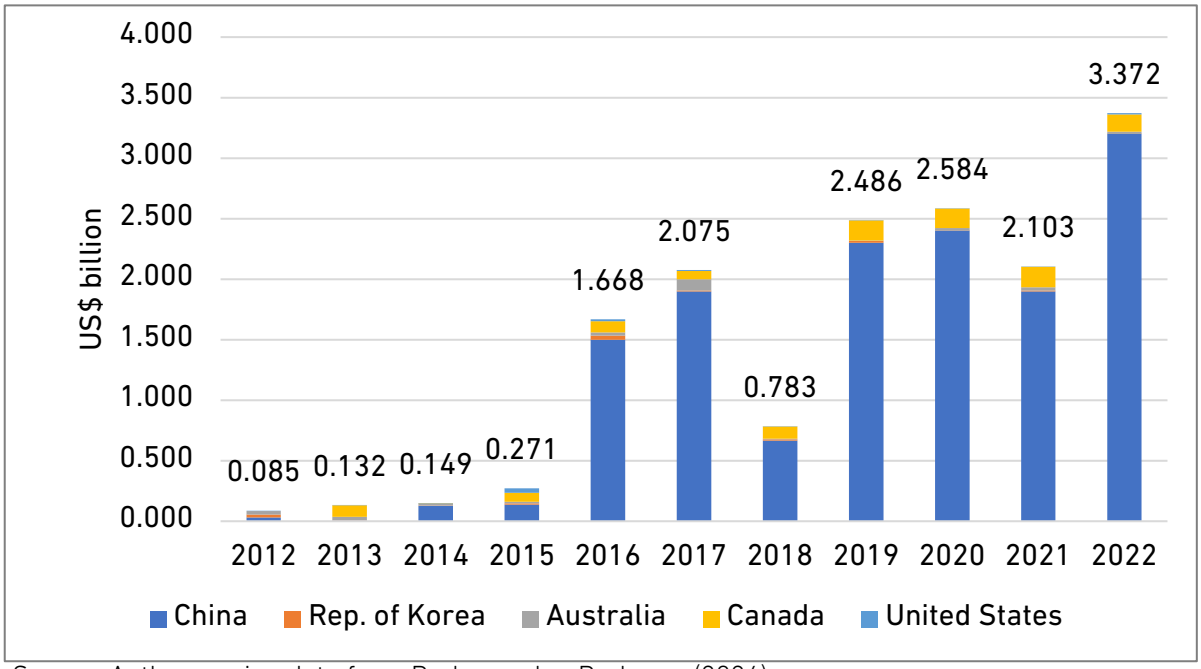
The ban on nickel ore exports put in place in parallel with the implementation of the downstreaming policies has also triggered a strong increase in foreign direct investment (FDI) in nickel processing and refining concentrated in Sulawesi Island and Halmahera Island (North Maluku province).

As shown in Figure 1.5. FDI in Sulawesi and Halmahera Islands jumped more than sixfold from 2015 to 2016 following the restriction of raw materials exports in 2014. However, the second relaxation of the nickel ore export moratorium in 2018 was followed by a drop of more than 60% between 2017 and 2018. The 2020 requirement for all companies to increase the added value of minerals in mining business activities was followed first by a small decrease of nearly 19% between 2020 and 2021 and a strong increase of more than 60% between 2021 and 2022.

Overall, the amount of FDI in the two islands has increased by almost a factor of 40 from 2012 to reach around US$3.3 billion in 2022. The FDI shares originating from China, Australia, and the Republic of Korea (henceforth, Korea) were 38%, 35%, and 27%,

respectively, in 2012. FDI from China started to show clear domination in 2014. By 2016, Chinese FDI was almost 90% of the total and reached nearly 95% by 2022.

Figure 1.5. Investment in the Nickel Processing Sectors in Sulawesi and Halmahera by Country

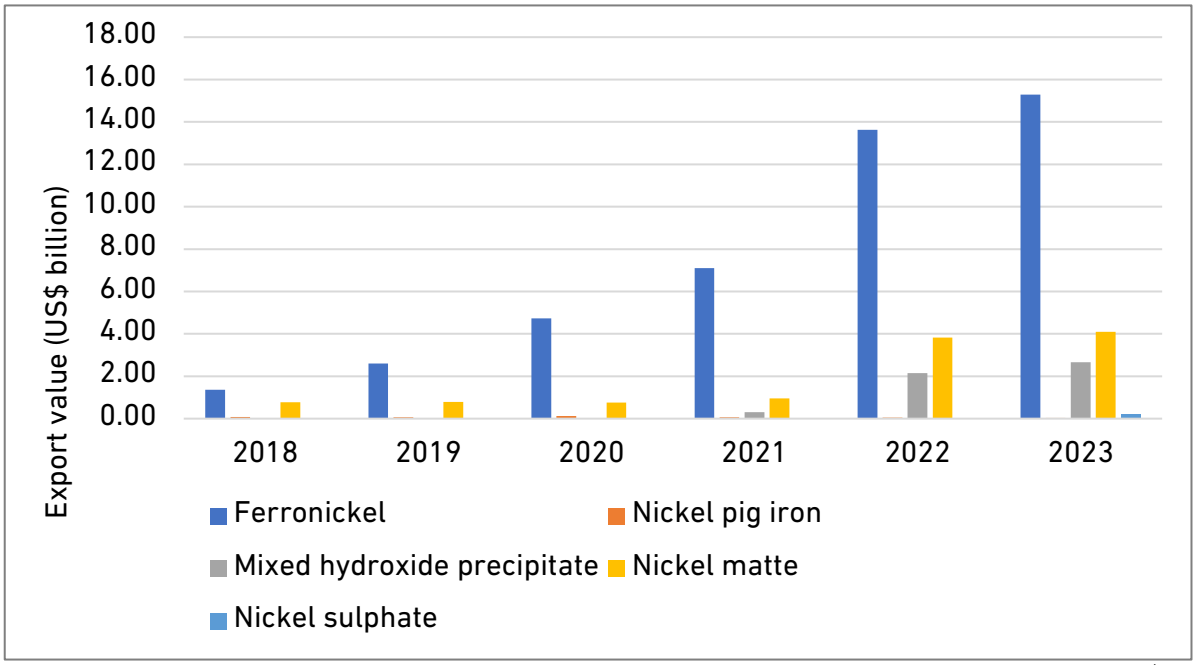


Source: Authors, using data from Perkumpulan Prakarsa (2024).

FDI in nickel processing and refining has focused on the development of smelters that deploy two main types of technology: rotary kiln electric furnace (RKEF) and high-pressure acid leaching (HPAL). RKEF is a higher-emission smelter technology than HPAL, whilst RKEF is used to produce ferronickel and nickel pig iron, which are nickel products commonly used as a combining agent in steelmaking. HPAL technology, considered to be cleaner technology, is used to produce higher-grade processed nickel that is more adequate for EV battery materials, such as mixed hydroxide precipitate (MHP), which can be used to produce nickel sulphate, a further processed nickel and precursor for EV batteries. Nickel sulphate can also be produced using nickel matte, i.e. materials produced in RKEF.

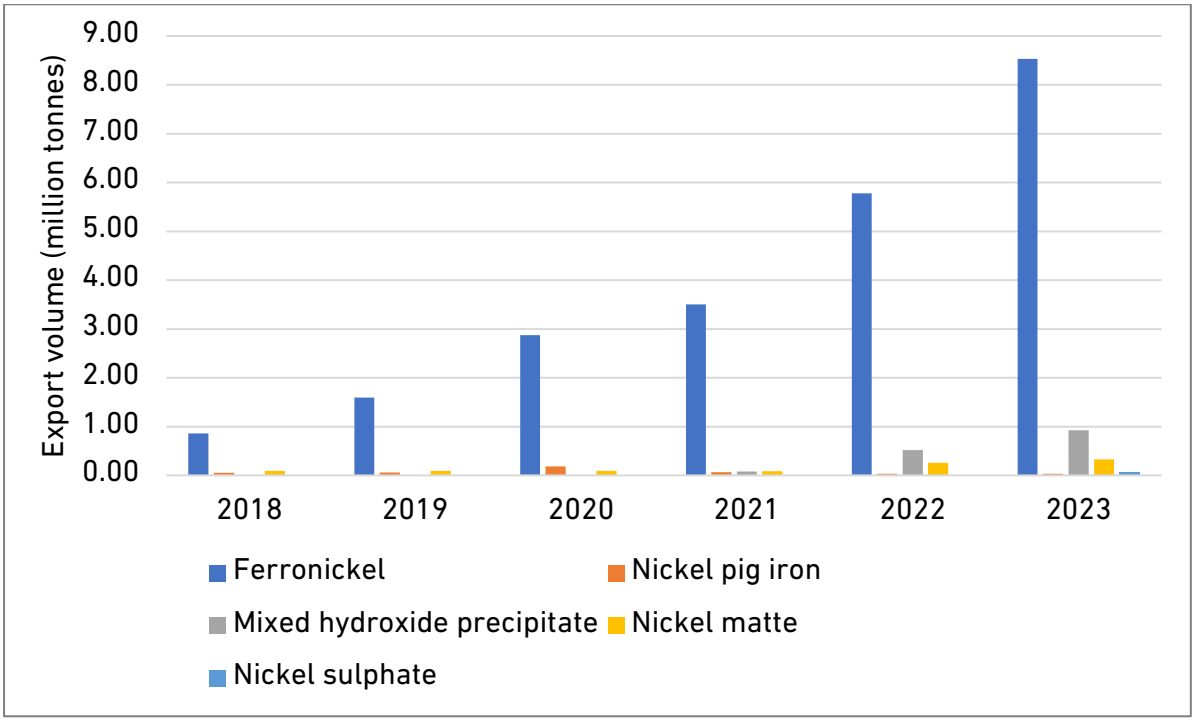
Following the downstreaming strategy and the strong FDI injections in Sulawesi and Halmahera Islands, export values and volumes of several nickel products have been recording steep growth since 2018 (see Figure 1.6 and Figure 1.7).

Figure 1.6. Export Values of Several Processed Nickel Products from Indonesia



Source: Authors, using data from the United Nations Commodity Trade Statistics Database (UN COMTRADE Database. https://comtradeplus.un.org/).

Figure 1.7. Export Volumes of Several Processed Nickel Products from Indonesia



Source: Authors, using data from the United Nations Commodity Trade Statistics Database (UN COMTRADE Database. https://comtradeplus.un.org/).

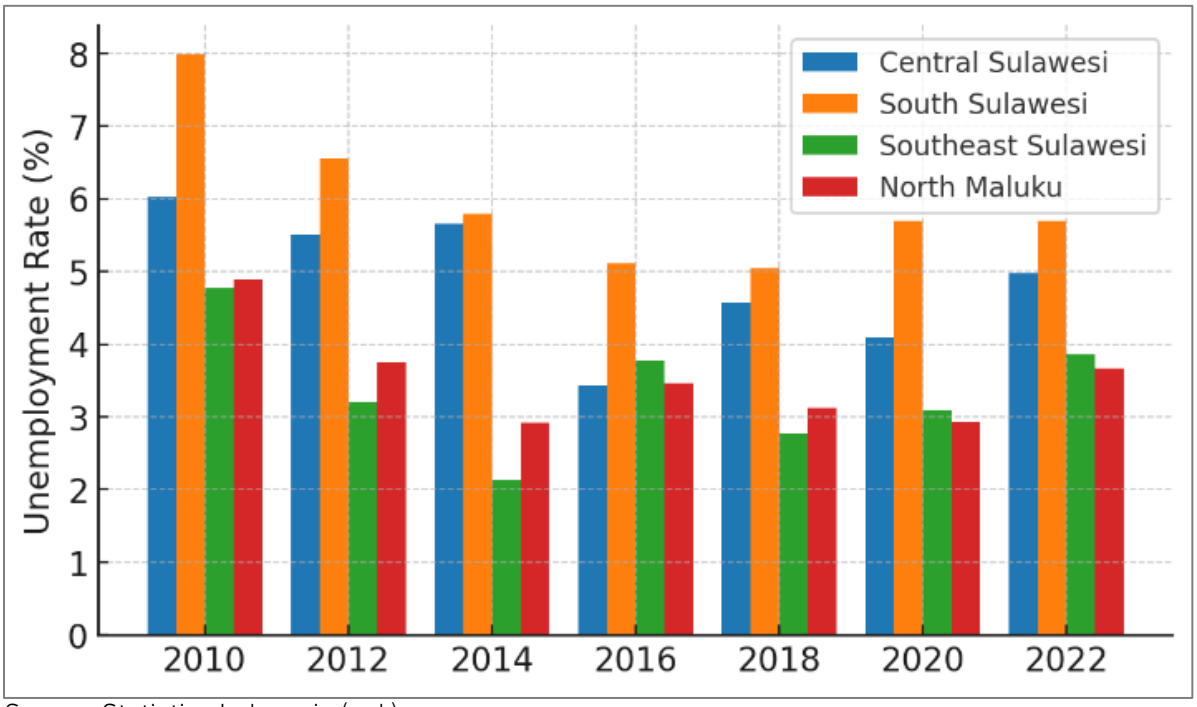
The ferronickel export value and volume increased by a factor of 11 and 10, respectively, between 2018 and 2023. The nickel matte export value and volume increased by a factor of 5.2 and 3.5, respectively, between 2018 and 2023. Indonesia started to export mixed hydroxide precipitate (MHP) in 2021 with a value of around US$0.3 billion (0.08 million tonnes in volume), increasing to around US$2.7 billion (0.9 million tonnes) by 2023. Only nickel pig iron (NPI) showed stagnant export values and volumes during the observed period.

China was almost the unique off-taker of Indonesia's exported processed nickel, especially in ferronickel, including NPI, MHP, and nickel sulphate. Indonesia exported nickel matte solely to Japan from 2018 to 2021, but Japan's share fell to almost 30% in 2022 and 2023, with the remaining share going to China.

Indonesia appeared suddenly as a very important exporter of nickel sulphate in 2023. With a total export value of US$234 million in that year, Indonesia's nickel sulphate exports contributed more than 19% of the world's total export by 2023, ranking second only after Korea, whose export value share reached 20%.

Whilst Indonesia's nickel downstreaming policy aims to drive economic growth and improve public welfare, challenges remain, particularly in employment distribution and the contribution of the manufacturing sector to gross domestic product. According to MEMR (2020), Indonesia's largest nickel reserves are concentrated in Central Sulawesi, South Sulawesi, Southeast Sulawesi, and North Maluku. Data from Statistics Indonesia (n.d.) show that after the export ban was implemented, the open unemployment rate in those provinces – representing the percentage of unemployed individuals in the labour force – generally declined from 2010 to 2022 (see Figure 1.8). At first glance, this suggests that nickel downstreaming activities positively impacted local communities. However, the decline was relatively modest, averaging only around 6% over the period. Additionally, between 2018 and 2022 – both two years before and after the export ban took effect – the unemployment rate showed a slight upwards trend. This rise was largely due to the dominance of foreign workers in nickel mining and smelting areas within the provinces, which limited the expected welfare benefits of nickel downstreaming for local communities (Isaac and Arkyasa, 2023).

Figure 1.8. Unemployment Rate, 2010–2022



Source: Statistics Indonesia (n.d.).

Despite Sulawesi and North Maluku's vast nickel reserves, these regions face rising unemployment rates and severe environmental degradation due to nickel mining. In key mining and processing areas such as Halmahera, Climate Rights International (CRI) (2024) has reported environmental damage and human rights violations. Large-scale nickel projects have led to the destruction of thousands of hectares of forest, the displacement of local communities, pollution of rivers and oceans, and significant harm to Indigenous peoples (EJAtlas – Global Atlas of Environmental Justice, 2019). According to Belseran (2022), nickel downstreaming operations are the main cause of Halmahera's deforestation and biodiversity degradation. Approximately 5,331 hectares of tropical forest have been cleared within a nickel mining concession, releasing an estimated 2.04 metric tonnes of greenhouse gases (CO_2e) that the forest previously stored.

Mining exploration has not only taken over natural resources and land that previously supported local livelihoods. In some cases, individuals with legal land ownership documents have had their property seized, whilst Indigenous communities lost their ancestral lands without prior notice. Additionally, some landowners received only partial compensation for their properties (CRI, 2024). Persistent conflicts between Indigenous groups and the government or corporations have arisen due to the government's apparent preference for extractive industries over the protection of customary forests (Ariadi, 2023).

1.4. The Future of Indonesia's Nickel Downstreaming Policy

Indonesia's nickel export ban is a strategic move to strengthen its domestic industry and capitalise on the growing EV market. Whilst downstream processing is intended to add value and drive industrialisation, concerns remain regarding sustainability, economic feasibility, and equitable benefits. The development of high-quality nickel reserves requires advanced technology, whilst environmental and social challenges – such as deforestation, pollution, and community displacement – raise questions about the long-term viability of the sector. Additionally, the ban has triggered international trade disputes, including an EU lawsuit and a WTO complaint, whilst an oversupply of nickel has contributed to falling global prices.

Beyond operational challenges, Indonesia must critically assess nickel's economic value and market conditions. The country's heavy reliance on China as its primary export destination suggests the need for diversified trade partnerships rather than restrictive policies. A reassessment of tax incentives and local content regulations is crucial to determining whether they genuinely enhance competitiveness or merely increase dependency on government support. Conducting a thorough cost-benefit analysis would help policymakers compare the advantages of incentivising smelter development versus allowing direct ore exports.

Furthermore, with EV manufacturers increasingly adopting alternatives such as lithium iron phosphate batteries, Indonesia should explore a broader range of nickel-based applications beyond batteries, including stainless steel, high-tech components, and emerging industrial uses. Environmental concerns also underscore the importance of integrating renewable energy into nickel processing, investing in carbon capture technologies, and promoting sustainable mining practices. Strengthening legal protections for biodiversity, ecosystems, and Indigenous communities is essential to ensuring that nickel industrialisation supports long-term economic growth without compromising environmental and social well-being.

1.5. Sustainable Nickel Mining as the Key

As discussed in the above sections, to enhance the competitiveness of Indonesia's nickel industrialisation, the Government of Indonesia has implemented several strategic initiatives. Key measures include a ban on unprocessed nickel exports and a progressive export tax on low-content nickel products to promote domestic value-added production and downstream investment. To attract investors, the government offers special tax incentives, including a tax holiday and import duty exemptions for capital goods.

Under this set of strategies, since 2018, nickel ores produced in Indonesia have been absorbed domestically to undergo further processing and refining processes supported by foreign investment to become different nickel commodities, especially those related to the production of batteries for EVs. As a result, export values and volumes of those

nickel commodities originating from Indonesia have been considerably increasing.

Whilst the increasing nickel product exports have been contributing positively to national revenues and the building of the EV industry ecosystem in Indonesia, preliminary observations have revealed that some environmental externalities have occurred related to the mining, processing, and refining industries, especially at the local level, and the employment effect has been limited.

This study tries to expand the analysis by focusing on the sustainability of the mining, processing and refining of nickel sulphate hexahydrate ($NiSO_4.6H_2O$), which is the precursor to lithium-ion batteries, taking into consideration the nickel reserves available in Indonesia and the Philippines to meet the demand coming from the growing number of EVs in the Association of Southeast Asian Nations (ASEAN) region. This research also analyses the decarbonisation strategies that can be implemented to improve the carbon footprint of mining, processing, and refining activities and the cost implications of implementing those strategies.

After this first chapter, which presents an introduction to the importance of the issues, the report is organised into the following four chapters.

Chapter 2 provides discussions and descriptions of the nickel deposits in Southeast Asia, specifically in Indonesia and the Philippines, their characteristics, and the required processing technology and applications. The chapter analysis models and simulates the resilience of the nickel reserves of Indonesia and the Philippines to assess the resilience of the supply chain of critical minerals in supporting the manufacturing of clean technologies, namely nickel-based EV batteries, in the ASEAN region.

Chapter 3 estimates the supply of MHP and nickel sulphate hexahydrate derived from limonite in Indonesia and the Philippines for lithium-ion batteries for EVs through to 2040.

Chapter 4 models the supply and demand of nickel sulphate hexahydrate for battery EVs, plug-in hybrid EVs, and hybrid EVs in ASEAN to assess the feasibility of implementing ambitious electrification strategies in the region based on the available nickel resources.

Finally, Chapter 5 discusses the carbon footprint associated with the production of 1 kilogramme of nickel sulphate hexahydrate, the decarbonisation potential, and the cost implications associated with decarbonising nickel sulphate hexahydrate production in Indonesia. The analysis includes the applied life cycle assessment method following ISO 14040/14044 and ISO 14067 standards to assess the product carbon footprint. Three groups of decarbonisation strategies are considered in this study: fuel optimisation, energy profile management, and supply chain (Scope 3 emission) management. Finally, life cycle costing is applied to quantify the potential cost implications associated with the implemented decarbonisation strategies.

Chapter 2
Nickel in ASEAN

2.1. Nickel in Lithium-ion Batteries for Electric Vehicles

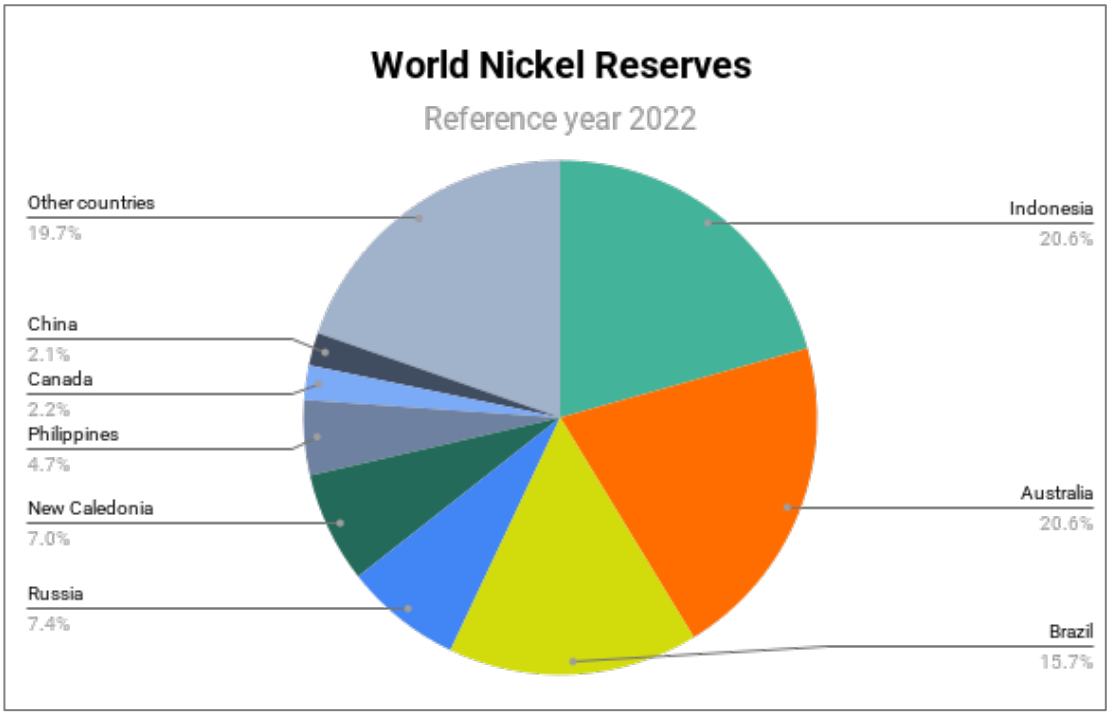
The adoption of electric vehicles (EVs) plays a pivotal role in global decarbonisation efforts. In recent years, there has been a positive, growing trend in the use of EVs worldwide, including in Indonesia and the Association of Southeast Asian Nations (ASEAN) region. A study by Suehiro and Purwanto (2019) estimates that passenger light-duty vehicle cars will double by 2040, with around 32% of the total cars (stock) in Indonesia being EVs (i.e. approximately 20 million units). This highlights the potential EV growth in the biggest country in ASEAN (by population) and the whole region. However, EVs are more mineral-intensive than traditional internal combustion engines. Therefore, unprecedented amounts of critical raw materials will be needed to supplement future demand. The raw materials for lithium-ion batteries (LIBs) for EVs, such as nickel for nickel manganese cobalt (NMC) battery types, are critical amongst other metals. To improve the performance of LIBs, the mass ratio between nickel, manganese, and cobalt has grown from 1:1:1 to 8:1:1 and 9:0.5:0.5, containing up to 80% more nickel in a LIB cell. Therefore, the demand for nickel is projected to rise nearly fourfold, up to 7,000 kilotonnes of nickel equivalent by 2040, to meet the growing need for clean energy technologies, as outlined in the net-zero scenarios by the International Energy Agency (IEA, 2024).

2.2. Nickel Deposits in Southeast Asia

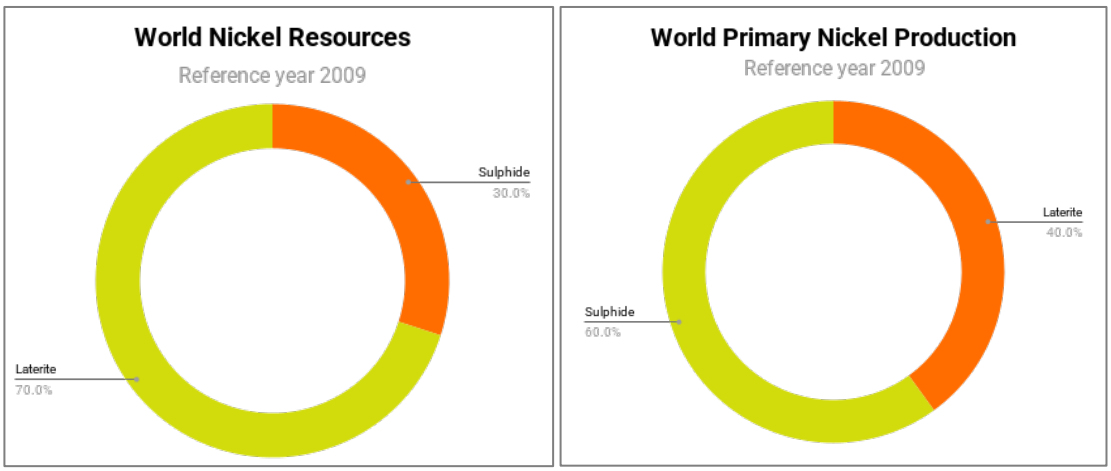
Of the more than 95 million tonnes (Mt) of global nickel reserves in 2022, it is estimated that around 70.3 Mt are located in Indonesia, the Philippines, Australia, Brazil, and Russia (Figure 2.1(a)). Nickel is found in two deposit types: nickel laterites and nickel sulphides. In 2009, despite 70% of the world's nickel reserves being found in laterite deposits, 60% of the world's nickel production came from nickel sulphide ores, as shown in Figure 2.1(b) (Hazarbedia et al., 2023; Crundwell et al., 2011). In early 2010, laterites were mostly used to produce nickel for the steel industry, such as ferronickel, and some laterites were processed into high-grade nickel products. On the contrary, most of the high-grade nickel is produced from sulphide ores via the pyrometallurgy process. However, in 2019, over 50% of the global nickel supply came from laterite resources and the rest from sulphide resources, and Indonesia played an important role in supplying nickel ores globally (Tijsseling et al., 2023).

Figure 2.1. Global Nickel Ore Reserves in 2022 (a) by Nickel Deposit Type and Primary Production, 2010 (b)

(a)



(b)

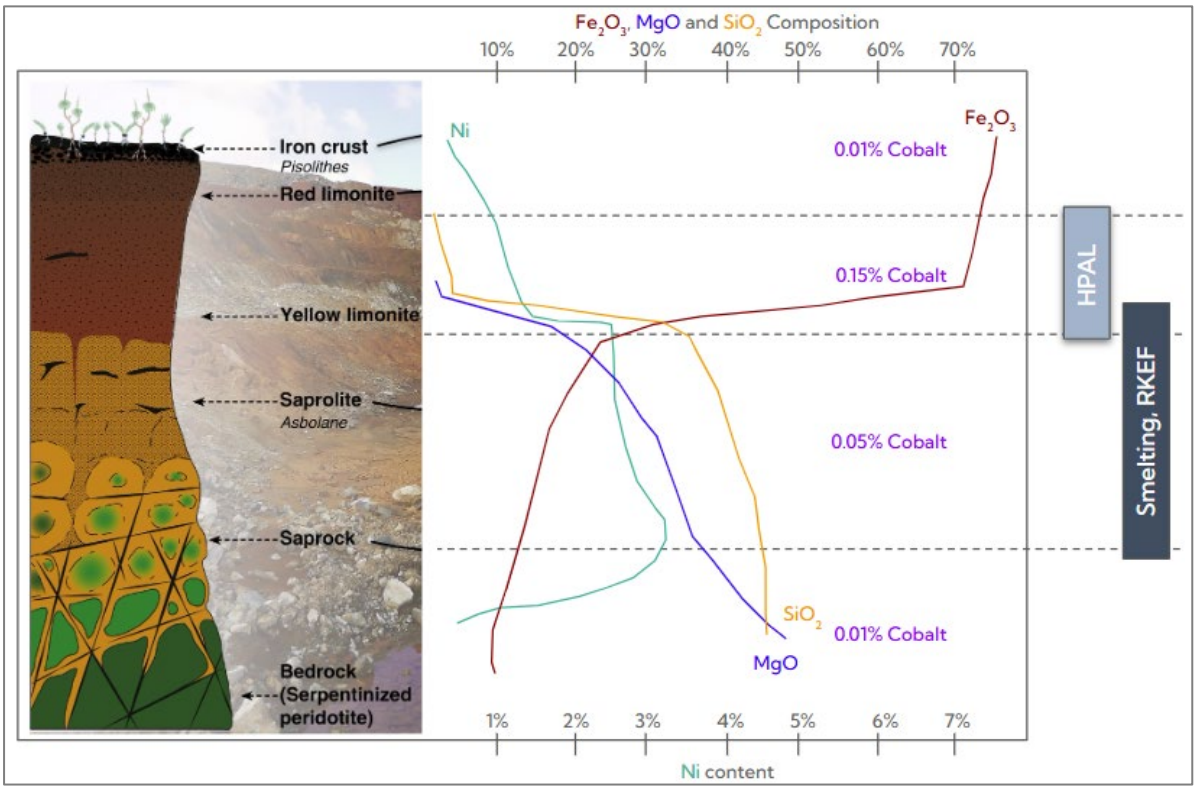


Source: Adapted from Zhang et al. (2025), Hazarbedia et al. (2023), and Nickel Institute (2024a).

Nickel laterite deposits are found in Southeast Asia in Indonesia and the Philippines specifically because of their geographical location. Laterites are found mostly in tropical regions with intense weathering of ultramafic (basement) rocks leading to nickel enrichment in the mid-to-top soil layers. As laterites occur near the surface, they are typically mined by surface-mining methods in Indonesia and the Philippines (Crundwell et al., 2011). Laterite ores are subdivided into limonite and saprolite ores, which are characterised by their chemical composition, such as moisture content and metal content, as illustrated in Figure 2.2. Limonite ores are found closer to the surface and

are characterised by high iron content (40%–70%), low magnesium oxide content (<5%), and low nickel content (<1.5%). On the other hand, saprolite ores are characterised by their low iron content (10%–25%), high magnesium oxide content (15%–35%), and high nickel content (>1.5%). Both limonite and saprolite ores contain a considerable amount of cobalt, which can be recovered and processed with suitable processing technology. The cobalt content in the limonite ore ranges from 0.1%–0.2%, whilst the cobalt content in saprolite ore ranges from 0.02%–0.1%. The gangue metals, such as iron, magnesium, and silica, are generally considered penalty metals, and their concentrations determine the processing technologies (Crundwell et al., 2011).

Figure 2.2. Nickel Laterite Vertical Profile, Including the Associated Metal Content and Suitable Processing Technologies (High-pressure Acid Leaching and Rotary-kiln Electric Furnace)



HPAL = high-pressure acid leaching, RKEF = rotary-kiln electric furnace.
Source: Adapted from Crundwell et al. (2011).

2.3. Nickel Laterite Reserves and Resources in Indonesia and the Philippines

Indonesia holds over 20% of global nickel ore reserves,[1] whilst the Philippines accounts for over 4% of global nickel ore reserves (Nickel Institute, 2024a; Wahyono et al., 2024). However, since 2017, Indonesia has been the largest nickel ore producer, contributing

[1] Reserves are defined as the economically mineable part of measured and/or indicated mineral resources, according to the Joint Ore Reserves Committee (JORC).

approximately 50% to global nickel production. The nickel deposits and operational mines in Indonesia are mainly found in South and Central Sulawesi, North Maluku, and West Papua provinces (Figure 2.3), whilst nickel reserves in the Philippines are mainly located in the southern part of the country, e.g. in the Caraga region (Figure 2.4) (Nickel Institute, 2024a; Kementerian ESDM, 2020; Philippine Statistics Authority, 2020).

According to data from Asosiasi Penambang Nikel Indonesia (APNI) and the Ministry of Energy and Mineral Resources of Indonesia (Kementerian ESDM), total nickel reserves in Indonesia are estimated to be approximately 5.2 billion tonnes, of which 30% are limonites and 70% are saprolite ores. In the Philippines, according to the Philippine Statistics Authority (PSA), total nickel reserves are estimated to be approximately 0.5 billion tonnes. However, the PSA does not provide further information on the split between limonite and saprolite ores (APNI, 2024; Kementerian ESDM, 2020; Philippine Statistics Authority, 2020). In this respect, the 30:70 split between Indonesian limonite and saprolite ores is applied to the 0.5 billion tonnes of nickel reserves in the Philippines in this study.

Furthermore, both Indonesia and the Philippines still have enormous nickel resources.[2] It is estimated that Indonesia has 9.8 billion tonnes of limonite ores and 7.5 billion tonnes of saprolite ores. The PSA reports total nickel resources in the Philippines of 1.9 billion tonnes (with no breakdown of the potential laterite and saprolite resources).

Figure 2.3. Simplified Heat Map of Nickel Reserves in Indonesia



Source: Adapted from Kementerian ESDM (2020) and APNI (2024).

[2] Resources are defined as the concentration or occurrence of metals of economic interest in or on the Earth's crust, according to the Joint Ore Reserves Committee (JORC).

Figure 2.4. Simplified Heat Map of Nickel Reserves in the Philippines



Source: Adapted from S&P Global (2023).

2.4. Nickel Laterite Processing Technologies and Applications

The mineralogical characteristics of the nickel ore determine the economic and processing route for limonite and saprolite ores. Limonite ores are usually processed via the hydrometallurgy process (i.e. high-pressure acid leaching (HPAL)), whilst saprolite ores are usually processed via the pyrometallurgy process (i.e. rotary-kiln electric furnace (RKEF)).

Saprolite ore has high nickel content as well as magnesium and silica (Figure 2.2), making hydrometallurgical technology costly because of the chemical consumption used to remove the gangue minerals (e.g. magnesium and silica). In this respect, pyrometallurgy has advantages, such as shorter process flows and simpler operation, to produce nickel-iron alloy. Moreover, the iron content determines the selection of the processing technology. The iron content of saprolite ore is about 15%, much lower than limonite ore (Figure 2.2). The choice of pyrometallurgy for saprolite ore processing ensures that the nickel-iron alloy product is not excessively diluted by iron (Crundwell et al., 2011; Zhang et al., 2025).

Hydrometallurgy technology is used primarily to produce higher-purity end products (e.g. nickel sulphate hexahydrate) from laterite ores with relatively fewer gangue minerals (e.g. limonite), whereas pyrometallurgy is used primarily to obtain nickel-iron alloy (Crundwell et al., 2011). Limonite ore is characterised by low nickel content as well as magnesium and silica. The main impurities are iron and aluminium, which can be economically removed through chemical treatment, such as hydrometallurgy. Furthermore, a higher purity of nickel products can be achieved through hydrometallurgical treatment, making HPAL more suitable for limonite-to-$NiSO_4.6H_2O$ production (Crundwell et al., 2011; Zhang et al., 2025).

Generally, nickel ores can be refined into nickel products, which are categorised into Class I (nominally pure nickel metal, with >99% nickel content) and Class II (nickel content <99%), with a number of intermediates used in different process routes (Crundwell et al., 2011; Tijsseling et al., 2023).

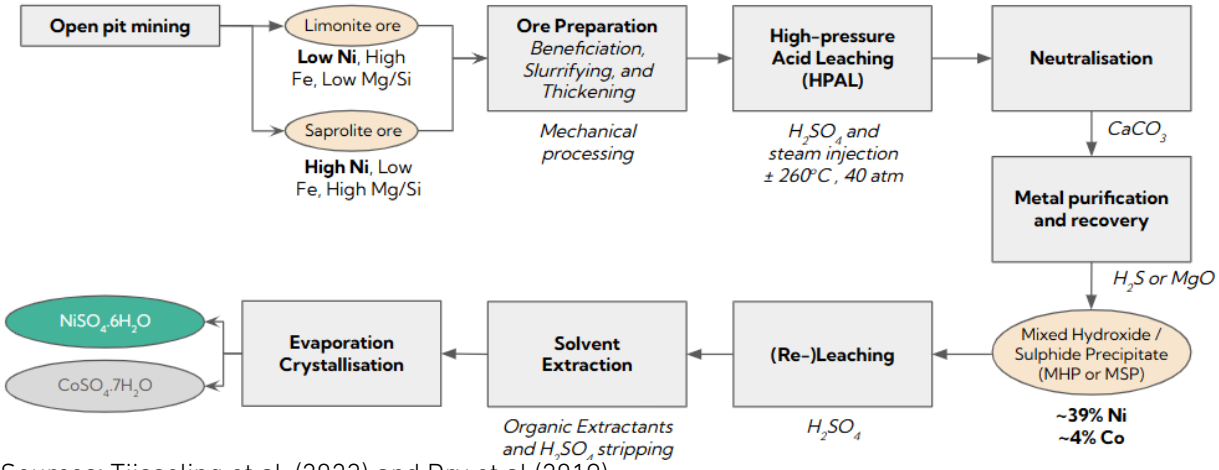
Nickel sulphate hexahydrate ($NiSO_4.6H_2O$) is the precursor to lithium-ion batteries (LIBs), which are used in EVs, and can be produced by processing limonite ore using HPAL technology, producing an intermediate product of mixed hydroxide precipitate (MHP) or mixed sulphide precipitate (MSP). These intermediate products are then refined to separate the nickel and cobalt and processed into $NiSO_4.6H_2O$ as the final product. Although HPAL technology is used mainly to process limonite ore, a small quantity of saprolite ore can be added to reduce the lime consumption in the neutralisation step (Gultom and Sianipar, 2020).

The simplified HPAL process flow diagram is presented in Figure 2.5, which is based mainly on the leaching of limonite ore with high iron and low magnesium content under high temperature with sulphuric acid. The leaching step dissolves nickel and cobalt, leaving behind a residue of iron (as hematite) and aluminium oxides. The leachate is then neutralised to remove the iron and aluminium residue (Crundwell et al., 2011; McDonald and Whittington, 2008). The nickel and cobalt in the solution are precipitated into MHP or MSP by setting the pH to 7–8. In this step, hydrogen sulphide gas, sodium hydroxide, and/or magnesium oxide are added to produce MHP or MSP as intermediate products with approximately 40-55% nickel and 4-5% cobalt. The nickel and cobalt from the intermediate product can be recovered into battery-grade $NiSO_4.6H_2O$ and $CoSO_4.7H_2O$ by leaching the MHP with sulphuric acid followed by a series of metal extraction techniques (i.e. solvent extraction) to separate impurities, nickel, and cobalt from the other metal impurities. The final step is evaporation-crystallisation, in which battery-grade $NiSO_4.6H_2O$ is produced from the intermediate product of MHP (Dry et al., 2019; Zhang et al., 2025; Gultom and Sianipar, 2020; Crundwell et al., 2021).

As shown by Tijsseling et al (2023), $NiSO_4.6H_2O$ can also be produced by converting and refining nickel pig iron (NPI), a product derived from saprolite ore processing via RKEF. However, as demand for NPI for stainless steel applications is expected to increase and NPI conversion and refinement into $NiSO_4.6H_2O$ have not yet taken place in Indonesia,

this processing route is excluded from this study. The Philippines' NPI market condition is expected to be similar to the Indonesian market, and it is excluded from this study.

Figure 2.5. Simplified Process Flow Diagram of High-pressure Acid Leaching and Metal Refining to Produce Nickel Sulphate Hexahydrate



Sources: Tijsseling et al. (2023) and Dry et al (2019).

2.5. Reserve Resilience of Limonite Ores in Indonesia and the Philippines

Energy transition and decarbonisation efforts globally require significant quantities of metals and minerals, including those sourced from Indonesia, the Philippines, and other countries in the ASEAN region. According to the International Energy Agency (IEA, 2024), nickel demand is expected to double by 2030 and increase 2.5 times by 2040 compared to 2023 levels to meet the ambition of replacing conventional internal combustion engine cars with EVs. In this respect, mineral extraction and processing of nickel in Indonesia and the Philippines will play a pivotal role in achieving energy transition goals.

A summary of limonite ore reserves and resources in Indonesia and the Philippines, as well as the HPAL processing capacity in Indonesia and The Philippines, is summarised in Table 2.1. As of mid-2024, five HPAL processing facilities in Indonesia are reported to have a total annual processing capacity of 48 million tonnes of nickel ores. An additional three HPAL processing facilities are under construction, which could add another 33 million tonnes of nickel ore processing capacity annually. Furthermore, up to 19 HPAL processing facilities are planned to be constructed in the future, with a total additional capacity estimated at 68 million tonnes of nickel ores annually once in operation. The reported two HPAL processing capacity in the Philippines is estimated to be approx. 7 million tonnes nickel ores annually. The intermediate product produced from the HPAL facilities are MSP, different to the intermediate products MHP produced in Indonesia HPAL facilities (Kementerian ESDM, 2020; APNI, 2024; Sumitomo Metal Mining, 2022; Rio Tuba Nickel Mining Corporation, n.a.). Furthermore, the increase in nickel ore exports

from the Philippines to Indonesia also occurs as smelters face competition to secure domestic nickel ore feedstock in Indonesia (Liu and Nguyen, 2023; Gibbs, 2024; Karyza, 2025). Due to the global or regional nickel market dynamics, closer attention should be made to the ASEAN nickel ore trading activities to improve nickel supply and demand modelling, analysis, and interpretation.

In this study, the resilience of the nickel reserves of Indonesia and the Philippines is modelled and simulated to assess the resilience of the supply chain of critical minerals (i.e. nickel in this case) to support the manufacturing of clean technologies (i.e. LIB for EVs) in the ASEAN region. A summary of limonite ore reserves and resources in Indonesia and the Philippines is provided in Table 2.1. Figure 2.6 illustrates the depletion rate of the limonite ore nickel reserves in Indonesia and the Philippines, considering three potential scenarios: Indonesian and The Philippines HPAL is in operation, under construction, and planned (as summarised in Table 2.2). From Figure 2.6, without new additional reserves, it can be observed that the nickel supply from limonite ore reserves in Indonesia and the Philippines is projected to be depleted after 30 years in 2054 if only the existing seven HPAL facilities remain in operation. The depletion rate will accelerate as more HPAL facilities are built in the future.

However, if the three 'under construction' HPAL facilities in Indonesia become operational by 2027 (i.e. a total of ten HPAL facilities with over 87 million tonnes of nickel ore processing capacity annually from 2027 onwards), it is estimated that the nickel supply from limonite ore will be depleted by 2044. Finally, in the most ambitious scenario, assuming that all 19 of the 'planned to be constructed' HPAL facilities are operational by 2031 (i.e. a total of 29 HPAL facilities with over 150 million tonnes of processing capacity annually from 2031 onwards), it is estimated that the nickel supply from limonite ore depletion could occur by 2038, just 13 years from now.

It is important to note that Indonesia and the Philippines have over 9 billion tonnes and 1 billion tonnes of limonite ore resources, respectively, which could potentially be explored and exploited (Table 2.1) and converted into mineable reserves in the future. Additionally, Indonesia applies policies to ban nickel ore exports and cap their ore supply, known as mining quotas (RKAB), to develop the downstream nickel supply chain and maintain a balance between the supply and demand of nickel ores from Indonesia (Reuters, 2024). Similarly, the authority in the Philippines is also planning to apply a nickel ore export ban, which would influence the nickel supply and demand in the region (Karyza, 2025). These two factors (i.e. resources and domestic policies) could still affect the resilience of the limonite ore reserves in the region, which could prolong or shorten the lifetime of nickel supply from these regions, as shown and illustrated in Figure 2.6. The future of nickel supply and the lifetime of limonite ore mining in Indonesia and the Philippines remain critical considerations to ensure a sustainable feedstock supply to the smelters and raw material availability for final applications (e.g. for LIBs).

Table 2.1. Total Estimated Limonite Ore Reserves and Resources in Indonesia and the Philippines. Source: APNI, 2024; Kementerian ESDM, 2020; Philippine Statistics Authority, 2020

Description	Data
Estimate of limonite ore reserves in Indonesia and the Philippines	Approximately 1,700 million tonnes (approx. 78% probable and 22% proven reserves)
Estimate of limonite ore resources in Indonesia and the Philippines	Approximately 10,950 million tonnes (no probable/proven reserves data are provided)

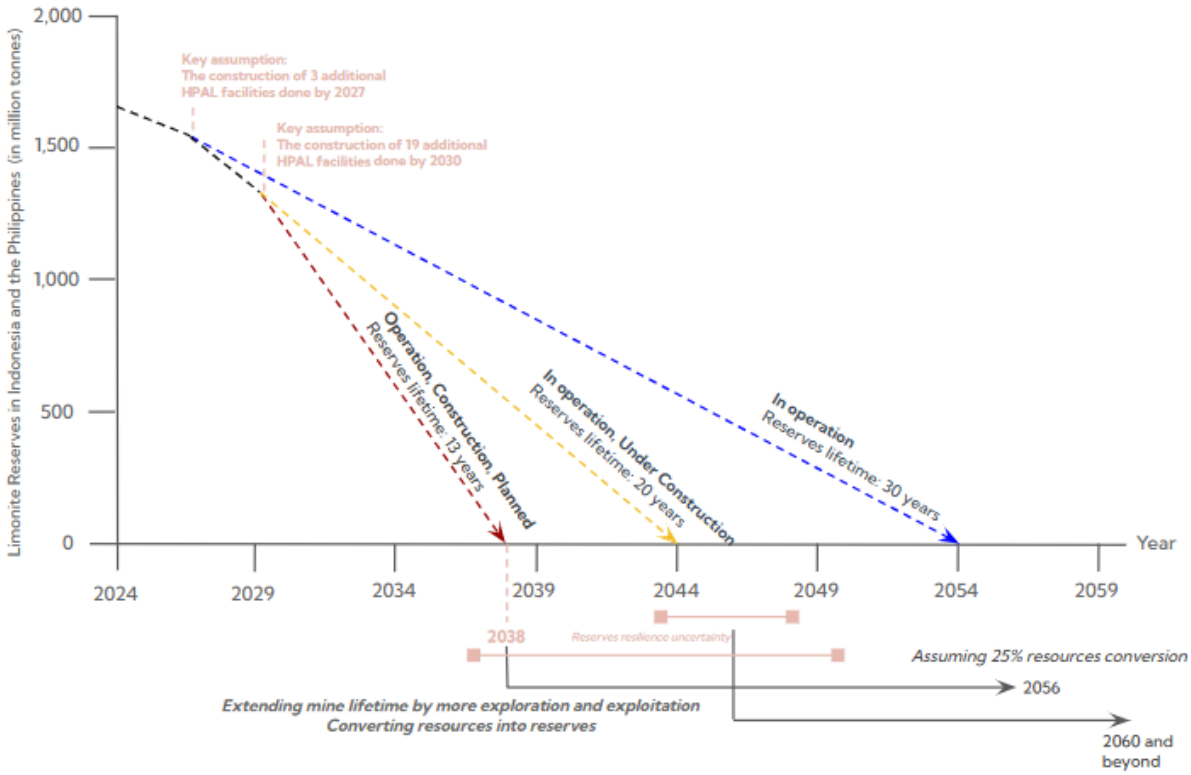
Table 2.2. HPAL Processing Capacity in Indonesia: In Operation, Under Construction, and Planned (as of Mid-2024 Data), Located in South/Central Sulawesi, North Maluku, and North Papua Provinces. HPAL Processing Capacity in the Philippines: In Operation

HPAL Processing Capacity	
In operation	5 facilities, 48 million wet metric tonnes annually (Indonesia) 2 facilities, approx. 7 million wet metric tonnes annually (The Philippines)
Under construction	3 facilities, 33 million wet metric tonnes annually
Planned to be constructed	19 facilities, 68 million wet metric tonnes annually

Note: The annual processing capacity is the reported annual nickel ore consumption for the existing and future facilities, which is considered in the reserve resilience and depletion rate model (APNI, 2024).

Sources: Kementerian ESDM (2020); APNI (2024); Sumitomo Metal Mining (2022); Rio Tuba Nickel Mining Corporation (n.a.).

Figure 2.6. Reserve Resilience and Depletion Rate of Limonite Ores in Indonesia and the Philippines, Based on Minviro Modelling Simulation Under Three HPAL Processing Scenarios



Source: Authors' analysis.

Chapter 3

Nickel Supply for Lithium-ion Battery Electric Vehicles in ASEAN

In Chapter 2, three scenarios of high-pressure acid leaching (HPAL) processing facilities were presented based on data available in mid-2024. The chapter also elaborated on the process flow diagram of limonite ore processing via HPAL, in which intermediate products such as mixed hydroxide precipitate (MHP) are produced after the leaching and neutralisation steps. The MHP can thus be refined into $NiSO_4.6H_2O$ following a series of solvent extraction processes (see Chapter 2, Figure 2.4).

This chapter estimates the potential MHP and $NiSO_4.6H_2O$ supply for lithium-ion batteries (LIBs) used in electric vehicles (EVs), including full-battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs). The modelling is based on Minviro's LIB for EV internal databases, including the pCAM, CAM, and LIB manufacturing production datasets.[3]

3.1. Nickel Sulphate Hexahydrate Supply from Limonite in Indonesia and the Philippines

The limonite ore reserves and HPAL processing into MHP, followed by refining processes, are translated into the estimated MHP and $NiSO_4.6H_2O$ production under three scenarios (i.e. annual HPAL processing capacity; Table 2.1 in Chapter 2), as shown in Figure 3.1. For simplicity, this study considers a constant yield of 5% from limonite ore to MHP and approximately 3% from limonite ore to $NiSO_4.6H_2O$ based on Minviro's database. It is important to note that yields can vary depending on ore grades; this study assumes grades of 1.3% nickel and 0.12% cobalt. Moreover, HPAL processes limonite ore (mixed with a small quantity of saprolite ore, as shown in Figure 2.5) to produce the intermediate product (i.e. MHP).

At the time of writing this report, there were no data available on refining capacity in Indonesia (i.e. processing MHP into $NiSO_4.6H_2O$). In practice, MHP is often traded on the global market and shipped to other countries for refining (e.g. MHP production in Indonesia and refining in China). According to the UN Comtrade database, approximately 92,5000 tonnes of MHP and 66,500 tonnes of $NiSO_4.6H_2O$ were exported from Indonesia

[3] As a sustainability solutions provider, Minviro Ltd.'s Research & Development (R&D) department generates high-quality life cycle inventory data across the supply chains of different energy transition technologies, including the upstream (mining), midstream (pCAM and CAM), and downstream (battery manufacturing) lithium-ion battery supply chain.

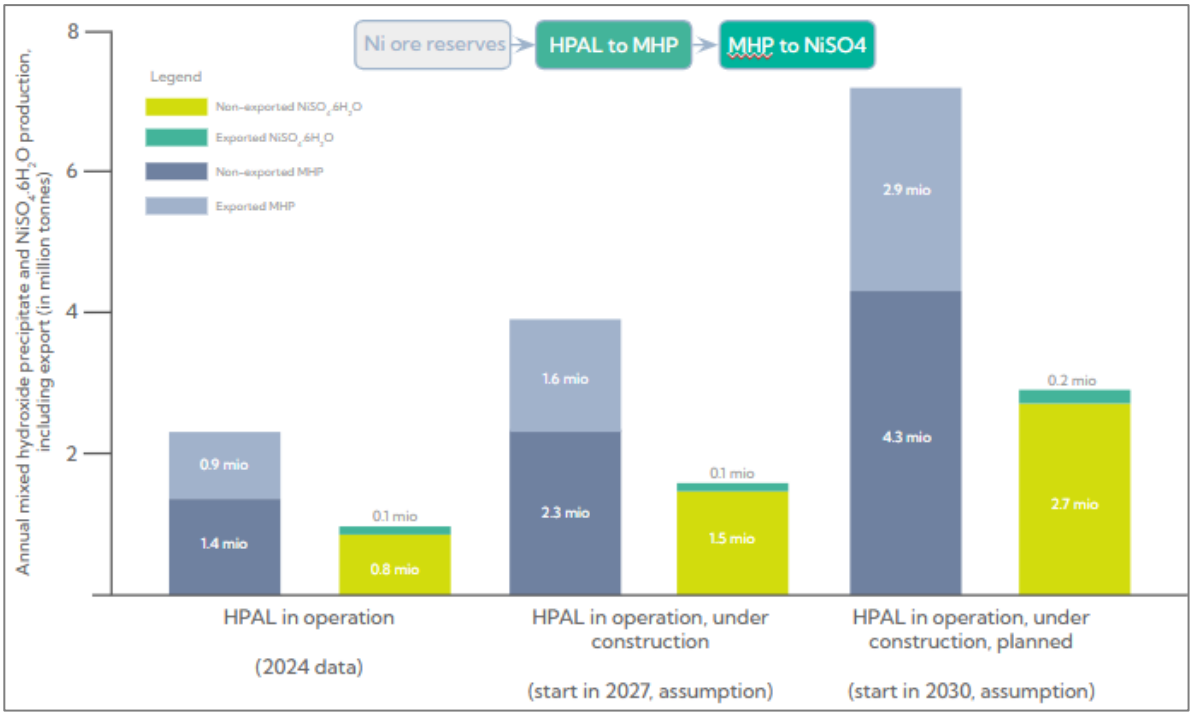
globally in 2023 (United Nations, 2025). These export activities are considered in this study to calculate the net supply of MHP and $NiSO_4.6H_2O$ for meeting ASEAN's EV targets. Furthermore, the impact of ore grade and MHP-to-$NiSO_4.6H_2O$ refining in Indonesia is subjected to future investigation to evaluate a more accurate estimation of $NiSO_4.6H_2O$ supply from and for Southeast Asia.

Figure 3.1 summarises the total potential MHP and $NiSO_4.6H_2O$ production under three HPAL processing scenarios. It is assumed that 90% of the $NiSO_4.6H_2O$ is used for EV applications, and the remaining 10% is used for other applications (Fraser et al., 2021).

- In the first scenario, as of mid-2024, five Indonesia HPAL facilities in operation could produce up to 2.3 million tonnes of MHP. Assuming 0.9 million tonnes of MHP exports (2023 data; United Nations, 2025), approx. 1.4 million tonnes of MHP (i.e. 60% of the total MHP production annually) is available for refining in Indonesia. The estimated $NiSO_4.6H_2O$ production from the available 1.4 million tonnes of MHP is estimated to be 0.9 million tonnes. Assuming approximately 0.1 million tonnes of $NiSO_4.6H_2O$ exports (2023 data; United Nations, 2025), approximately 0.8 million tonnes of $NiSO_4.6H_2O$ (i.e. 90% of the total $NiSO_4.6H_2O$ production annually) could be used for new LIB manufacturing in ASEAN.
- In the second scenario, which includes an additional three Indonesia HPAL facilities under construction with a total capacity that could reach over 80 million tonnes of limonite ore per annum, it is estimated that MHP production could rise up to 3.9 million tonnes annually. Assuming the same export rate of MHP as in the previous scenario (i.e. assuming 40% MHP exports), 2.3 million tonnes of MHP could be available for the production of $NiSO_4.6H_2O$ in ASEAN. The estimated $NiSO_4.6H_2O$ production from the available MHP is 1.6 million tonnes annually, of which 0.1 million tonnes could be exported (i.e. assuming 7% $NiSO_4.6H_2O$ exports).
- In the third scenario, assuming the construction of all 19 planned Indonesia HPAL facilities (a total of 27 facilities in operation with over 140 million tonnes of limonite ore processing capacity annually), MHP production could reach 7.2 million tonnes. Assuming the same export rate of MHP as in the previous scenario (i.e. assuming 40% MHP exports), 4.3 million tonnes of MHP could be available for the production of $NiSO_4.6H_2O$ in ASEAN. The estimated NiSO4.6H2O production from the available MHP is 2.9 million tonnes annually, of which 0.2 million tonnes could be exported (i.e. assuming 7% $NiSO4.6H_2O$ exports).

However, there are uncertainties around the potential MHP and $NiSO_4.6H_2O$ production and export activities in the future, which could be affected, amongst others, by factors such as domestic policies (e.g. mining quotas), ore grade, and business ecosystem and commitment to building more HPAL processing capacities (e.g. foreign direct investment) in Indonesia. These uncertainties, alongside the potential for additional resources and reserves, are elaborated in Chapter 2.

Figure 3.1. Estimated MHP and $NiSO_4.6H_2O$ Production from Estimated Limonite Ore Reserves and HPAL Facilities (Data for Mid-2024)



HPAL = high-pressure acid leaching, MHP = mixed hydroxide precipitate, $NiSO_4.6H_2O$ = nickel sulphate hexahydrate.
Source: Authors' analysis.

3.2. Nickel Sulphate Hexahydrate for Electric Vehicle Lithium-ion Batteries in 2040

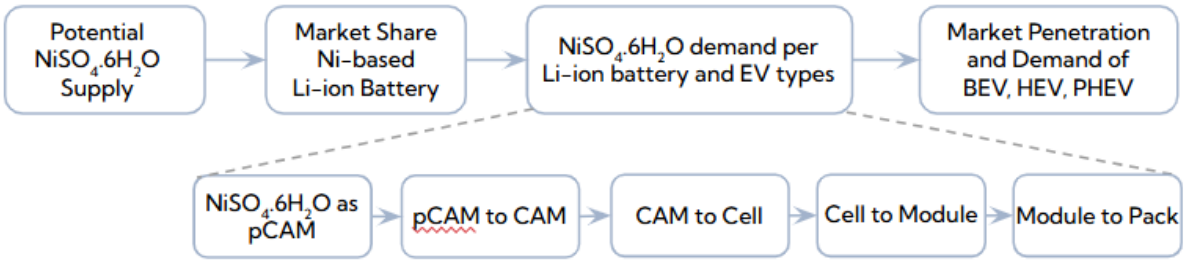
The next modelling step is to calculate and estimate the potential LIBs that could be produced from the available potential $NiSO_4.6H_2O$. This modelling focuses on meeting the projected EV demand in ASEAN by 2040 and sustainability goals for electrifying the transport sector.

For this purpose, the following key modelling parameters are required and obtained from Minviro's and ERIA's internal databases, as summarised in Table 3.1. Furthermore, Figure 3.2 summarises the modelling process applied in this study, which considers factors such as the market share of nickel-based LIBs for EVs, the $NiSO_4 \cdot 6H_2O$ demand for various LIB chemistries (e.g. nickel cobalt aluminium (NCA), nickel manganese cobalt (NMC) 622, etc.) and EV types, and EV market penetration in ASEAN.

Table 3.1. Key Modelling Parameters to Quantify Potential Lithium-ion Batteries for Electric Vehicles Based on Potential $NiSO_4.6H_2O$ Production

Modelling Parameters	Source
Market share of nickel-based LIBs for EVs	Minviro internal database
$NiSO_4.6H_2O$ demand for various LIBs (i.e. NCA, NMC 111, NMC 622M, etc) and EV types (BEV, HEV, PHEV)	Minviro internal database
EV sales in ASEAN	ERIA internal database

Figure 3.2. Conceptual Framework and Modelling Approach to Estimate Potential Li-ion Battery Production Based on Available Potential $NiSO_4.6H_2O$ Production from the Processing of Limonite Ore in Indonesia and the Philippines



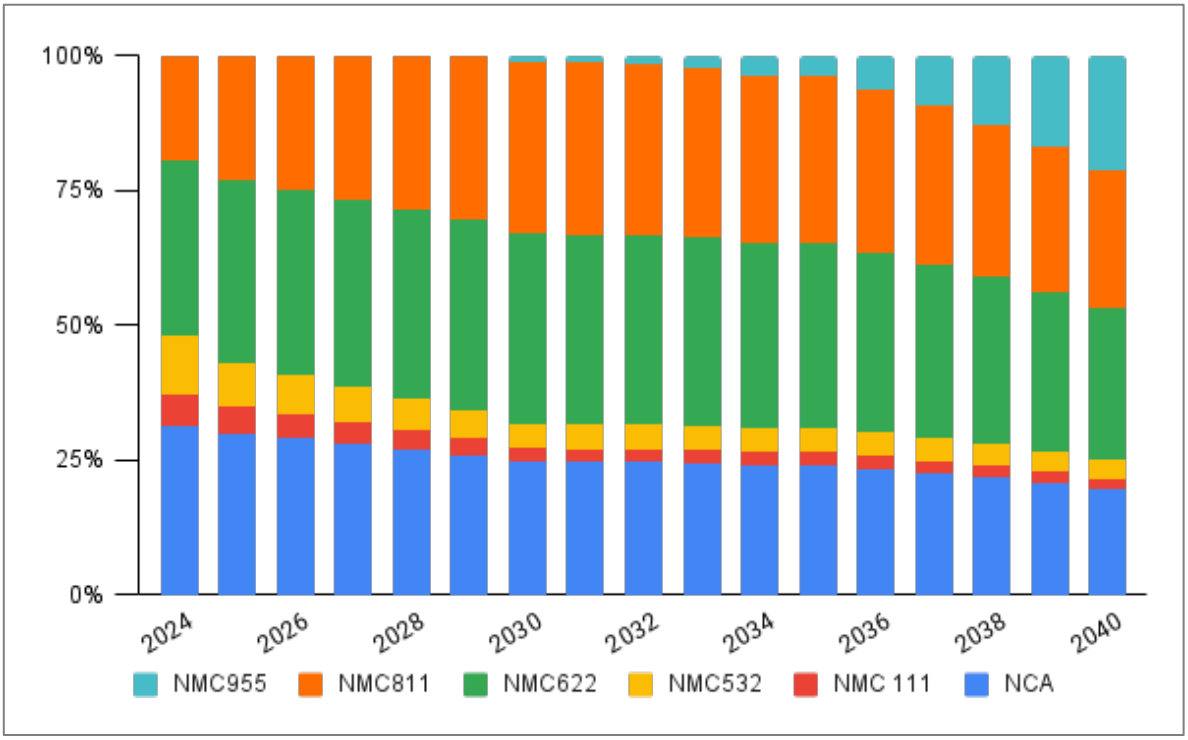
BEV = battery electric vehicle, CAM = cathode active material, EV = electric vehicle, HEV hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle, pCAM = precursor cathode active material.
Source: Pell et al. (2023).

The first modelling step is to understand the potential market share of various nickel-based LIBs in the future; as the demand for EVs grows, LIB chemistries and technologies evolve too. Whilst LIBs such as NCA and NMC 622 still dominate the LIB market, several next-generation LIB technologies, such as NMC 955, are under development and might enter the market in the future. For instance, NMC 955 is expected to boost the energy density of its battery cells and allow a greater range of travel for consumers (Nickel Institute, 2024b). Therefore, the future market penetration and evolution of LIBs for EVs should be modelled and considered.

In this study, the projected market share of various nickel-based LIBs for EVs is obtained from the Minviro database and shown in Figure 3.3. The projection reflects the global market share of LIBs from current major battery roadmaps in the United States, Europe, and China. The domination of nickel-based chemistries is likely to continue in the coming decades, as are anode materials, as reflected in the commercial activities of LIB producers (Xu et al., 2020; Avicenne Energy, 2019). Whilst data are available, this study excludes the market share of other next-generation batteries, such as sodium-ion, solid-state, and lithium iron phosphate, because the study focuses on understanding the nickel

supply and demand of LIBs for EVs in ASEAN. The complete LIB market share projection, including lithium iron phosphate and other next-generation batteries, can be found in Alacacayir et al. (2024). From Figure 3.3, it can be observed that NMC 955 is expected to account for more than 15% of the LIB market share, whilst NCA's market share is expected to decrease by just under 20% in 2040.

Figure 3.3. Projection of Market Shares of Different Nickel-based Lithium-ion Batteries for Electric Vehicles in Southeast Asia Based on the Minviro Internal Database



Source: Alacacayir et al. (2024).

Once the market share of different LIB chemistries has been modelled and projected, the next modelling step is to quantify the demand for $NiSO_4.6H_2O$ (in kg) per unit of LIB pack for EVs, as depicted in Figure 3.2. In this study, the LIB battery cell is assumed to be a prismatic type as it dominates the market, with an approximate 40% market share (Corfas, 2024). The battery power and storage considered for BEVs, PHEVs, and HEVs are 70 kWh, 15 kWh, and 32 kW, respectively, for EV models for 2015–2021. The generic specific power/energy of the BEV, HEV, and PHEV (50 km all-electric range) passenger light-duty vehicle cars considered in this study is provided in Table 3.2, and is used to estimate the total weight of the LIB pack. It is assumed that one LIB pack consists of 20 battery modules, each containing 20 battery cells. More information regarding the LIB characteristics and properties, such as the cell mass for NCA and various different NMC types, the precursor demand for making the CAM (i.e. pCAM), CAM demand per cell, and the share and weight of nickel content in CAM, are provided and sourced from the Minviro

internal database. Considering the pCAM, CAM, battery cells, and battery modules requirements to make one LIB pack of NCA and NMCs, the demand for $NiSO_4.6H_2O$ per unit of LIB pack is estimated and summarised in Figure 3.4.

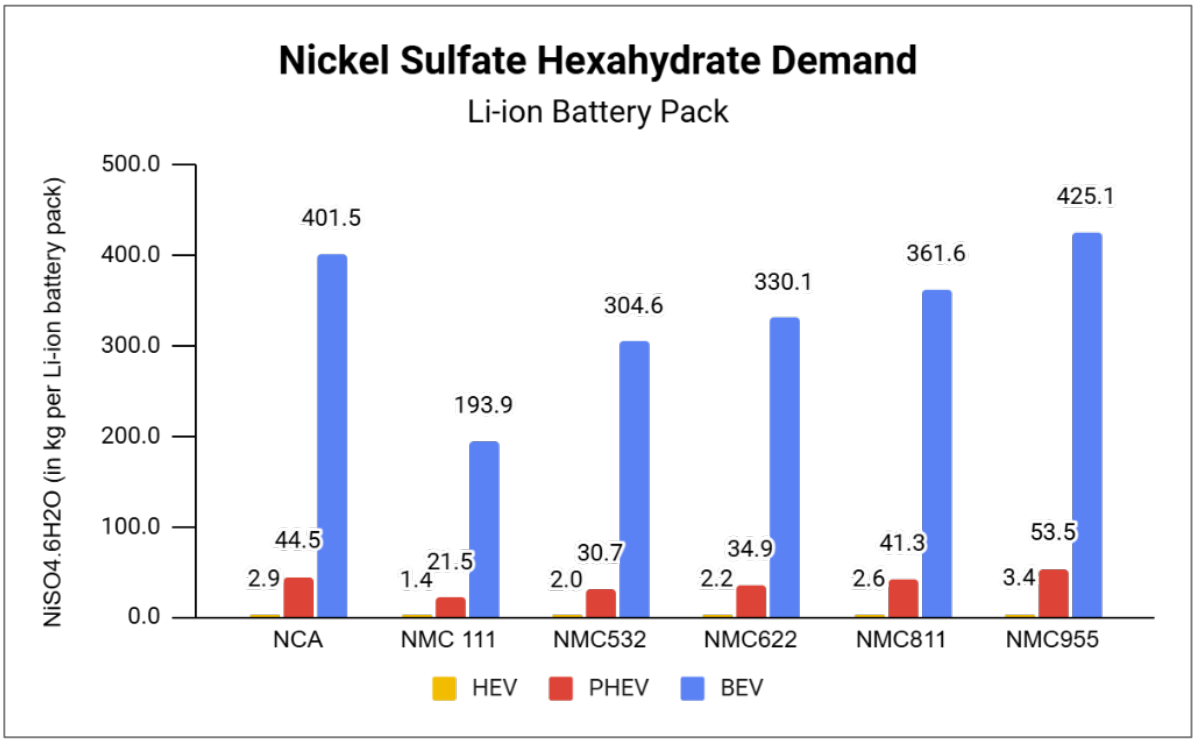
It can be observed that the $NiSO_4.6H_2O$ demand for making 1 unit of BEV LIB pack across different chemistries is up to 9 times higher than that for a PHEV LIB pack. Similarly, the $NiSO_4.6H_2O$ demand for making 1 unit of PHEV LIB pack across different chemistries is up to 15 times higher than the demand for HEV LIB packs. This variation highlights the substantial nickel intensity required for BEVs compared to other EV types.

Table 3.2. Specific Power and Energy of the Battery Electric Vehicles, Hybrid Electric Vehicles, and Plug-in Hybrid Electric Vehicles Considered in This Study

	NCA	NMC 111	NMC 532	NMC 622	NMC 811	NMC 955
PHEV (Wh/kg)	185	171	178	179	189	195
HEV (W/kg)	2,434	2,379	2,419	2,421	2,484	2,527
BEV (Wh/kg)	263	225	236	252	260	297

BEV = battery electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Minviro database.

Figure 3.4. Nickel Sulphate Hexahydrate Demand per Unit of Lithium-ion Battery Pack for Battery Electric Vehicles, Hybrid Electric Vehicles, and Plug-in Hybrid Electric Vehicles



BEV = battery electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Authors' analysis.

Chapter 4

Nickel Supply and Demand for Battery Electric Vehicles, Hybrid Electric Vehicles, and Plug-in Hybrid Electric Vehicles in ASEAN

This chapter models the supply and demand of nickel sulphate hexahydrate ($NiSO_4.6H_2O$) for battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs) in ASEAN. The purpose of the simulation is to assess the feasibility of implementing ambitious electrification strategies in the region based on the available nickel resources. As highlighted in the previous chapter, the data for $NiSO_4.6H_2O$ supply from mining-to-refining is collated from the Minviro internal database, whilst the data for electric vehicle (EV) penetration (sales) for 2040 are collated from the ERIA internal database. The modelling approach is also summarised and presented in Figure 3.2.

4.1. Projected Electric Vehicle Demand in Southeast Asia by 2040

There are a few potential future scenarios regarding EV penetration in the Southeast Asia region. A previous study by ERIA simulated three potential EV penetration scenarios: Reference ('business as usual' (BAU)), HEV Bridge, and BEV Ambitious scenarios. In the BAU scenario, EV penetration is expected to be slow, with EVs making up around 20% of the passenger light-duty vehicle market by 2040. In the HEV Bridge scenario, the EV market share is expected to reach up to 60% of the market share by 2040, with the HEV type dominating the market. Finally, in the BEV ambition scenario, it is projected that EVs will dominate the passenger light-duty vehicle market by 2040 (accounting for up to 90% of the market), with BEVs taking the largest market share (Suehiro and Purwanto, 2019). The scenarios have been elaborated with the exogenous sale share percentage of each of the vehicle propulsion technologies to represent a situation where EV penetration is slow, as no policy measure intervention is made to accelerate EV penetration (BAU); where EV penetration is stronger, driven first by HEVs and then by BEVs; and where EV penetration is the strongest, boosted by BEV sales. The main objective of these three simplified scenarios is to illustrate the potential impacts on the energy system and emissions under three different profiles of energy use in the four-wheeled road transport mode (cars).

In this study, the projected EV demand in the HEV Bridge and BEV Ambitious scenarios is provided in Figure 4.1. Additionally, the EV and LIB lifespans are assumed to be 15 years and 8 years, respectively (Xu et al., 2020). This implies that the lithium-ion battery (LIB) needs to be replaced throughout an EV's life. The projected number of EV sales is expected to increase gradually from around approximately 725,000 units in 2025 to

approximately 2 million units by 2040 in the HEV Bridge scenario. In the same scenario, the demand for EV battery replacement is also expected to increase from approximately 32,000 units in 2025 to 1.3 million units by 2040. In the BEV Ambitious scenario, the share of BEV cars is expected to grow faster from 2037 onwards, with total EV demand expected to reach 3.5 million units by 2040. In both the HEV Bridge and BEV Ambitious scenarios, it is expected that HEV cars will dominate the market in the earlier years of EV adoption (i.e. 2025–2035), whilst the sales of BEV units are expected to increase by 2040. In the BEV Ambitious scenario, the market share of BEV sales is expected to reach 78% by 2040. Meanwhile, in the HEV Bridge scenario, the market share of BEV sales is only expected to reach 62% in the ASEAN region by 2040 (Figure 4.1).

Figure 4.1. Projected EV Sales and Battery Replacement in ASEAN by Vehicle Type in the HEV Bridge and BEV Ambitious Scenarios

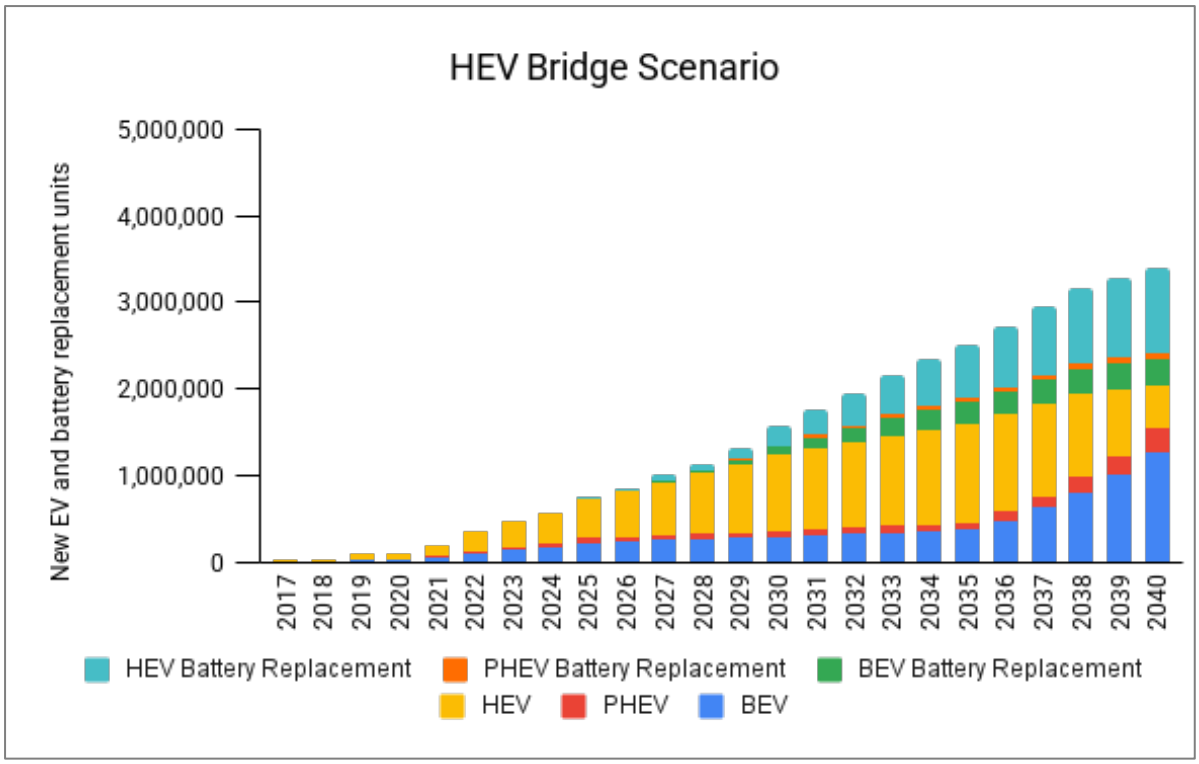
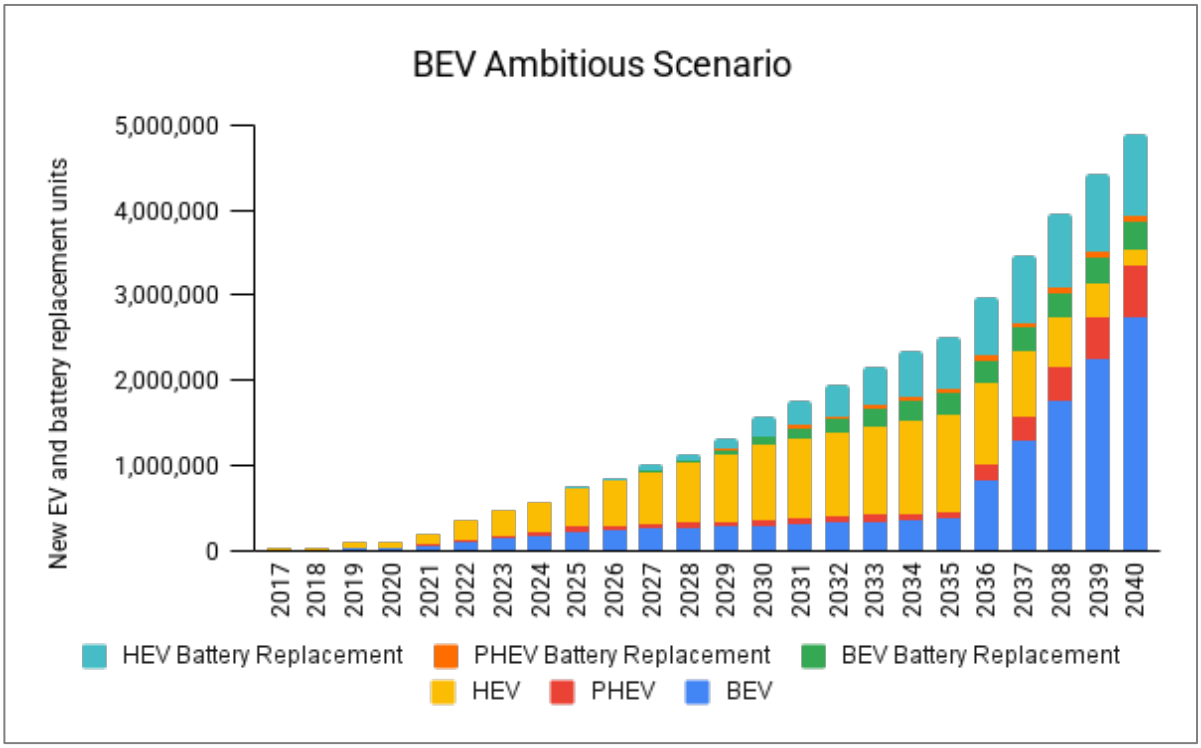


Figure 4.1. *Continued*



BEV = battery electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Suehiro and Purwanto, 2019.

4.2. Nickel Sulphate Hexahydrate Supply and Demand by 2040

The potential $NiSO_4.6H_2O$ supply and demand (in tonnes, annually) based on the supply modelling (in Chapter 4) and projection of EV market penetration (in sub-chapter 5.1) is simulated and discussed in this chapter. The results of the $NiSO_4.6H_2O$ supply and demand modelling in the Southeast Asia region are presented in Figure 4.2 (HEV Bridge scenario) and Figure 4.3 (BEV Ambitious scenario). In particular, two scenarios of potential $NiSO_4.6H_2O$ supply are considered in this study and illustrated in Figure 4.2 and Figure 4.3:

- Potential $NiSO_4.6H_2O$ supply from eight HPAL facilities in Indonesia (i.e. in operation and under construction; see Table 2.1)
- Potential $NiSO_4.6H_2O$ supply from 27 HPAL facilities in Indonesia (i.e. in operation, under construction, and planned; see Table 2.1).

The two scenarios are simulated to account for any uncertainties associated with the total number of HPAL facilities that would be installed by 2040, depending on the domestic socio-economic development, policies (e.g. mining quotas), ore grade, business ecosystem, and commitment to nickel downstreaming strategies in Indonesia.

In the HEV Bridge under the eight HPAL facilities scenario (top graph, Figure 4.2), it can be observed that the total $NiSO_4.6H_2O$ demand to meet LIB applications for EVs is

projected to reach 0.5 million tonnes annually in 2040, in which 96% is projected to be needed to fulfil BEV demand (new BEVs and battery replacement) and 4% to fulfil both HEV and PHEV demand (new and battery replacement) in ASEAN. In this scenario, the total potential $NiSO_4.6H_2O$ supply in Southeast Asia is projected to reach 1.3 million tonnes annually in 2040, leaving a surplus of 0.8 million tonnes that could be, for example, exported.

On the other hand, under the 27 HPAL facilities scenario (bottom graph, Figure 4.2), it can be observed that up to 2.4 million tonnes of $NiSO_4.6H_2O$ could be supplied for meeting the ASEAN EV demand by processing the existing limonite reserves until 2038. However, as described in Chapter 3, with the current existing reserve estimation, the resilience of the nickel reserves model suggests that nickel ore will be depleted by 2038, and thus more exploration and exploitation campaigns could be carried out to convert some of the known resources into mineable reserves. Whilst the nickel demand for EVs in ASEAN can be sufficiently supplied with the current reserves (as shown in Figure 4.2), nickel mining and processing would still be needed to meet the global nickel demand for the energy transition. Furthermore, mining activities contribute to national gross domestic product growth (Baskaran, 2024); however the ASEAN mining stakeholders should ensure that future nickel mining and processing activities are done responsibly and sustainably, following sustainable mining frameworks and circular economy principles to minimise potential socio-environmental impacts.

In the BEV Ambitious scenario with eight HPAL facilities (top graph, Figure 4.3), the total $NiSO_4.6H_2O$ demand to meet LIB applications increases exponentially from 2033 onwards due to higher BEV car sales in the ASEAN market, as shown in Figure 4.1. In this scenario, approximately 1.0 million tonnes of $NiSO_4.6H_2O$ will be needed annually by 2040. Similarly, the supply of $NiSO_4.6H_2O$ for ASEAN use is projected to reach 1.3 million tonnes annually under the eight HPAL facilities scenario. In the BEV Ambitious scenario with 27 HPAL facilities (bottom graph, Figure 4.3), it can be observed that up to 2.4 million tonnes of $NiSO_4.6H_2O$ could be supplied for meeting EV demand in ASEAN by processing the existing limonite reserves until 2038. However, sustainable and responsible nickel exploration and exploitation campaigns will be needed from 2038 onwards to continue the $NiSO_4.6H_2O$ production.

A few conclusions and recommendations can be drawn from the results presented in Figure 4.2 and Figure 4.3, summarised in the bullet points below:

- Given the potential excessive $NiSO_4.6H_2O$ supply based on the known limonite ore reserves (as of mid-2024), the Southeast Asia region could implement a more ambitious target (e.g. doubling their BEV sales target in the HEV Bridge and BEV Ambitious scenarios) for more BEV penetration to achieve further decarbonisation targets for the transport sector, especially passenger light-duty vehicles. This could be achieved by establishing strategic planning to position the region as an EV manufacturing hub, for example, and/or integrating LIB

manufacturing (i.e. pCAM, CAM, Cell, etc.) with the automotive industry (i.e. EV manufacturing facilities).

- Alternatively, Indonesia and the Philippines could export the excessive $NiSO_4.6H_2O$ and become global suppliers of EV manufacturing outside of Southeast Asia.
- Given the existing reserves (as of mid-2024), more strategic thinking and planning regarding nickel midstream (and downstream) processing capabilities are needed. As illustrated in Figure 4.2 and Figure 4.3 (and elaborated in Chapter 3), the resilience of nickel reserves must be accounted for to ensure sustainable nickel extraction in the region. Converting some of the resources to minable reserves is deemed viable, provided the potential socio-economic and environmental impacts are carefully considered.
- Government bodies should play a more active role in balancing the supply and demand for nickel ore and $NiSO_4.6H_2O$ products by applying mining quotas and/or limiting the construction of HPAL facility projects. These strategies could help prolong the lifetime of mining and metal processing in Indonesia and secure the long-term financial benefits of the nickel midstream and downstream processing industries.

Figure 4.2. Nickel Sulphate Hexahydrate Supply and Demand in the HEV Bridge Scenario to Meet EV Penetration Targets and Sales in ASEAN by 2040

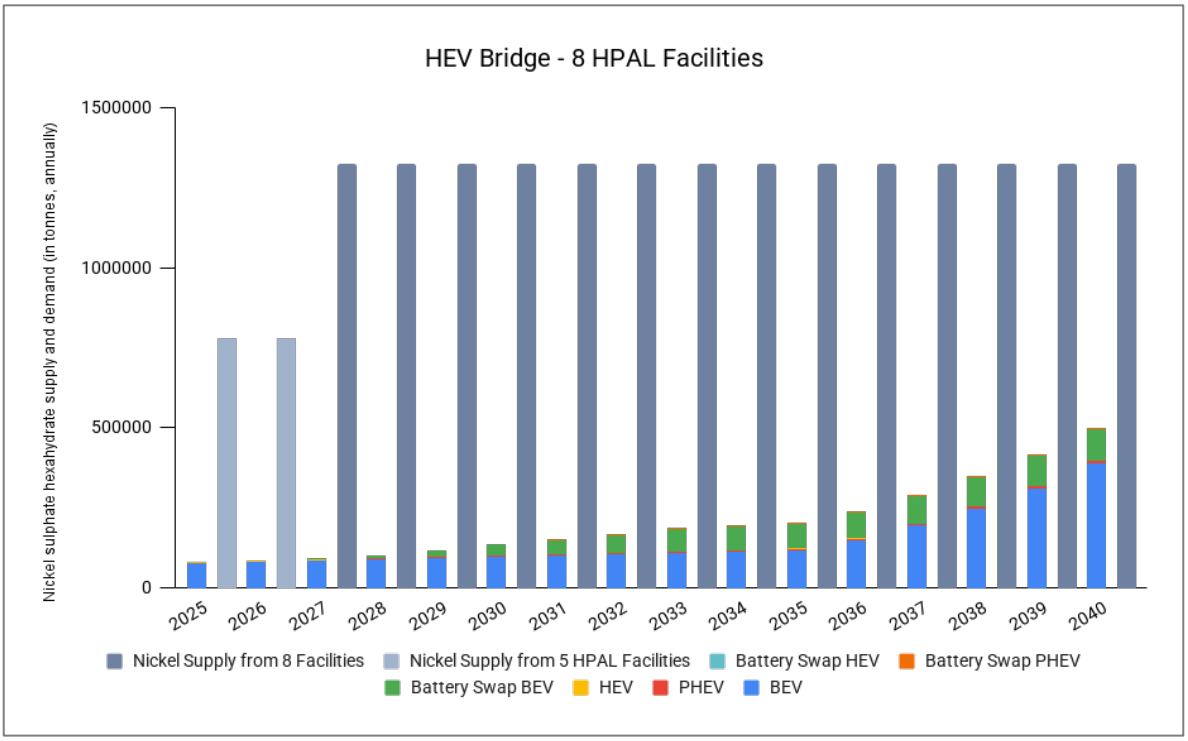
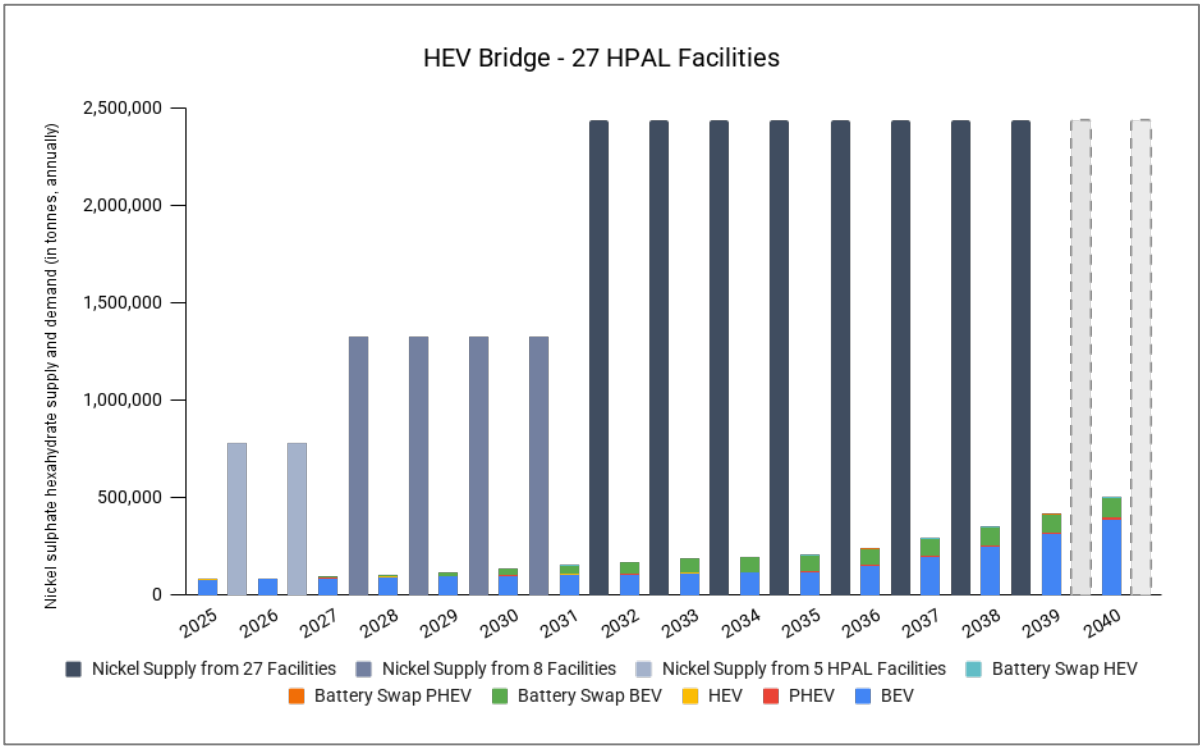


Figure 4.2. *Continued*

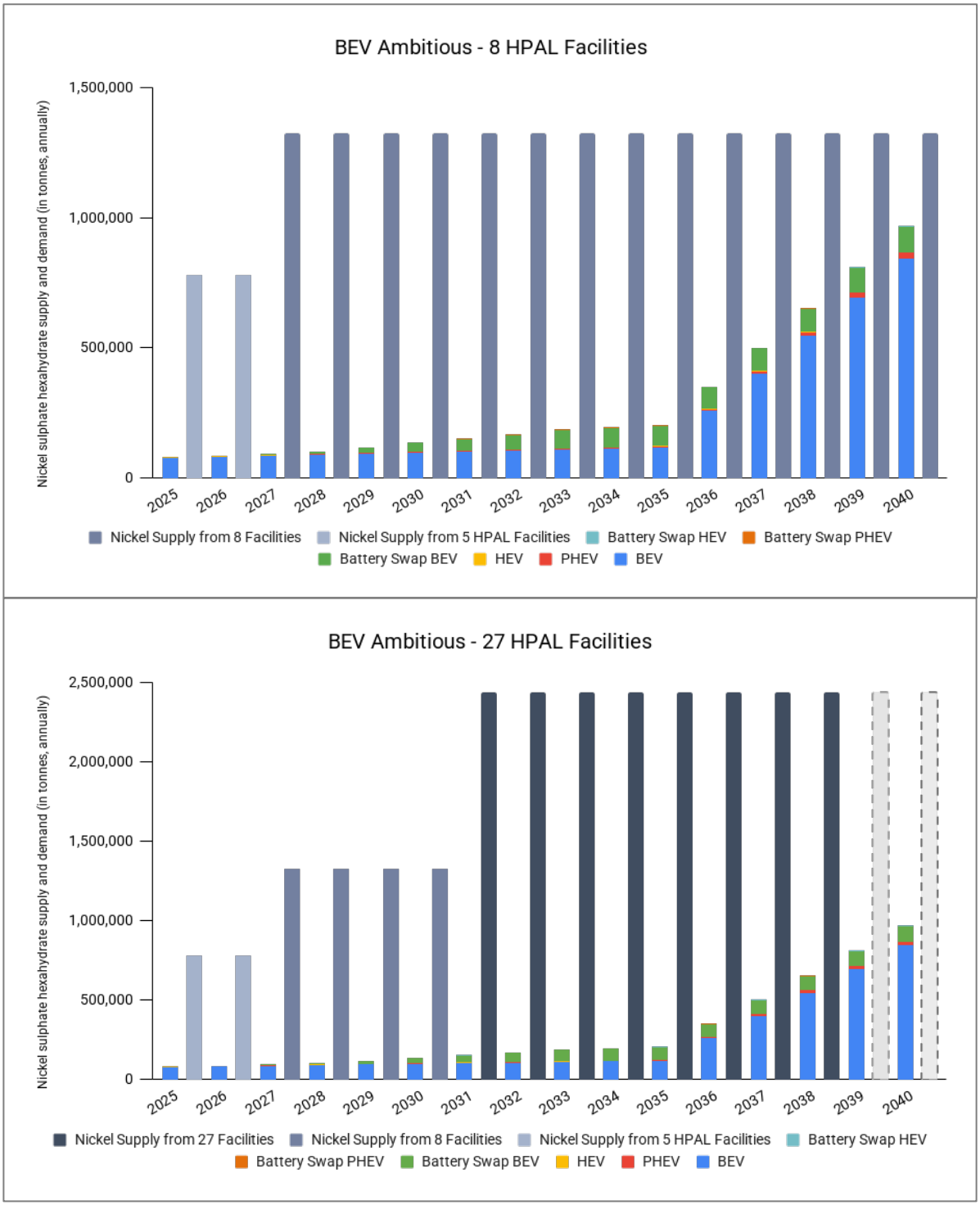


BEV = battery electric vehicle, HEV = hybrid electric vehicle, HPAL = high-pressure acid leaching, PHEV = plug-in hybrid electric vehicle.

Note: The supply and demand models considering 8 HPAL facilities (top) and 27 HPAL facilities (bottom) are shown. The light-grey dashed-line box (bottom) illustrates that the limonite ore reserves will be depleted by 2038 (Chapter 3), and an exploration-exploitation campaign is needed to fill the supply gap.

Source: Authors' own estimation.

Figure 4.3. Nickel Sulphate Hexahydrate Supply and Demand in the BEV Ambitious Scenario to Meet EV Penetration Targets and Sales in ASEAN by 2040



BEV = battery electric vehicle, HEV = hybrid electric vehicle, HPAL = high-pressure acid leaching, PHEV = plug-in hybrid electric vehicle.

Note: The supply and demand models considering 8 HPAL facilities (top) and 27 HPAL facilities (bottom) are shown. The light-grey dashed-line box (top) illustrates that the demand exceeds supply in the BEV Ambitious scenario. The light grey dashed-line box (bottom) illustrates that the limonite ore reserves will be depleted by 2038 (Chapter 2), and an exploration-exploitation campaign is needed to fill the supply gap.

Source: Authors' own estimation.

Chapter 5

Sustainability of Nickel and the Electric Vehicle Industry in ASEAN

In this chapter, the carbon footprint associated with the production of 1 kilogramme (kg) of nickel sulphate hexahydrate ($NiSO_4.6H_2O$) (baseline), the decarbonisation potential, and the cost implications associated with decarbonising $NiSO_4.6H_2O$ production in Indonesia are discussed. In particular, the life cycle assessment (LCA) method following ISO 14040/14044 and ISO 14067 standards has been applied to assess the product carbon footprint of $NiSO_4.6H_2O$ using the Minviro LCA software, XYCLE. The foreground data are collected from the Minviro internal database containing high-quality and granular raw material supply chain data, whilst the Ecoinvent 3.10 database is used for the background database. The allocation procedure is also applied in quantifying the carbon footprint of $NiSO_4.6H_2O$ because cobalt is also found in the mixed hydroxide precipitate (MHP) and final metal salts, as described in Chapter 3. Three groups of decarbonisation strategies were considered in this study, namely (1) fuel optimisation, (2) energy profile management, and (3) supply chain (Scope 3 emission) management, which is elaborated on further in this chapter. Finally, life cycle costing (LCC) is applied to quantify the potential cost implications associated with the implemented decarbonisation strategies.

5.1. Carbon Footprint of Nickel Sulphate Hexahydrate Production

From the LCA studies carried out by Minviro using XYCLE, it is estimated that 1 kg of $NiSO_4.6H_2O$ emits around 8 kg of carbon dioxide (CO_2)-equivalent, excluding the transport of the materials from mining to processing facilities. The climate change impact of $NiSO_4.6H_2O$ in this study is relatively higher compared to other $NiSO_4.6H_2O$ productions in the same processing route, as reported by Armstrong et al. (2024) and Tijsseling et al. (2023).

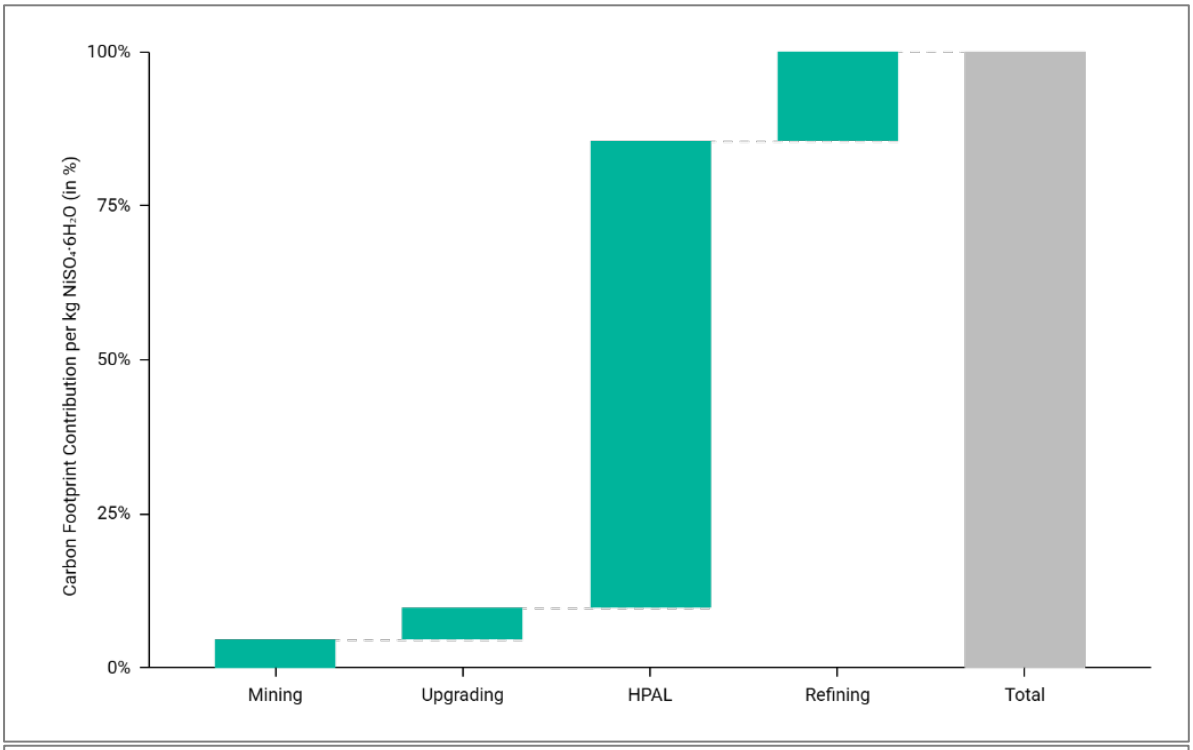
Figure 5.1 provides the climate change impact contribution by stage and material/energy consumption. The mining stage refers to limonite open pit ore extraction, including diesel consumption for the heavy equipment. The upgrading stage refers to ore beneficiation, where nickel and cobalt are contained in the finer size fractions of limonite ore. Coarse particles are removed using screening, from which chromite-containing material is isolated and removed. The high-pressure acid leaching (HPAL) stage refers to sulphuric acid leaching at high temperatures and pressures to produce pregnant leach solution. The solution is neutralised, and nickel and cobalt are precipitated into MHP. Finally, the refining stage refers to MHP releaching with sulphuric acid followed by solvent extraction

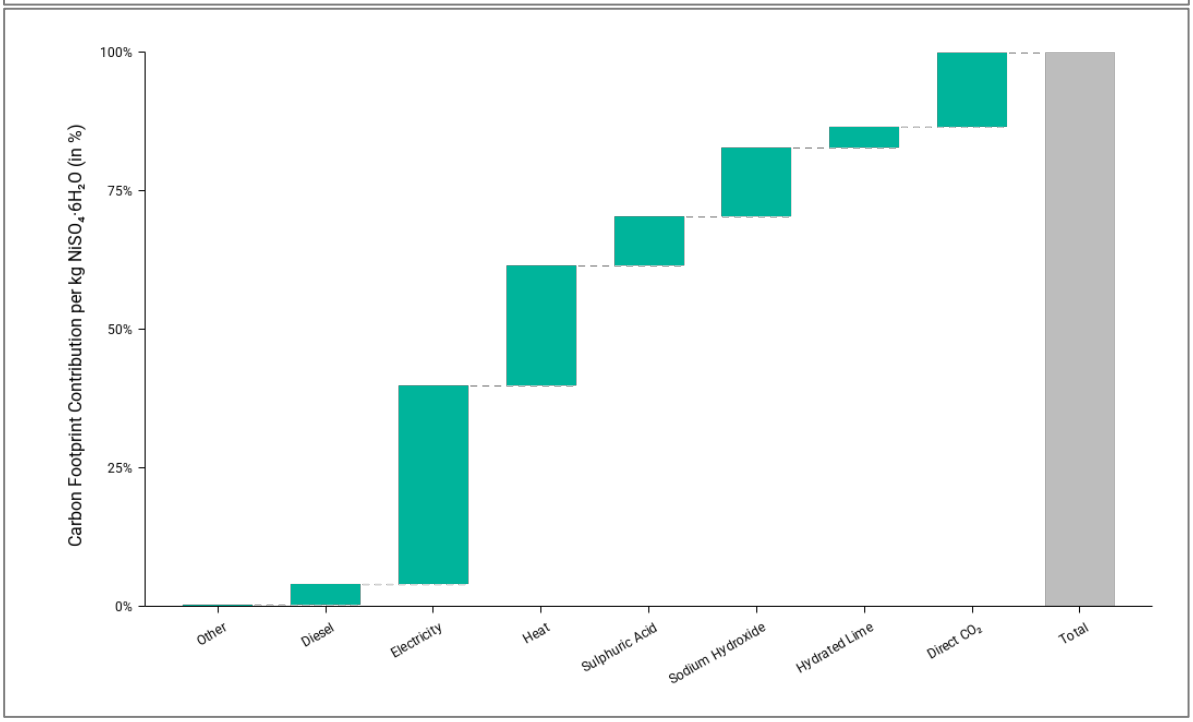
to separate nickel and cobalt from MHP. Nickel contained in solution is isolated and crystallised into $NiSO_4.6H_2O$ using thermal energy. More detailed information can be found in Chapter 3.

From Figure 5.1, it can be observed that the mining, upgrading (i.e. ore beneficiation), and refining stages contribute only around 25% of the total climate change impact, whilst the leaching and neutralisation processes (i.e. the HPAL processing) account for the rest of the climate change impact. The climate change impact from HPAL processing is mainly driven by the direct CO_2 emissions generated from the neutralisation steps and energy consumption (i.e. electricity and heat sources), as the HPAL process is operated under the temperature of around 250 °C and high pressure (i.e. approximately 45 bar). Furthermore, Figure 5.1 also provides the climate change impact contribution by material and energy consumption, in which energy consumption (i.e. heat and electricity) accounts for more than half of the climate change impact. Direct CO_2 emissions are also estimated to contribute around 10%–15% of the total climate change impact. In terms of chemical consumption, sodium hydroxide (as a neutralising agent) is estimated to contribute around 10% of the total emissions, followed by sulphuric acid (as a leaching agent) and hydrated lime.

The LCA findings are then used as the foundation for building the potential decarbonisation strategies to reduce the impact of climate change by producing $NiSO_4.6H_2O$ as a precursor for LIBs. The strategies primarily aim to reduce the impact associated with energy and material consumption (i.e. Scope 3 supply chain management). Finally, the potential impact associated with decarbonisation strategies is elaborated on and discussed in the next chapter.

Figure 5.1. Climate Change Impact Contribution of 1 kg of Nickel Sulphate Hexahydrate Processed via HPAL Followed by the Refining Process, Shown by Processing Stage (top) and Material and Energy Contributions (bottom)





HPAL = high-pressure acid leaching.
Source: Authors' LCA model in XYCLE.

5.2. Potential Decarbonisation Strategies of Nickel Sulphate Hexahydrate Production and Cost Implications

5.2.1. Decarbonisation Scenarios

As briefly mentioned in the previous section, the decarbonisation strategies of nickel sulphate hexahydrate production are established by identifying the environmental 'hotspots', as shown in Figure 5.1. In this study, three groups of decarbonisation strategies are elaborated on: (1) fuel optimisation, (2) energy profile management, and (3) supply chain (Scope 3 emission) management.

In the fuel optimisation scenario, the impact of using biodiesel is evaluated as a substitute for conventional diesel used in the mining equipment. In particular, two sources of biodiesel are investigated: palm oil and used cooking oil-based diesel following the B30 scenario (i.e. 30% blend of biodiesel). In the case of palm oil-based biodiesel, the climate change impacts of palm oil plantation (i.e. fresh fruit bunches production), palm oil production (i.e. crude palm oil production), and refining to fatty acid methyl ester (FAME) via transesterification are considered and modelled using Minviro's internal database. In the case of used cooking oil-based biodiesel, similar biodiesel production (FAME) is considered using Minviro's internal database, whilst the feedstock is treated as waste (i.e. following the waste-LCA approach), and waste collection is assumed to be negligible (i.e. excluded from the calculation). Finally, the lower heating value considered for the biodiesel is estimated to be 36–37 MJ/kg (Biograce, 2015).

In the energy profile management scenario, a few renewable energy sources are considered in the decarbonisation strategies, replacing the baseline coal-based electricity generation from captive coal power plants in industrial parks. In this scenario, the renewable energy sources are used in all $NiSO_4.6H_2O$ production stages described in the previous paragraph and Chapter 3. The first decarbonisation strategy looks at the potential impact of co-firing biomass (i.e. 5% of woodchips, with 50% carbon content) (Engineering Tool Box, 2024) in coal power plants, considering around a 9.9 MJ/kg lower heating value of woodchips. The second decarbonisation strategy explores potential carbon reduction, assuming the 30% renewable energy target is achieved in 2040. In this decarbonisation scenario, the following energy mix is considered: 42% coal, 28% natural gas, 13% hydropower, 9% geothermal, 4% wind, and 4% solar energy (Surhayati, 2023). The third decarbonisation scenario explores potential natural gas-based electricity generation. Finally, the fourth decarbonisation scenario investigates the climate change impact from 100% renewable energy sources (hydropower, geothermal, solar, and wind energies), in which the climate change impact of renewable energy generation is collected from the Ecoinvent database.

In the supply chain (Scope 3 emission) management scenario, a low-impact sodium hydroxide production route is considered. As most of the climate change impacts are generated from upstream activities, supply chain management and supplier

engagement sustainability programmes can be implemented in the corporate decarbonisation strategies (Patil et al., 2022). In this decarbonisation scenario, it is assumed that sodium hydroxide is produced via chlor-alkali electrolysis using membrane cell processing technology, which consumes a considerable amount of electricity. Thus, in the decarbonisation scenario, the electricity source needed to produce sodium hydroxide from the chemical supplier is assumed to be sourced from renewable sources (i.e. a 50:50 scenario and 100% renewable energy source), reducing the climate change impact of producing 1 kg of sodium hydroxide used in the $NiSO_4.6H_2O$ neutralisation step.

To complement the environmental assessment, a life cycle costing (LCC) analysis was conducted to assess the economic implications of decarbonising $NiSO_4.6H_2O$ production. The LCC methodology employed in this study focuses on operational expenses, specifically energy and consumables, whilst excluding capital investment costs.

Prior to exercising the LCC methodology, an assessment was performed to evaluate the most suitable methodology, including a techno-economic assessment. The findings indicated that LCC would provide the most practical framework for understanding the economic implications of decarbonisation within the scope of this study. A techno-economic assessment evaluates the technical feasibility and economic viability of processes, and it is often used in emerging technologies at their pre-commercialisation stages. It focuses on the innovation and market potential of these processes, whilst LCC focuses on the financial sustainability and ownership aspects of the same processes. Additionally, since LCC inherently considers the full life cycle of products, it is deemed to be a more suitable methodology for this project.

The LCC analysis assumes that prices are representative of the global market unless otherwise specified. Data from Chinese markets and, where available, the Indonesian market were included to reflect regional variances, although Indonesian market data were more limited. Indonesia's levelised cost of electricity values, which were sourced from the Institute for Essential Services Reform (Arinaldo, 2019), were applied to the electricity prices model. Prices for consumables were derived from Chinese market data due to the strong supply, whilst nickel price data were obtained from industry leaders, such as S&P Global and Fastmarkets. In most cases, the average price of historical 3-year data is used in the LCC modelling. The analysis also underwent global validation using data from the United States Geological Survey (USGS) and technical engineering documents to ensure robustness.

The decarbonisation scenarios were analysed to understand the cost implications of decarbonisation strategies. The baseline, set at 100% in Figure 5.3, served as the reference point. In the biodiesel scenario, the cost increased by approximately 6% compared to regular diesel. For sodium hydroxide sourced via a low-impact route, a 20% cost increase was considered relative to conventional sodium hydroxide. The coal and biomass co-firing scenario assumed a 20% increase in cost compared to using coal

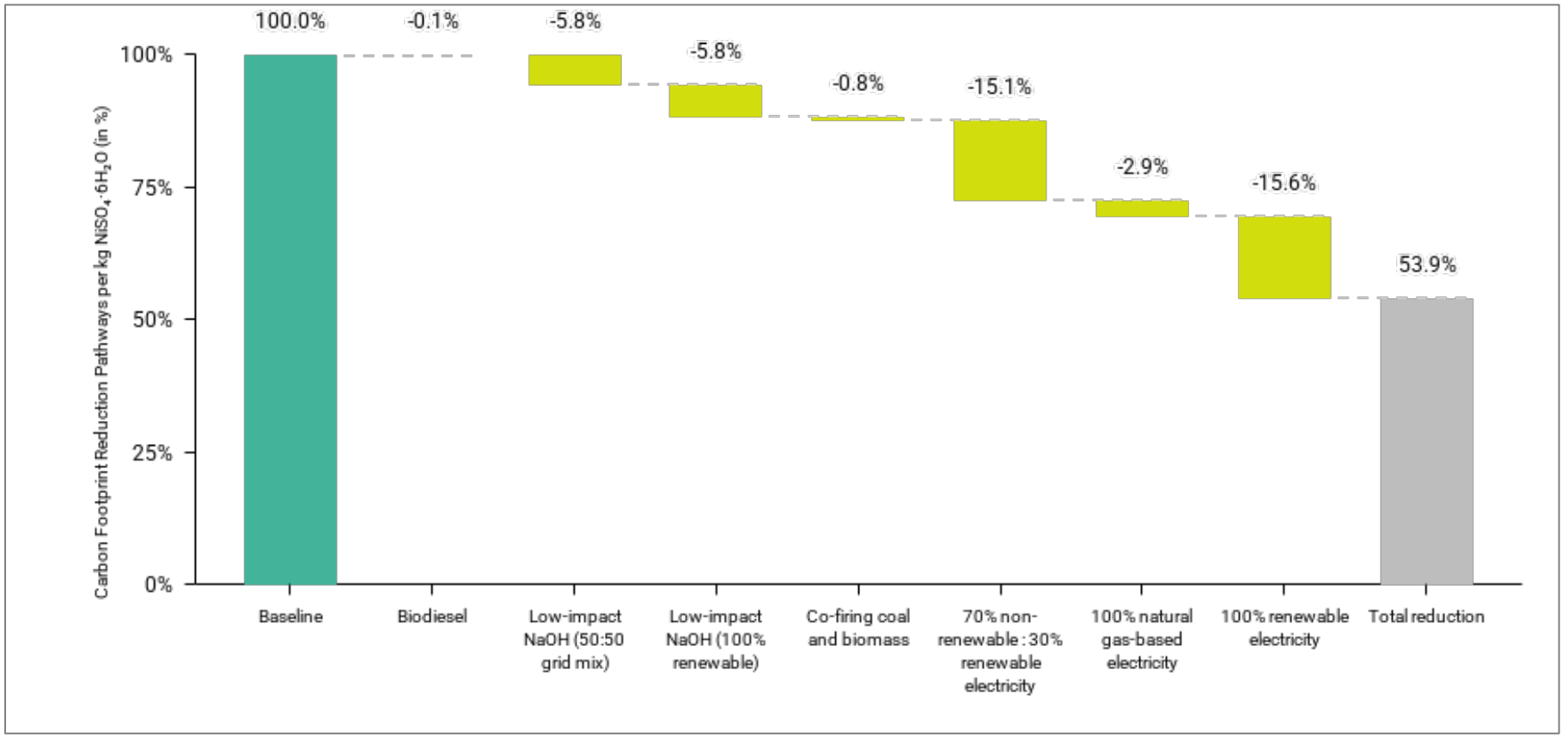
alone. Additionally, energy mix transitions were analysed, exploring shifts from predominantly fossil energy (70% fossil:30% renewable) to natural gas-based energy and, ultimately, to a 100% renewable energy mix.

5.2.2. Climate Change Impact and Reduction Pathways of Nickel Sulphate Hexahydrate

The potential climate change impact reduction pathways of decarbonising $NiSO_4.6H_2O$ production are provided in Figure 5.2. In particular, Figure 5.2 provides the potential climate change reduction pathways for producing 1 kg of $NiSO_4.6H_2O$. From Figure 5.2, up to 54% of climate change impact reduction can be achieved when all decarbonisation strategies in this study are implemented: fuel optimisation (i.e. using alternative B30 diesel), energy profile management (i.e. 100% renewable energy source), and supply chain management (i.e. low-carbon sodium hydroxide consumption).

The most significant reduction can be achieved when the production of $NiSO_4.6H_2O$ is powered by 100% renewable energy. Switching from conventional diesel to biodiesel and co-firing coal and biomass are estimated to have a marginal reduction impact (0.1% climate change impact reduction). The consumption of lower-carbon sodium hydroxide has the potential to reduce up to 10% of the impact of climate change, depending on the electricity source used in the production of sodium hydroxide (Figure 5.2).

Figure 5.2. Climate Change Reduction Pathways of Nickel Sulphate Hexahydrate Production via High-pressure Acid Leaching Followed by the Refining Process

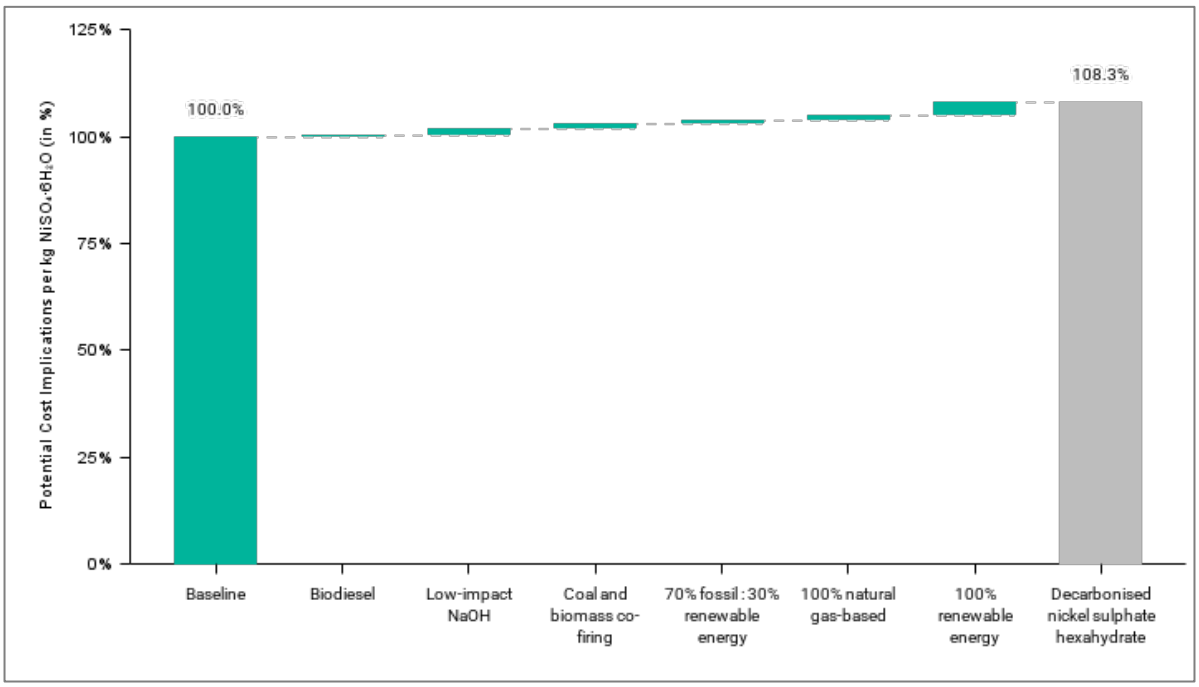


NaOH = sodium hydroxide.
Source: Authors' LCA Model in XYCLE.

5.2.3. Cost implications of decarbonised nickel sulphate hexahydrate

From Figure 5.3, it can be seen that the costs associated with material and energy consumption (i.e. consumables) are expected to increase by 8%–12% (considering the uncertainties around energy and material prices). The electricity price and low-carbon sodium hydroxide price are expected to be the main drivers of the higher costs of low-carbon $NiSO_4.6H_2O$ production. Overall, the results indicate that whilst there is a cost increase for all actions, these are marginal for most scenarios. This suggests that process changes, such as using biodiesel, adopting low-impact sodium hydroxide, or switching energy sources, do not drastically alter operational costs. Smaller interventions, such as biodiesel use or low-impact sodium hydroxide, result in less significant cost impacts, whereas energy-related changes tend to have a greater influence. Transitioning from natural gas-based energy to 100% renewable energy results in an approximate 8%–12% variation in cost compared to the baseline. These findings demonstrate that the operational costs for producing nickel sulphate hexahydrate remain relatively stable against the assessed process modifications.

Figure 5.3. Potential Cost Implications of Producing Decarbonised Nickel Sulphate Hexahydrate



Source: Authors' LCC Model in XYCLE.

5.2.4. Decarbonisation of Nickel Sulphate Hexahydrate: Future Perspectives

Some aspects require further research, such as capital investment costs (e.g. the capital investment for installing solar PV) and feasibility studies to allow a complete cost-benefit analysis of decarbonising $NiSO_4.6H_2O$ production via the HPAL route in Indonesia. In particular, a site-specific or region-specific feasibility study should be conducted to assess the potential cost-benefit of using low-carbon materials and energy sources. Furthermore, the potential climate change reduction and cost implications of low-carbon heat generation should be investigated, such as natural-gas-based heat generation and on-site sulphuric acid production combined with heat exchangers (i.e. heat recovery from the exothermic reaction of acid production to reduce heat demand in $NiSO_4.6H_2O$ production). Nonetheless, this study has indicated that potential climate change impact reduction can be achieved with relatively minimal cost implications from the material and energy consumable perspectives.

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