Critical Minerals in the ASEAN region: assessing the *opportunities* and risks

PUBLISHED

DEPARTMENT OF ENGINEERING,
UNIVERSITY OF CAMBRIDGE,
CAMBRIDGE, UNITED KINGDOM

15 AUGUST 2025

AUTHORS

GRETEL CUEVAS VERDIN,
LIHANI DU PLESSIS AND
JONATHAN M CULLEN (EDITORS)

BAPTISTE ANDRIEU,
KARLA CERVANTES BARRON,
ELLA JENNINGS, ALEXEY NOSKOV,
SAMUEL STEPHENSON AND ANDRÉ
CABRERA SERRENHO (AUTHORS)

UNIVERSITY OF CAMBRIDGE

THE AUTHORS HAVE ASSERTED THEIR RIGHT UNDER THE COPYRIGHT, DESIGNS AND PATENTS ACT 1988 TO BE IDENTIFIED AS AUTHORS OF THIS WORK. GRETEL CUEVAS VERDIN, LIHANI DU PLESSIS, JONATHAN M CULLEN (EDITORS). BAPTISTE ANDRIEU, KARLA CERVANTES BARRON, ELLA JENNINGS, ALEXEY NOSKOV,

SAMUEL STEPHENSON, ANDRÉ CABRERA SERRENHO

PLEASE CITE AS: CUEVAS VERDIN G, DU PLESSIS L, CULLEN JM. (EDS.) (2025). CRITICAL MINERALS IN THE ASEAN REGION: ASSESSING THE OPPORTUNITIES AND RISKS. UNIVERSITY OF CAMBRIDGE.

DOI: 10.17863/CAM.123365

GET IN TOUCH: CCML-CONTACT@ENG.CAM.AC.UK

RESEARCH IN THIS REPORT IS FUNDED BY CCG, CLIMATE COMPATIBLE GROWTH: HTTPS://CLIMATECOMPATIBLEGROWTH.COM/ABOUT-US/

EXECUTIVE SUMMARY

The ASEAN (Association of Southeast Asian Nations) is a regional organisation of ten Southeast Asian nations, promoting political stability, economic growth, and collaboration. Its member States are rich in critical minerals (CM), which are essential for renewable energy technologies and hold significant geopolitical value. However, foreign control over various parts of the CM value chain has raised concerns among countries that are transitioning to or involved in producing low-carbon energy technologies that rely on these materials. There is a significant risk of disruptions and shocks throughout the entire value chain, including mining, manufacturing, transport routes, and technology markets. Therefore, it is essential for countries to understand the flows of critical materials (CM) and the involved actors in order to establish more resilient CM value chains.

KEY TAKEAWAYS

→ The ASEAN region is strategically positioned to meet the growing global demand for critical minerals in both raw material supply and advanced manufacturing, thereby contributing to the energy transition. ASEAN countries hold an estimated 47% of the world's nickel reserves, 35% of the global tin reserves, and substantial quantities of rare earth elements, bismuth, tungsten, and bauxite.

→ There are several opportunities for ASEAN countries, including the expansion of lithium-ion battery production, improved regional power grid integration, and the utilization of renewable energy sources like solar, wind, and hydropower. However, financial and technological barriers still pose challenges.

→ Development in the ASEAN region is currently carbon-intensive, with emissions rising alongside GDP growth. This situation underscores the urgent need for decarbonisation and reduced reliance on fossil fuels. Additionally, the region is particularly vulnerable to climate change, making the shift to cleaner energy even more critical.

→ ASEAN Member States face challenges in balancing resource extraction with sustainable development. Addressing environmental and social vulnerabilities while simultaneously strengthening regulatory frameworks must be a priority.

THIS REPORT CONTAINS AN INTRODUCTION AND THREE SECTIONS:

1

Section 1 gives an overview of the ASEAN region's current mining activity and CM reserves.

2

Section 2 provides a summary of the region's renewable energy potential, calculates the copper demand based on current and future electrification demand, and estimates the material demand of transport decarbonisation.

3

Section 3 reviews the development and environmental issues facing in the ASEAN region in relation to CMs and renewable energy development.

This scoping report is intended to showcase the types of modelling and analysis available from the Cambridge Critical Materials Lab (CCML) at Cambridge University, working as part of the Climate Compatible Growth programme. The results we present on critical mineral risks and opportunities for the ASEAN region are not intended to be exhaustive but are instead provided as examples of the modelling capabilities and research strengths currently being developed at CCML. This report should serve as the basis for further discussions, between the ASEAN team and Cambridge University, about more specific research and analysis directions.

CONTENTS

Introduction

Context for the ASEAN region

The ASEAN states possess significant economic relevance, making them key players in the global manufacturing supply chains. According to the International Monetary Fund (2024), the bloc generated USD 10.2 trillion, amounting to 6.5% of the global gross domestic product (GDP) in 2022. As the population keeps rising, the International Energy Agency (IEA, 2023) estimates that by 2050, the population of Southeast Asia will exceed 800 million, and the economic output will grow by an annual average rate of 3.8%. While such growth is expected to contribute to the socio-economic development in the region and poverty reduction efforts, according to the Intergovernmental Forum (IGF) on Mining, Minerals, Metals and Sustainable Development (2023) and the IEA (2024b), emissions will continue to rise in conjunction with GDP. Figure 1 shows the political map for the ASEAN region.

In addition to the economic relevance of the region, ASEAN countries are crucial to meet the global net-zero and decarbonisation goals. The area possesses significant CM reserves needed for the manufacturing of renewable technologies such as solar panels, electric batteries, electric vehicles (EVs), wind turbines, and other renewable energy technologies. ASEAN Member States have an estimated 47% of global nickel reserves, 35% of global tin reserves, and large reserves of other critical minerals such as rare earths, bismuth, tungsten, and bauxite (IGF, 2023). As the energy transition advances, increasing demand for critical minerals places the ASEAN region in a strategic position to become a central part of the CM value chain.

Developing the mineral sector is also crucial for meeting the region's own CM demand, as it pursues its own decarbonisation goals. As a region particularly vulnerable to climate change and already experiencing its impacts, reducing reliance on fossil fuels is crucial. While there are varying levels of development and economic structures across Member States, the IGF (2023) indicates that the region is well-positioned to lead both in the supply of raw materials and in advanced manufacturing hubs in the digital transformation and energy transition.

Against a background of China's increased control in critical mineral value chains, the ASEAN region has gained geopolitical importance as a potential CM supplier for countries with high mineral demand. The United States and the European Union have adopted bilateral trade agreements, onshoring (developing production capacity within a country), and nearshoring (setting up production capacity near consumption) to counterbalance China's influence over the CM supply chain (Majkut, 2023; European Commission, 2023). In 2022, the Biden-Harris Administration launched the Indo-Pacific strategy and released the Indo-Pacific Economic Framework (IPEF) and the Americas Partnership for Economic Prosperity (APEP). In the same year, the Group of Seven (G7) signed Just Energy Transition Partnerships (JETPs) with Indonesia and Vietnam, among other countries, to address the critical minerals' supply security.

As the geopolitical tensions between China and the West rise, ASEAN Member States face increasing international pressure to extract their mineral reserves and choose sides in a brewing geopolitical conflict. Patterson (2022) explains that ASEAN countries walk on a geopolitical tightrope, making partner diversification an increasingly relevant strategy to achieve value addition and resilience within the mineral value-chain.

FIG. 1

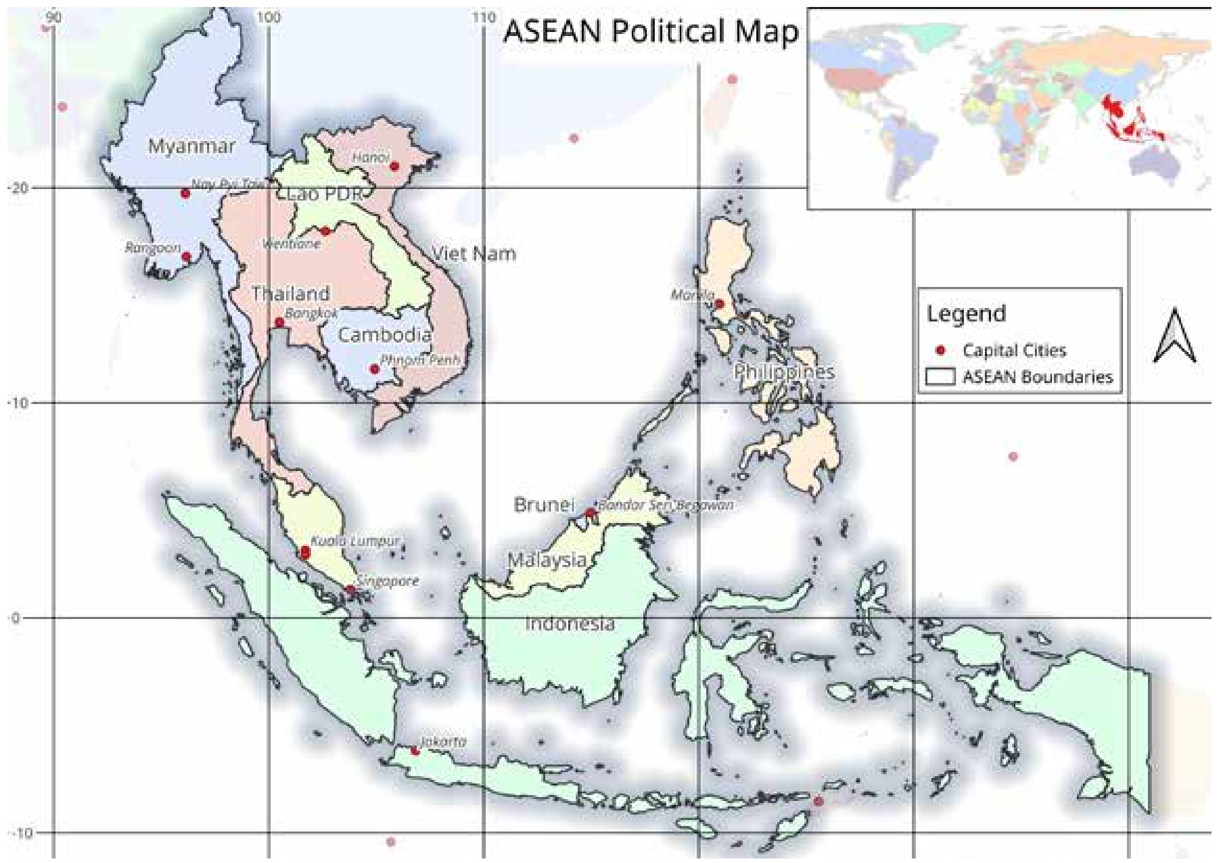


FIGURE 1: POLITICAL MAP OF ASEAN MEMBER STATES AND CAPITAL CITIES.

Collaborative initiatives among ASEAN countries have emerged to foster integrated approaches to critical mineral management. For instance, Velasco (2023) indicates that the ASEAN Economic Community (AEC) is setting a precedent for regional cooperation in mining policies and facilitates knowledge-sharing and best practices across borders. According to the Center for International Law (2023), ASEAN Member States have created initiatives such as the 2023 Regional Electric Vehicle Ecosystem (EV) to diversify Member States' supply chains and create a technology manufacturing hub. Since then, the Philippines has expanded its extractive and mineral refining capacities across sectors, while Malaysia, Vietnam, Cambodia, and Lao PDR have developed mineral strategies toward a 2030 vision. Ultimately, the ASEAN economies have united with the objectives of expanding mining production and upgrading critical mineral manufacturing supply chains.

This scoping report provides a high-level overview of the critical minerals available in the region and opportunities to increase value capture. The report seeks to answer the following overarching questions:

→ What is the current state of mining capacity and critical mineral availability in the ASEAN region?

→ How are ASEAN Member States positioned to address the energy transition challenges and the global critical mineral demand?

→ What are the key issues facing the ASEAN region concerning critical minerals and renewable energy development?

The report is structured into three main parts: Section 1 reviews the current mining capacity and critical mineral reserves in ASEAN countries; Section 2 provides a summary of the region's renewable energy potential, calculates the copper demand based on current and future electrification demand, and estimates the material demand of transport decarbonisation; and Section 3 discusses the development and environmental issues faced in the ASEAN region, related to critical minerals and renewable energy development.

Section 1: Current Mining Activity in ASEAN Countries

THIS SECTION PROVIDES AN ANSWER TO THE FOLLOWING QUESTION:

What is the current state of mining capacity and critical mineral availability in the ASEAN region?

The ASEAN region is currently undergoing a significant transformation in its mining sector, driven by the increasing demand for technologies which underpin the energy transition. While in previous decades, the mining industry primarily focused on non-metallic minerals such as sand and gravel (Emami et al., 2024), ASEAN countries are currently seeking opportunities to develop their critical minerals mining sector along with their manufacturing capacity of batteries, electronics, and renewable energy technologies. To follow, is a description of the production, potential reserves and policy initiatives related to CMs, in each of the ten ASEAN countries.

Indonesia is the ASEAN Member State with the highest mining and processing capacity, positioning itself as a primary global supplier of nickel and a leading processor of smelted nickel, smelted tin, and ferronickel (IGF, 2023; Qurbani et al.,2021). In just three years, from 2020 to 2023, Indonesia grew nickel production from 34% of global output to 52%. Simiarly, refined nickel increased from 23% of the global exports in 2020 to 37% in 2023 (IEAc, 2024). The government, through the adoption of a various policy agendas (local content policies, export bans of raw nickel), is actively encouraging the development of further mining and refining capabilities (Lèbre et al., 2020; Tkachenko et al., 2022).

According to the ASEAN-IGF Mineral Cooperation (2023), Indonesia holds 22% of the world's nickel reserves, 16% of its tin reserves, and 4% of its bauxite reserves. Additionally, Indonesia is rapidly increasing its cobalt production and has become the second-largest producer worldwide in 2023, following the Democratic Republic of Congo (IEA, 2024). The International Energy Agency (IEA, 2024) estimates that by 2030, Indonesia will account for 10% of global cobalt mining, amounting to approximately 50 kt (kilotonnes). Furthermore, Lèbre et al. (2020) report that Indonesia possesses 2.9 billion tonnes of tin reserves, establishing it as a significant player in both local and export markets. The country has boosted its copper production since 2020, achieving a global share of 5% (approximately 863 kt), with the PT Freeport Indonesia (Grasberg) mine ranking among the top three copper-producing mines in 2023 (IEA, 2024).

Myanmar is another crucial player in the region. According to the ASEAN-IGF Mineral Cooperation (2023), the country holds 18% of the world's rare earth elements (REEs, such as dysprosium, Terbium, Neodymium, and Praseodymium) and 14% of the tin reserves. Driven by increasing global demand for technologies dependent on minerals, Myanmar has seen a substantial increase in its mining capacity, demonstrating the possibility of increasing mining capacity in a short period of time (Chinkaka et al., 2023). Since 2015, Myanmar has grown its share of REE global production from 0.2% to 14% (IEA, 2024). Consequently, the IEA (2024) estimates that by 2030, Myanmar will be among the top three producers of REEs mining.

Myanmar has not only expanded its extraction capacity but also its mineral processing capabilities. For instance, copper refined exports grew from USD 50 million in 2010 to USD 943 million in 2020 (IGF, 2023).

As shown in Figure 2, most of the current mining activity is concentrated in Indonesia and northern Myanmar. While the rest of the ASEAN region has developed plans to develop its mining sectors in the context of the energy transition, current mining activity is still in its early stages of development.

FIG. C1

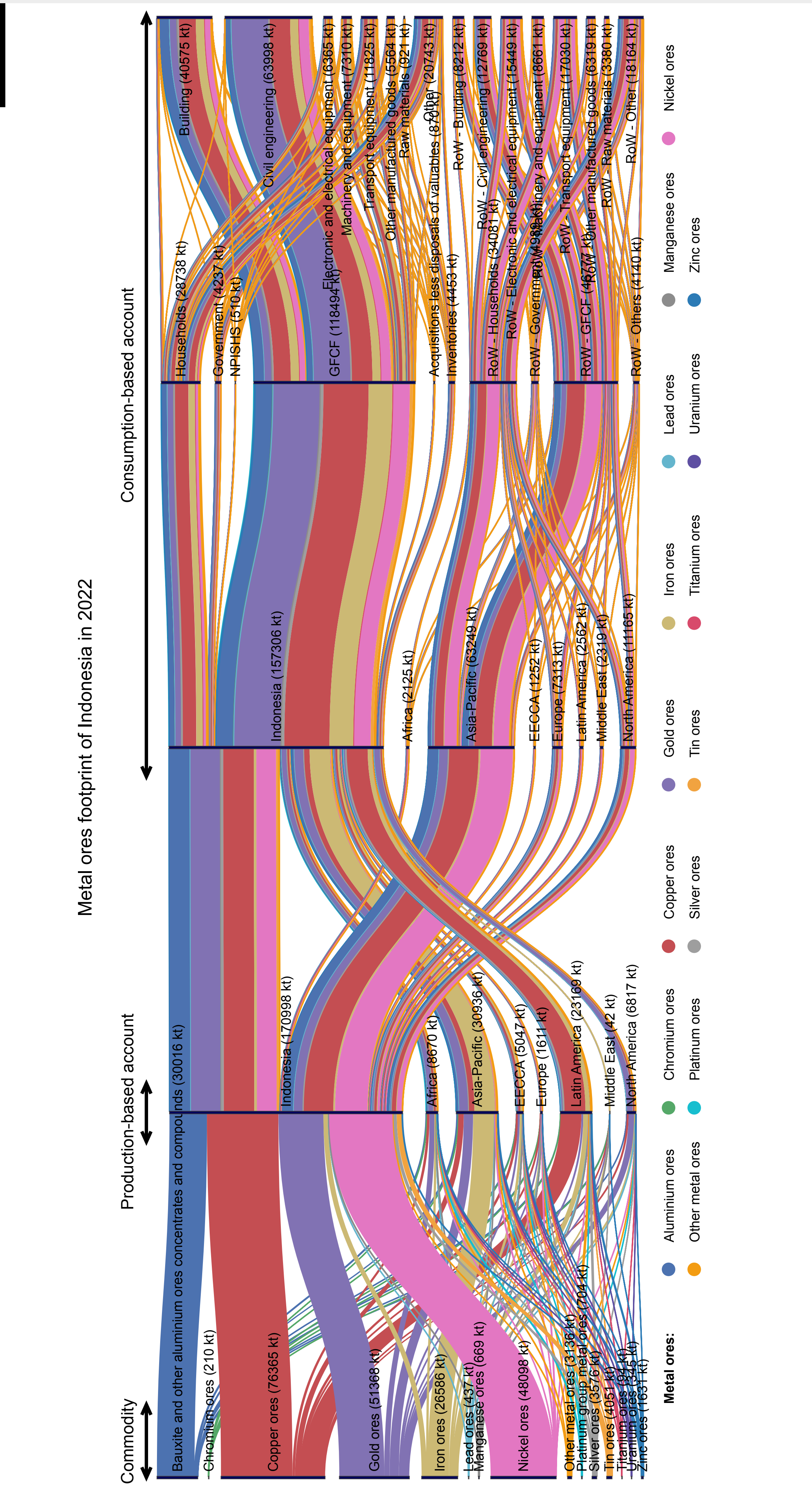


FIGURE C1: METAL ORES FOOTPRINT OF INDONESIA IN 2022. THE FIRST STEP CORRESPONDS TO THE COMMODITY, THE SECOND STEP TO THE PRODUCTION-BASED ACCOUNTS (EXTRACTION) AND THE LAST THREE STEPS TO THE CONSUMPTION-BASED ACCOUNT BY REGION, FINAL CONSUMER, AND FINAL CONSUMPTION SECTOR. ANY FLOW REPRESENTED IN THE DIAGRAM IS EITHER PRODUCED IN INDONESIA OR EMBODIED IN INDONESIA'S FINAL CONSUMPTION. SANKEY DIAGRAMS FOR OTHER CRITICAL MINERALS AVAILABLE IN THE ANNEX AND ONLINE: HTTPS://APPLICATION-SANKEY-RM.ONRENDER.COM/ .

Vietnam is another country in the region that offer an alternative source for rare earth elements (REEs), radioactive materials, and tungsten, from China. With an estimated 22 Mt (million tonnes) of REEs reserves and 4 Mt of tungsten reserves, the country is positioned to be a crucial player in global tungsten markets and has the potential to cater to global demands for high-tech applications (Gel et al., 2021; Verbiest, 2013; Vongphakdy, 2023; Gel et al., 2021). Since 2010, Japan and Singapore have been conducting mining exploration in the country, seeking a strong alternative to Chinese REE suppliers (Moody, 2013). With its extensive REE reserves, Vietnam is positioning itself to be a significant player in the global critical minerals market. Loo (2019) highlights Vietnam's potential for significant foreign direct investment (FDI) in mining, considering that, despite the available REE reserves, the mining sector is still in its infancy.

Vietnam, like Indonesia, has also established a protective and restrictive regulatory regime that aims to achieve economic competitiveness while minimising socio-environmental impacts. Through initiatives such as the 2010 Mineral Law, the country has initiated reforms to attract FDI in its mineral sector.

The **Philippines** is a significant player in the copper ad nickel sector. With estimated copper reserves of 4.2 Gt (billion tonnes) the country ranks among the top ten global producers (Amelia et al., 2023; Verbiest, 2013). The considerable gold reserves of over 2,000 t (tonnes) and nickel reserves of 4.8 Mt further position the Philippines as one of the leading mineral producers in Asia (Voingpuhakdy, 2023; Gel et al., 2021). The country's policy approach has focused on enhancing the institutional capacity of regulatory and legal institutions to boost foreign investment and increase environmental production (Caballero- Anthony, 2014).

Malaysia possesses bauxite and tin reserves, approximately 40 Mt and 1.5 Mt respectively, which have contributed to Malaysia's production of tin and aluminium for decades (Verbiest, 2013; Gel et al., 2021; Indraswari, 2022). In addition, the Malaysian government has launched initiatives to enhance the mining of rare earth elements (REEs) (Voingpuhakdy, 2023). However, the country is currently facing significant resource governance challenges due to a lack of comprehensive stakeholder engagement, which have led to increased conflict with local communities (Amelia et al., 2023; Voingpuhakdy, 2023).

FIG. 2

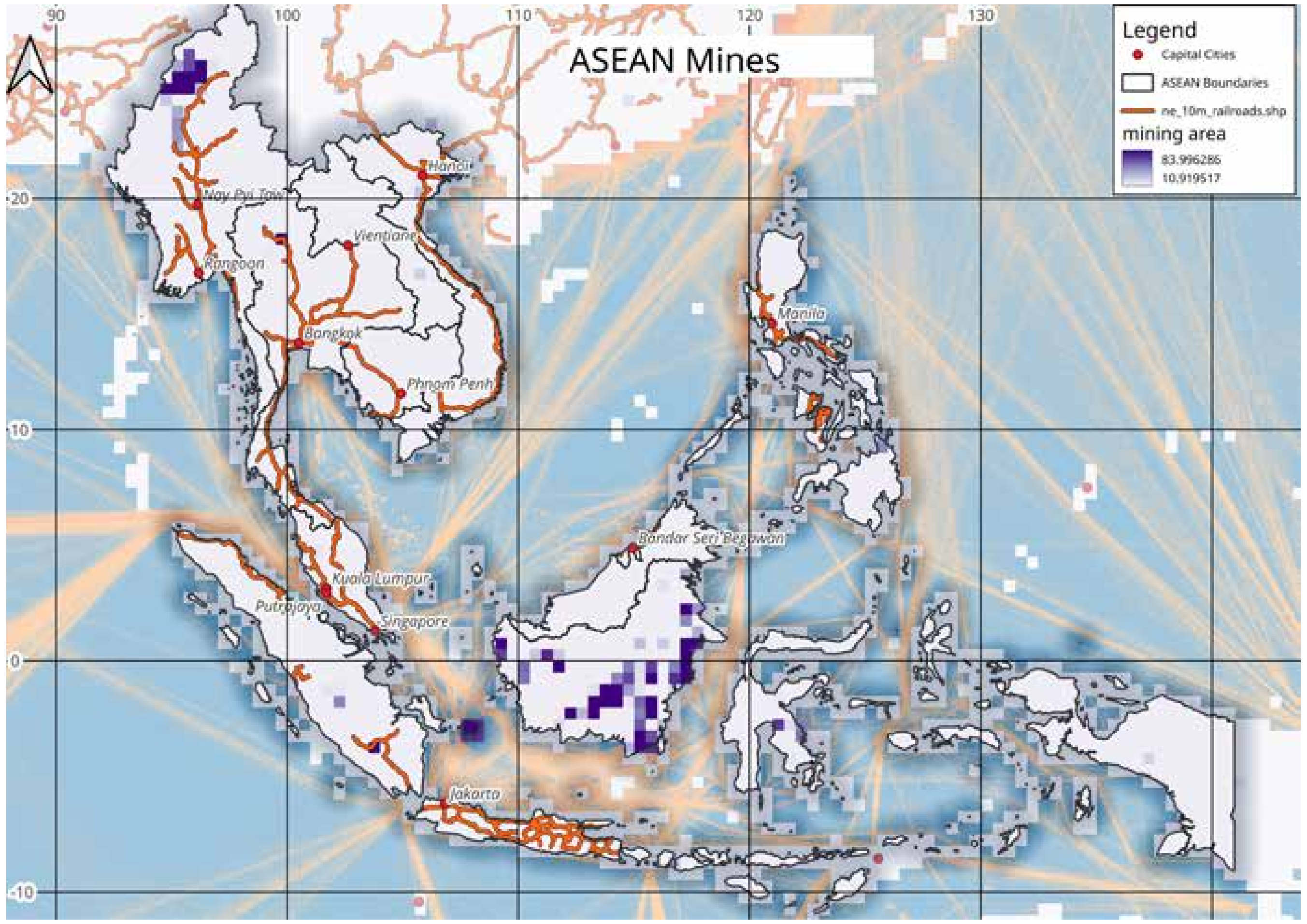


FIGURE 2: MAP OF ASEAN MINES, UNITS ARE SQUARE KILOMETRES OF ALL MINES' POLYGONS WITHIN A PIXEL. (THE MAP ALSO SHOWS IMPORTANT TRANSPORT ROUTES).

Thailand's mining sector is mainly focused on non-metallic minerals, with only limited capacity for CM extraction (IGF, 2023). However, with 300,000 t of gold and 200,000 t of tin reserves, Thailand still represents a potential supplier to meet the increasing global demand for CMs (Gel et al., 2021; Verbiest, 2013). Despite its significantly smaller reserves compared to other countries in the region, Thailand's government has been proactive in refining mining regulations and promoting the sustainable extraction of these resources.

Cambodia currently lacks significant mineral extraction and processing capacity (IGF, 2023) with land use conflicts, especially between artisanal miners and industrial mining activities, limiting development of the sector (Spiegel, 2014) (IEA, 2024b). Despite this, Cambodia's government has developed the "National Policy on Mineral Resources 2018-2028" as a guide for the expected development of the country's mining industry (IGF, 2023).

Lao PDR is another country where over 60% of its territory remains rural. Unlike other countries that have increased extraction and processing in the last decade, the ASEAN-IGF Minerals Cooperation (2023) estimates that copper production and refining in Lao PDR have decreased by 30% between 2010 and 2020. However, conscious of the need for increased production, the government established the National Green Growth Strategy in 2018 as guidelines to guide mining development until 2030. Further geological exploration work is required to determine mineral availability (IGF, 2023) of iron, gold, zinc and copper (Tuan et al., 2023; Nguyen et al., 2024). While the quantities of REE reserves are not yet precisely quantified, Sanematsu et al. (2011) identified the regions, such as the basalt-derived laterites in the Bolaven Plateau, as promising areas for REE exploration. Furthermore, the National-scale Geochemical Mapping Project established a geochemical baseline for these resources, offering valuable insights into the distribution and concentration of 69 elements across the country (Wang et al., 2022).

Finally, **Brunei Darussalam** and **Singapore** are two ASEAN countries with no significant mineral reserves or mineral processing capacity. However, they still represent crucial actors which can contribute to other parts of the CM value chain. In the case of Singapore, a country with high levels of access to technology and infrastructure, it stands as a strategic region for downstream sections of the CM value chain, such as component manufacturing and recycling (IGF, 2023). In the case of Brunei, the IGF (2023) identified the potential of their hydrocarbon sources to sustain the high-energy smelting processes in the rest of the region. Currently, geological explorations in Brunei Darussalam have focused mainly on hydrocarbon resources rather than mineral extraction. However, Roslim et al. (2020) propose that geological mapping and exploration efforts are necessary to better understand and exploit any hidden mineral resources that could support the country's economic future.

In Appendix C, we show Metal Ores Footprints of the ten ASEAN countries in 2022 using Sankey diagrams to visualize the metal flows from each ASEAN country.

KEY TAKEAWAYS FROM SECTION 1:

→ The ASEAN region is currently undergoing a significant transformation in its mining sector, driven by the increasing demand of the energy transition.

→ Currently, Indonesia and Myanmar are the ASEAN Member States with the highest mining and processing capacity. While Indonesia is positioning itself as a primary global supplier of nickel and a leading processor of smelted nickel, smelted tin, and ferronickel (IGF, 2023), Myanmar has become China's largest source of REEs, contributing about 14% of the global output (IGF, 2023) (IEA, 2024).

→ While in previous decades, the mining industry primarily focused on non-metallic minerals such as sand and gravel (Emami et al., 2024), ASEAN countries are currently seeking opportunities to develop their critical minerals mining sector along with their manufacturing capacity of batteries, electronics, and renewable energy technologies.

→ While substantial reserves of different CM exist across the region, countries still need to develop their mineral and processing capacity to become significant players.

Section 2: Member states Renewable Energy Potential

THIS SECTION PROVIDES AN ANSWER TO THE FOLLOWING QUESTION:

How are ASEAN Member States positioned to address the energy transition challenges and the global critical mineral demand?

2.1 Renewable energy potential and resulting CM demand in the ASEAN region

Through multilateral initiatives and collaboration efforts, the region is well-positioned to increase renewable energy production. Initiatives focused on solar energy have led countries such as Vietnam and Thailand to invest in large-scale photovoltaic (PV) projects, enhancing them with support mechanisms and regional policies (Pandey et al., 2022; Fahim et al., 2023). Similarly, the diverse landscape of ASEAN countries makes onshore and offshore wind generation viable renewable energy projects, especially for Vietnam, Indonesia, and the Philippines. Chang and Phoumin (2021) note that Vietnam can set a precedent for large-scale wind energy projects, which could be followed by other countries in the region.

The capacity of the region for increasing renewable energy production also means an increased demand for minerals from the region's countries. Figure 3 shows the expected critical mineral in 2050 from clean energy technologies deployed in the ASEAN, utilising data from IRENA & ACE (2022). Furthermore, in Figure 4 we have incorporated country specific data of mineral demand from the power sector according to the AR6 Scenarios Database of Vietnam, Indonesia and Thailand (Byers et al., 2022). The ASEAN regional data from IRENA & ACE (2022). See Appendix G for the renewable technologies included in the critical mineral demand.

FIG. 3

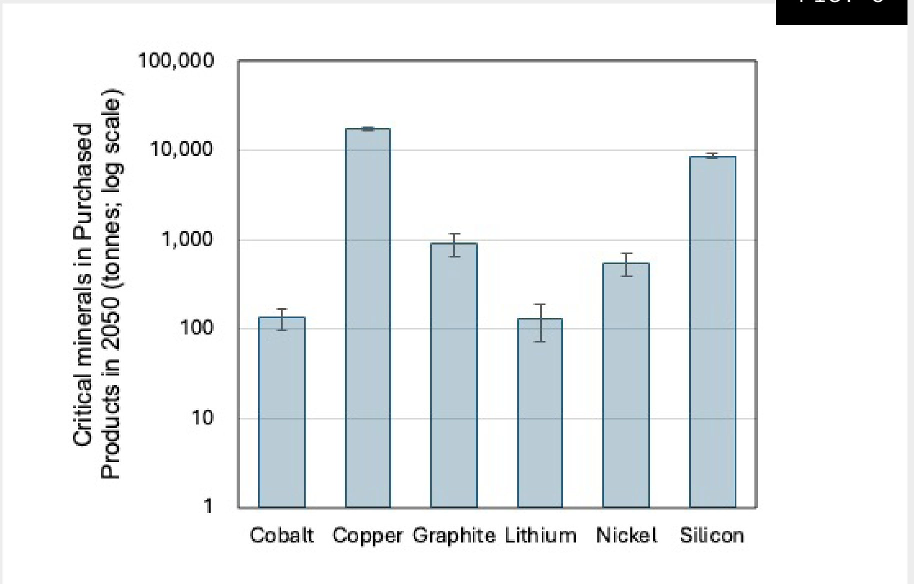


FIGURE 3:EXPECTED CRITICAL MINERAL USE IN CLEAN ENERGY TECHNOLOGIES DEPLOYED IN ASEAN NATIONS IN 2050 (ERROR BARS SHOW UPPER AND LOWER ESTIMATE)

FIG. 4

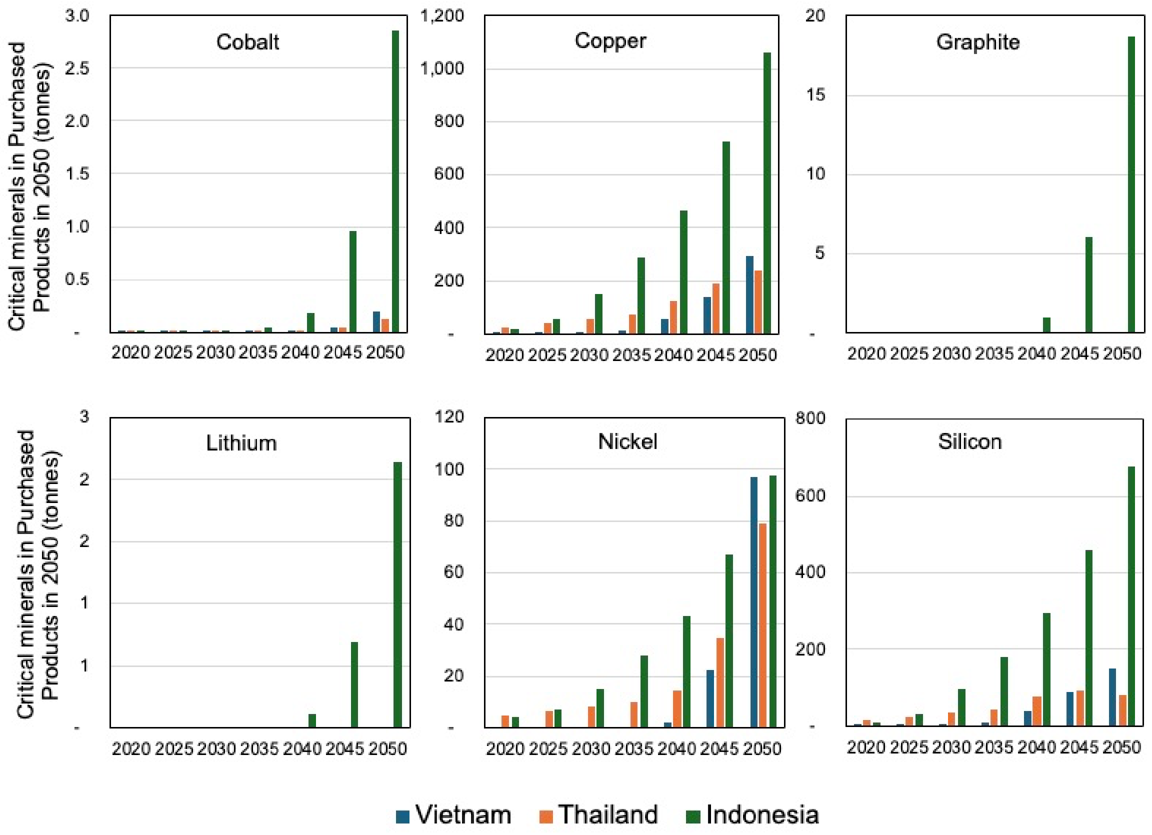


FIGURE 4: ESTIMATED CRITICAL MINERAL DEMAND FROM THE POWER SECTOR 2020-2050 (COBALT, COPPER, GRAPHITE, LITHIUM, NICKEL AND SILICON) [DATA SOURCE: AR6 SCENARIO EXPLORER BYERS ET AL., 2022]

Figures 3 and 4 provide an estimate for the amount of critical minerals in purchased clean energy technologies in use in 2050. This concept differs from annual demand, which only reflects the need for new materials each year and is not addressed in this context. The demand scenarios on this section focus solely on the demand from the power sector and does not include other uses for these same critical minerals.

2.2 Electricity Generation and Copper Demand

Electrification is central priority of the region. Through initiatives such as the ASEAN Plan of Action for Energy Cooperation (APAEC) and the ASEAN Power Grid (APG), the region has established ambitious targets to increase renewable energy production. By enhancing electrification and electricity delivery throughout the entire region, APG seeks to foster greater collaboration for more efficient energy generation and distribution (Budiman et al., 2021; Phoumin et al., 2021). In 2021, renewable energy accounted for 16% of the total electricity generation across the ASEAN region; however, the aim is to increase to 23% by 2025 and 31% by 2050 (Yana et al.,2021).

As the region continues to grow economically and demographically, the electricity demand in the ASEAN region is expected to increase from 993 TWh in 2018 to 2,200 TWh in 2040 (ACE & HAPUA, 2021) (ACE, 2024). Recently, the ASEAN Ministers on Energy Meeting endorsed the ASEAN Interconnection Masterplan Study (AIMS) III which outlines a three-phase plan to establish the ASEAN cross-border interconnection system between the north (Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, the south (Indonesia Malaysia and Singapore), and the east (Brunei, Indonesia, Malaysia, the Philippines) (ACE & HAPUA 2021; ACE, 2024).

Since 2022, a similar multilateral power trade agreement has been implemented through the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP), using existing interconnections to transport 100 MW of hydroelectric power from Lao PDR to Singapore via Thailand and Malaysia (ACE, 2020; ACE, 2024). Similar projects continue to be planned, such as The Brunei Darussalam-Indonesia-Malaysia-Philippines Power Integration Project (BIMP-PIP), which Malaysia-Philippines Power Integration Project (BIMP-PIP) aims to install 17 interconnections across four Member States (ACE, 2024).

Figure 5 illustrates the expanding ASEAN power grid, which remains a key regional priority for strengthening grid resilience, enhancing connectivity, and promoting sustainability through clean energy integration (ACE, 2020).

The transition from fossil fuels to renewable energy requires a significant increase in electricity interconnection capacity, estimated at 3.75 million km of additional cable (DNV, 2024, p. 9). Implementing bi- and multilateral electricity interconnection plans in the ASEAN region will come with significant material requirements for electricity interconnection, especially of copper, increasing the need to strengthen the mineral sector as soon as possible.

We estimate the total copper required for planned multi-lateral power projects in the ASEAN region to be 100,000 tonnes, equivalent to one billion USD using today's copper prices. Full details of transmission type, voltage, line capacity, distance and copper required are shown for each planned electricity connection, in Appendix D: Section 2.1. While the exact amount of copper needed for HVDC and HVAC power depends on different variables, our estimates uses typical cable construction values from Sumitomo Electrical (2016). The estimate for HVDC cables is based on XLPE subsea cables with a 500 kV capacity and a conductor size of 1100 mm2. The estimates for HVAC cables are based on XLPE land cables with a 330 kV capacity and a conductor size of 2000 mm2. On average HVAC cables will require more copper per kV as they are less efficient than HVDC cables.

FIG. 5

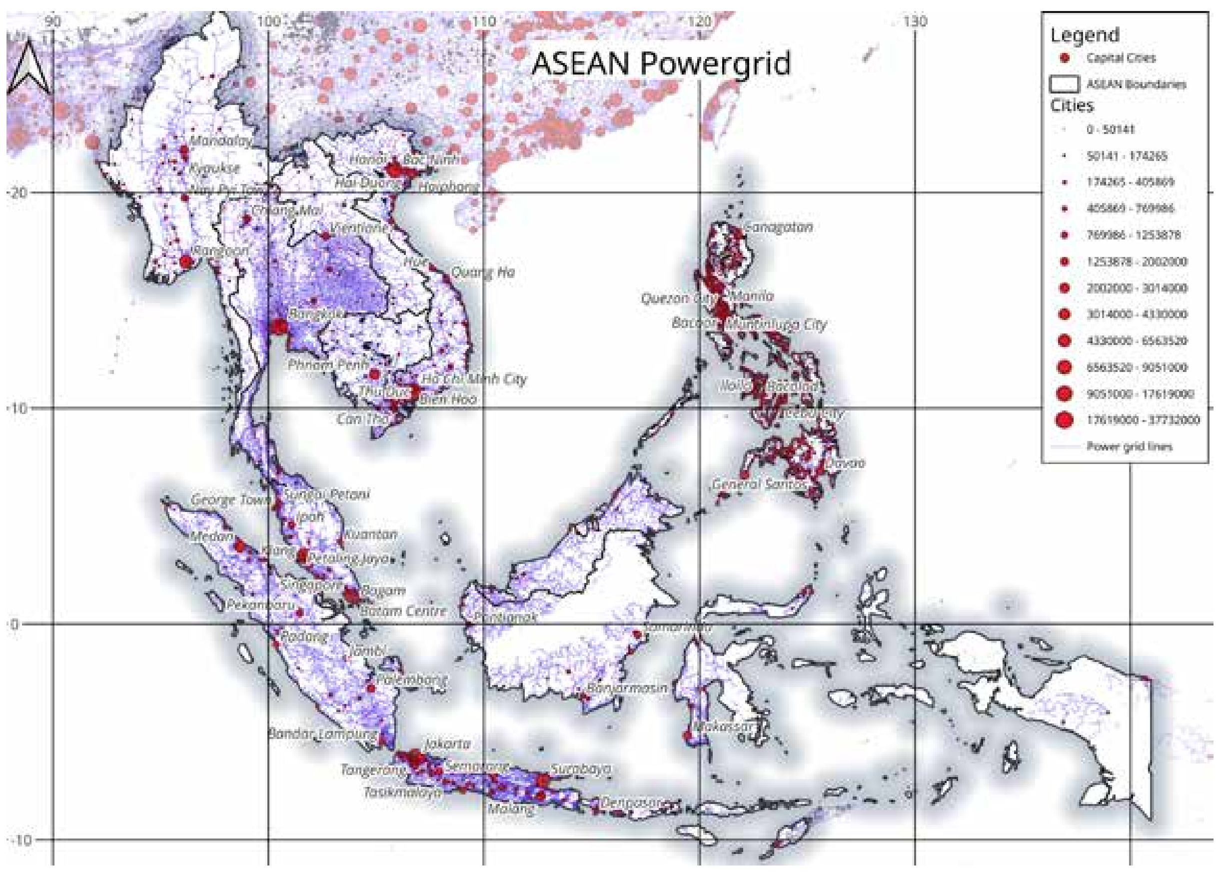


FIGURE 5: THE ASEAN POWERGRID IN 2020 (ACE, 2020).

2.3 Decarbonising Transport

2.3.1 Policies that support transport decarbonising in the ASEAN region

The transport sector is currently responsible for a significant percentage of greenhouse gas emissions (GHG) in the ASEAN region. It is therefore one of the central focus areas for decarbonisation plans. Figure 6 visualises the transport networks for the ASEAN region, including: major roads and road density, railroads, and ports and shipping density. Phoumin et al. (2021) indicate that through the ASEAN Framework for Energy Cooperation (AFEC) and the ASEAN Smart Cities Network initiatives, the region has committed to integrating clean transport. Furthermore, the region has established the ASEAN Connectivity Master Plan to enhance regional transport infrastructure and effectively connecting ASEAN Member States.

Examples include the ASEAN Highway Network and the Singapore-Kunming Rail Link Projects, which aim to facilitate commercial exchange while reducing environmental impacts (IMF, 2018; Aritenang, 2017). Sulisnaningrum et al. (2023) reveal that the introduction of policies such as 'environmental taxation' also encouraged investment in low-emission transport infrastructure. Furthermore, Wahab and Naim (2021) demonstrate that the introduction of ASEAN's Green Bond establishes an institutional precedent for facilitating funding for sustainable transport initiatives. This policy approach, in addition to supporting financing needs, also promotes long-term infrastructure resilience and sustainability goals (Sudan, 2023).

FIG. 6

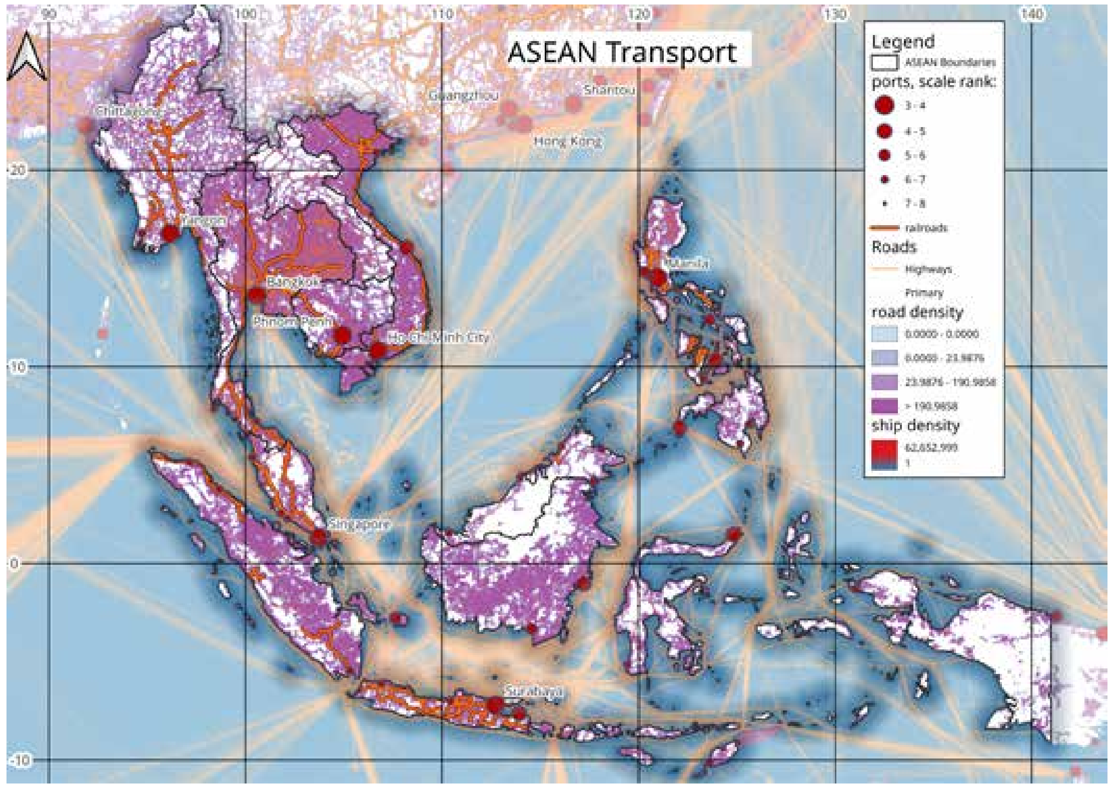


FIGURE 6: THE ASEAN ROAD TRANSPORT NETWORK. ROAD DENSITY UNITS ARE METERS OF ROAD PER KM2 WITHIN A PIXEL. SHIP DENSITY UNIT IS THE NUMBER OF VESSELS RECORDED IN A 0.005° × 0.005° PIXEL FROM JANUARY 2015 THROUGH FEBRUARY 2021. RED POINTS INDICATE PORTS ACCORDING TO PORT RANK (AN ESTIMATED RELATIVE PARAMETER).

Member States have adopted various goals and policies to support the decarbonisation of their transport systems. Thailand has set the goal of 1.2 million EVs (electric vehciles) in use by 2030 as part of its broader strategy to reduce emissions in transport systems, while Singapore has set the goal of only using clean energy vehicles by 2040 and adopted a roadmap for the development of a charging network (Øverland et al., 2021; Huang et al., 2023). Darwis and Wambrauw (2023) illustrate that Vietnam is increasing investment in the renewable energy and electric transport sectors, while pushing for an ambitious EV market strategy. Furthermore, Javed et al. (2024) propose that Vietnam has started to incorporate circular economy principles to reduce material consumption in the transition to sustainable transport.

As the world's largest producer of nickel, a key metal used in the manufacture of EV batteries, the Indonesian government is formulating a broader strategy to link their plan to scale up battery production to EV adoption, taking advantage of their domestic mineral resources and sustainable infrastructure (Bakker et al., 2017; Budiono & Virgianita, 2024). The government has set a target of having EVs make up 20 percent of all car sales by 2025, and for 600,000 EVs to be domestically produced by 2030. Similarly, Soh et al. (2014) indicate that Thailand has adopted the National Electric Vehicle Policy, which supports sustainable transport and incentivises EV manufacturing and the development of charging infrastructures. Thailand and the Philippines' latest policy efforts, like those of other countries in the region, have set a goal of capturing value from natural resources, increasing the competitiveness of local manufacturing while balancing environmental sustainability and advancing net-zero goals. Similarly, private sector initiatives such as Vinfast (2022), an EV manufacturing firm, are increasing the deployment of EVs. In the first month since its launch, it has become the number one car seller in Vietnam.

2.3.2 Required material demand to meet transport decarbonisation goals

For this report, we project demand for electric vehicles (EVs) in the ASEAN region from 2021 to 2025, using an in-house car stock projection, and estimate the material requirements to produce EVs, using our Mat-DP model. The estimation of future electric vehicle stocks involves GDP projections, population growth rates, projections for car stock growth, and penetration rates. The analysis includes expected uptake of Battery-Electric Vehicles (BEVs) and Plug-In Hybrid Vehicles (PHEVs).

Figure 7 shows the total sales of EVs for the ASEAN region, projected using our model. Electric car sales are projected to reach a peak of 9.3 million EVs in 2045, with the largest number of electric car sales being in Indonesia, followed by Thailand, Malaysia, and Vietnam.

As the demand for EVs grows, the materials required to produce these cars are expected to grow and reach a peak in 2045, at a value of 32 Mt per year, and then decrease to 27 Mt per year in 2050. Based on the saturation curves in the projections, once countries reach the saturation point ownership of electric cars is assumed to linearly decrease. Countries with the highest EV numbers are the ones with the highest material demand and material emissions over time.

Figure 8 shows the material demand resulting from EV sales from 2021 to 2050 for the ASEAN region plus Timor Leste (top) and the corresponding material emissions (bottom). The material demand is disaggregated to show the material requirements for EV battery compared to the car (left) and by country (right).

Material demand is also expected to increase to produce batteries, which are crucial components of the EV value chain. Figure 9 shows material demand by ASEAN country for selected critical minerals relevant for EV batteries. Among the selected minerals, the highest demand is for graphite due to its importance in battery anodes. However, as graphite anodes are reduced over time, graphite demand is reduced post 2045. High-nickel and NMC batteries result in nickel having the second-largest demand and trends in manganese and copper having also rising demand over the period. Cobalt has the lowest overall demand with less than 0.5 Mt in the peak year (2045) owing to the increasing use of LFP and other low-cobalt battery chemistries.

While our simulations are focused on the expected demand of the ASEAN region alone, it is important to mention that currently the demand is coming from the Global North, mainly from major western economies and China, while most of the supply comes from developing countries in Southeast Asia, such as Indonesia, Latin America and Africa (Ufimtseva et al., 2024 (Dou & Xu, 2022). The marked disparities in the supply and demand of minerals, make this value chain particularly vulnerable to geopolitical shifts and tensions between China and the West (Dou & Xu, 2022), (Agusdinata et al., 2022). Consequently, the ASEAN regions stand as a strategic region that can be both a consumer and a supplier of its own mineral demand, while also positioning itself as a global supplier of CMs.

FIGURE 7: PROJECTED SALES OF EVS IN THE ASEAN REGION BY COUNTRY 2021 TO 2050

FIG. 7

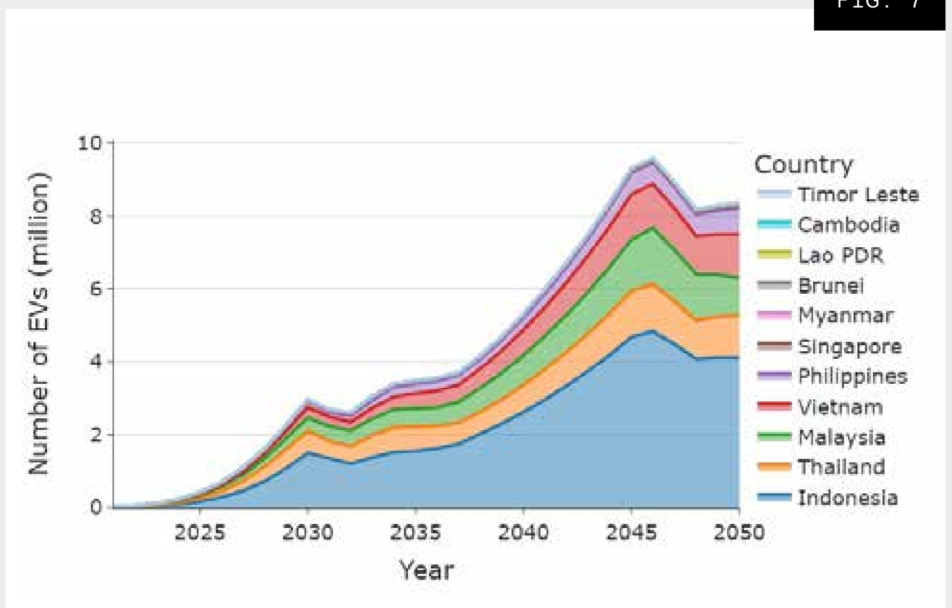


FIG. 8

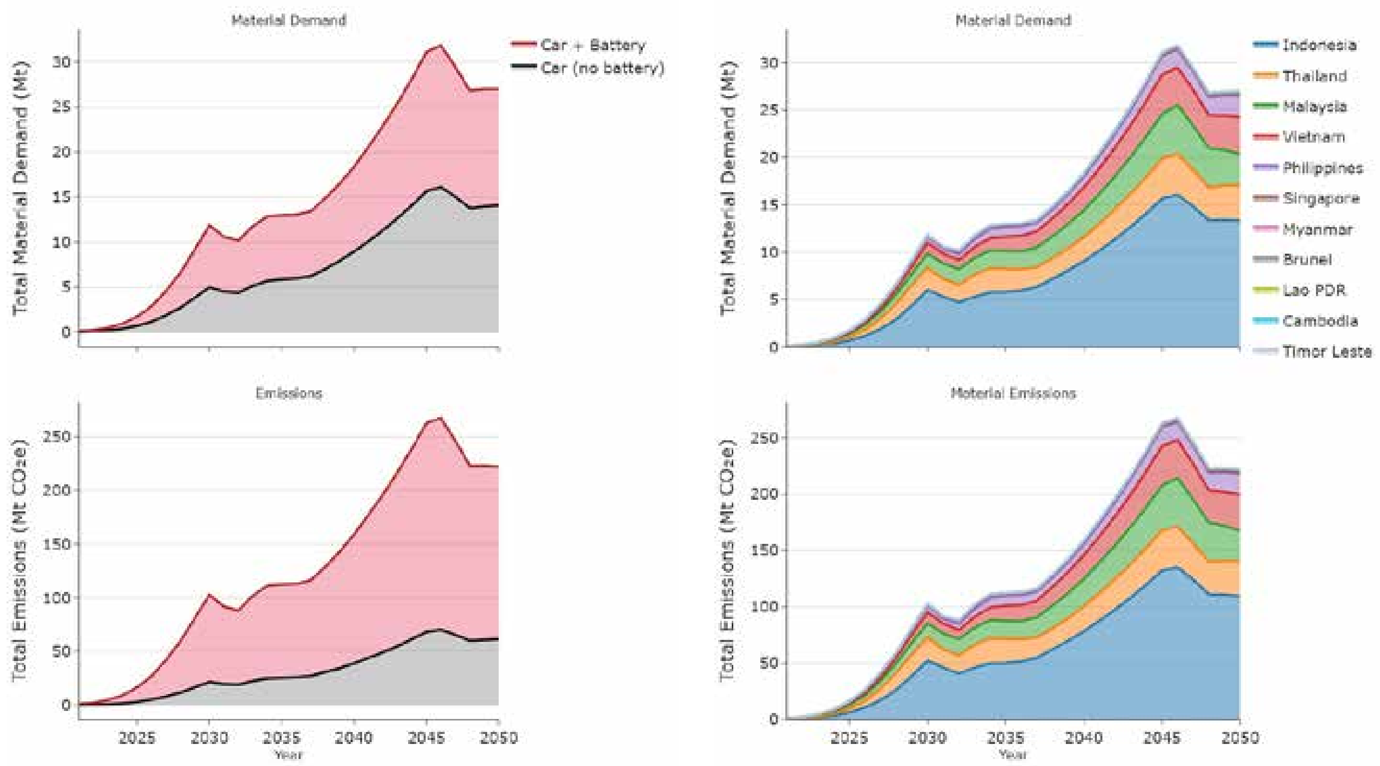
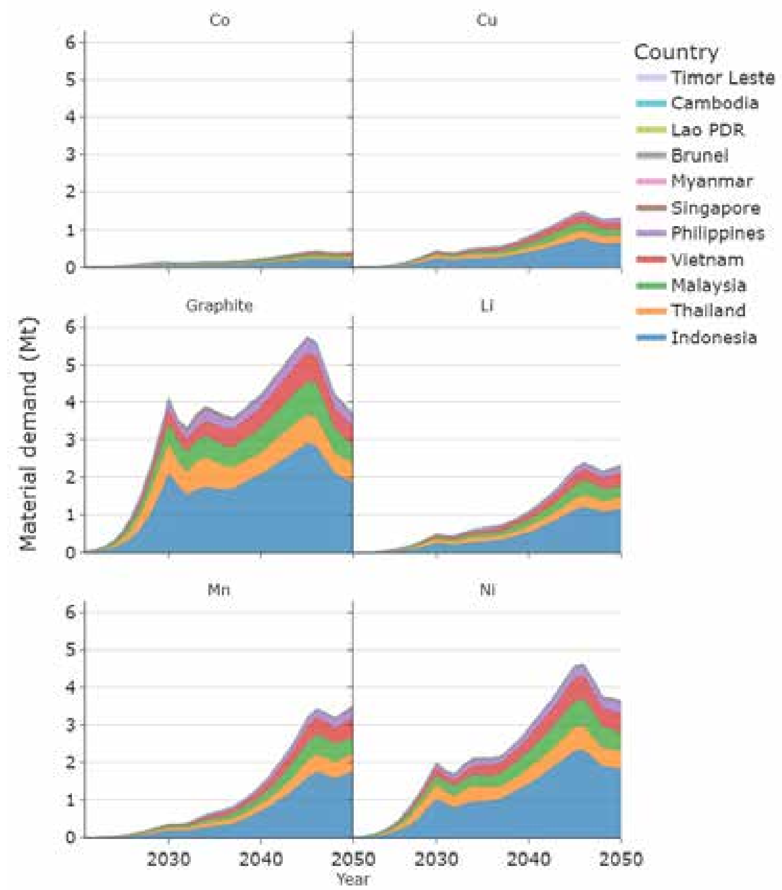


FIGURE 8: TOTAL MATERIAL DEMAND (TOP) AND EMISSIONS (BOTTOM) FOR EV SALES FROM 2021 TO 2050. THE TOTAL FOR ASEAN + TIMOR LESTE (LEFT) AND FOR EACH COUNTRY (RIGHT) ARE INCLUDED.

FIG. 9

FIGURE 9: MATERIAL DEMAND FOR SELECTED BATTERY-RELATED CRITICAL MINERALS BY COUNTRY AND YEAR. ABBREVIATIONS: CO: COBALT, CU: COPPER, LI: LITHIUM, MN: MANGANESE, NI: NICKEL.



KEY TAKEAWAYS FROM SECTION 2

→

As the region grows economically and demographically, electricity demand in the ASEAN region is expected to rise. Planned electricity interconnectors between ASEAN countries will require substantial resources, including approximately 100,000 tonnes of copper, to implement the planned HVAC and HVDC transmission systems.

→

The transport sector is a major source of greenhouse gas emissions in the ASEAN region. Policies are being introduced to encourage the use of clean transportation, including electric vehicles (EVs). The shift to EVs increases the demand for minerals, such as nickel, which is driving the regional growth of the EV supply chain.

→

ASEAN Member States aim to increase their share of renewable energy, with solar, wind, hydropower, and bioenergy from agricultural waste being key sources. However, financial and technological barriers, as well as political hurdles, slow the deployment of renewable energy projects in the region.

Section 3: ASEAN region barriers for CM sustainable extraction and carbon management strategies

THIS SECTION PROVIDES AN ANSWER TO THE FOLLOWING QUESTION:

What are the key issues facing the ASEAN region concerning critical minerals and renewable energy development?

3.1 Challenges for Sustainable Critical Mineral Extraction

The increased extraction of critical minerals to meet energy transition goals and fulfil the increasing demand comes with significant social, governance, and environmental challenges (Agusdinata et al., 2022). As Ding and Beh (2022) point out, environmental vulnerabilities continue to increase due to the inadequacy of regulatory frameworks. In recent years, ASEAN Member States have made significant efforts to improve their ESG (Environmental, Social and Governance) performance, however, due to the voluntary nature of the regulation, adequate protection of communities and ecosystems has not been achieved (Rizki & Hartanti, 2021). Furthermore, heavy dependency on external investment for the development of the mineral sector, exacerbates the geopolitical pressures from China and the West to extract minerals in the fastest possible way while minimising social and environmental concerns (Ufimtseva & Shapiro, 2024).

Loss of livelihoods, rights violations, and inadequate compensation for local populations are among the most common negative social consequences of the expansion of the mining sector in the ASEAN region (Astuti et al., 2025). For instance, Malaysia is currently facing increased conflicts with local communities, in part due to the lack of comprehensive stakeholder engagement (Amelia et al., 2023; Voingpuhakdy, 2023). Similarly, Cambodia is challenged by the complex interactions between globalisation, rural place-making, and the extractive industry, emphasising the significance of resettlement and land use conflicts inherent in gold mining operations in provinces like Kratie and Ratanakiri (Spiegel,2014).

In environmental terms, deforestation, soil degradation, and water pollution are some of the greatest impacts identified in the region (Agusdinata et al., 2022). Deforestation is a pressing environmental concern in mining areas. In Indonesia, the country with the most significant mining activity in the ASEAN region, the impacts are already evident (Husnah, 2023). Figure 10 show deforestation in the region from 2000 to 2023, illustrating a significant change.

While the region has ample room for improvement, Budiarto and Nainggolan (2023) demonstrate that Malaysia and Indonesia are among the leading ASEAN countries in taking steps to enhance ESG performance and promoting better governance and transparency in the mining sector. In Indonesia, Corporate Social Responsibility (CSR) has become legally mandated by the Mineral and Coal Mining Act, making companies move towards guaranteeing environmental protection and community engagement (Husnah, 2023). For example, Kohlis et al. (2020) indicate that PT Freeport Indonesia's environmental protection and community engagement practices resulted in improved operational sustainability and better relations with communities. Furthermore, a recent study from Indonesia by Husnah (2023) found that ESG disclosures had a positive impact on the sales and stock valuations of mining companies. Similarly, regulatory improvements have been made in Malaysia; the Malaysian Code of Corporate Governance was revised and replaced by a more comprehensive regulatory framework. Makhdalena et al. (2023) demonstrate that increased stakeholder pressure demanding better ESG standards and compliance has led to the development of new and stronger governance frameworks that promote corporate accountability. This, in turn, has been suggested by Sundoro et al. (2025) to have positively impacted the financial performance of companies in Malaysia.

In the Philippines, mining activity has historically been confronted by local opposition; however, recently, efforts that bring together multinational companies and local communities to develop a joint ESG strategy have been effective in promoting successful programs in areas such as reforestation and healthcare (Husnah, 2023). Similarly, in Vietnam, the government has been working to improve mining operations and implement a regulatory framework that emphasises ESG. Wahab et al. (2024) reveal that mining companies have also adopted efforts to adopt green mining technologies to mitigate the ecological impacts.

FIG. 10

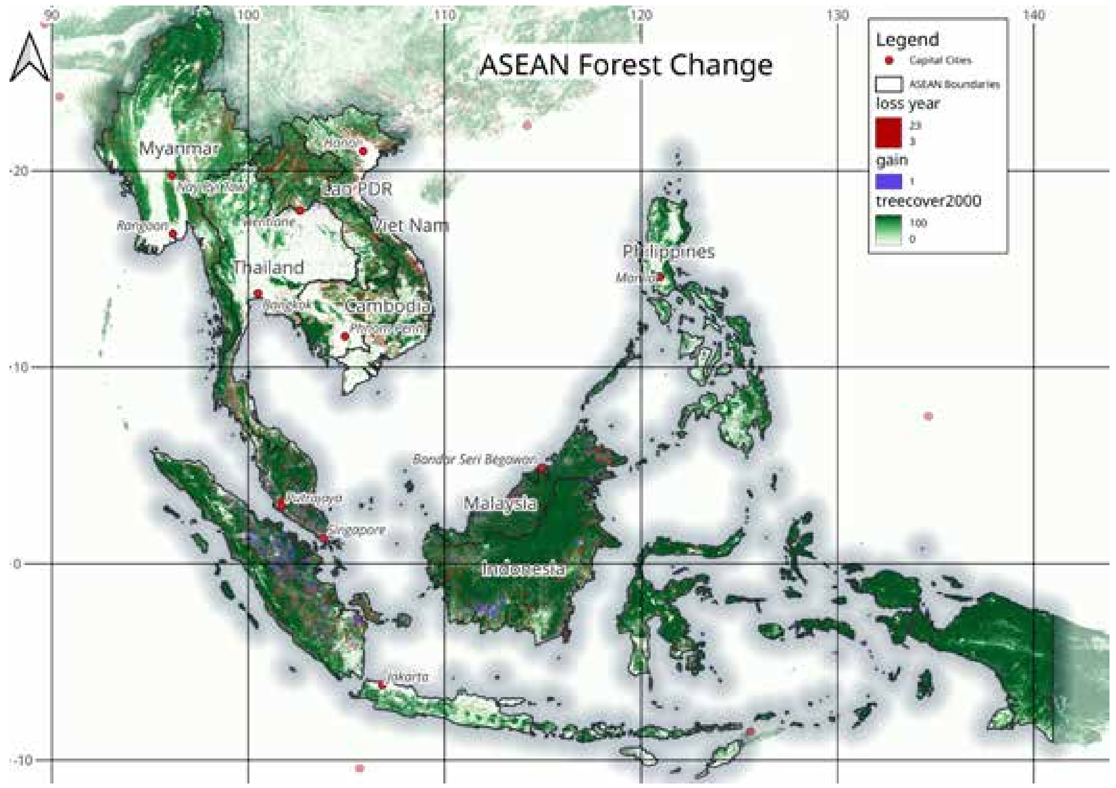


FIGURE 10: ASEAN FOREST CHANGE, I.E., DEFORESTATION FROM 2000 TO 2023.

3.2 Challenges for Renewable Energy Development

While the ASEAN region's clean energy potential is significant, meeting the energy mix targets of expanding renewable energy sources to 23% by 2025 and 31% by 2050 presents significant challenges (Claire & Widyawati, 2023). Some of the barriers include reliance on fossil fuels and increased greenhouse emissions; insufficient electricity infrastructure capacity; and technological gaps.

The region relies primarily on coal and natural gas for electricity generation, accounting for 57 % 9.6% of total electricity production (IEA, n.d.). Despite the current dependence on fossil fuels and stated goals to develop reliable and sustainable energy infrastructure, countries like Vietnam continue to construct coal-fired power plants (Chen & Mauzerall, 2021).

Such heavy reliance on fossil fuels, is increasing the risk of a "carbon lock-in" scenario, in which not only current emissions are perpetuated, but investment in renewable energy sources is blocked (Øverland et al., 2021; Yusoff et al., 2024; Vakulchuk et al., 2022). Fahim et al. (2023) demonstrate that ASEAN Member State economies currently rely heavily on fossil-fuel energy systems. Consequently, there is significant uncertainty in market dynamics, which hinders the financing of renewable energy projects. Countries like Vietnam continue to construct coal-fired power plants despite the urgency to develop reliable and sustainable energy infrastructure (Chen & Mauzerall, 2021).

Electricity demand and consumption have increased in parallel with GDP, alongside rising levels of urbanisation and industrialisation (Sabado et al., 2022). Increasing electrification projects such as the Brunei Darussalam-Indonesia-Malaysia-Philippines Power Integration Project (BIMP-PIP) have put the existing electricity infrastructure under increasing demand, making the need for electricity reliability and efficiency and urgent effort (Vu et al., 2019). According to the National Electricity Development Planning, the total electricity demand in

FIG. 11

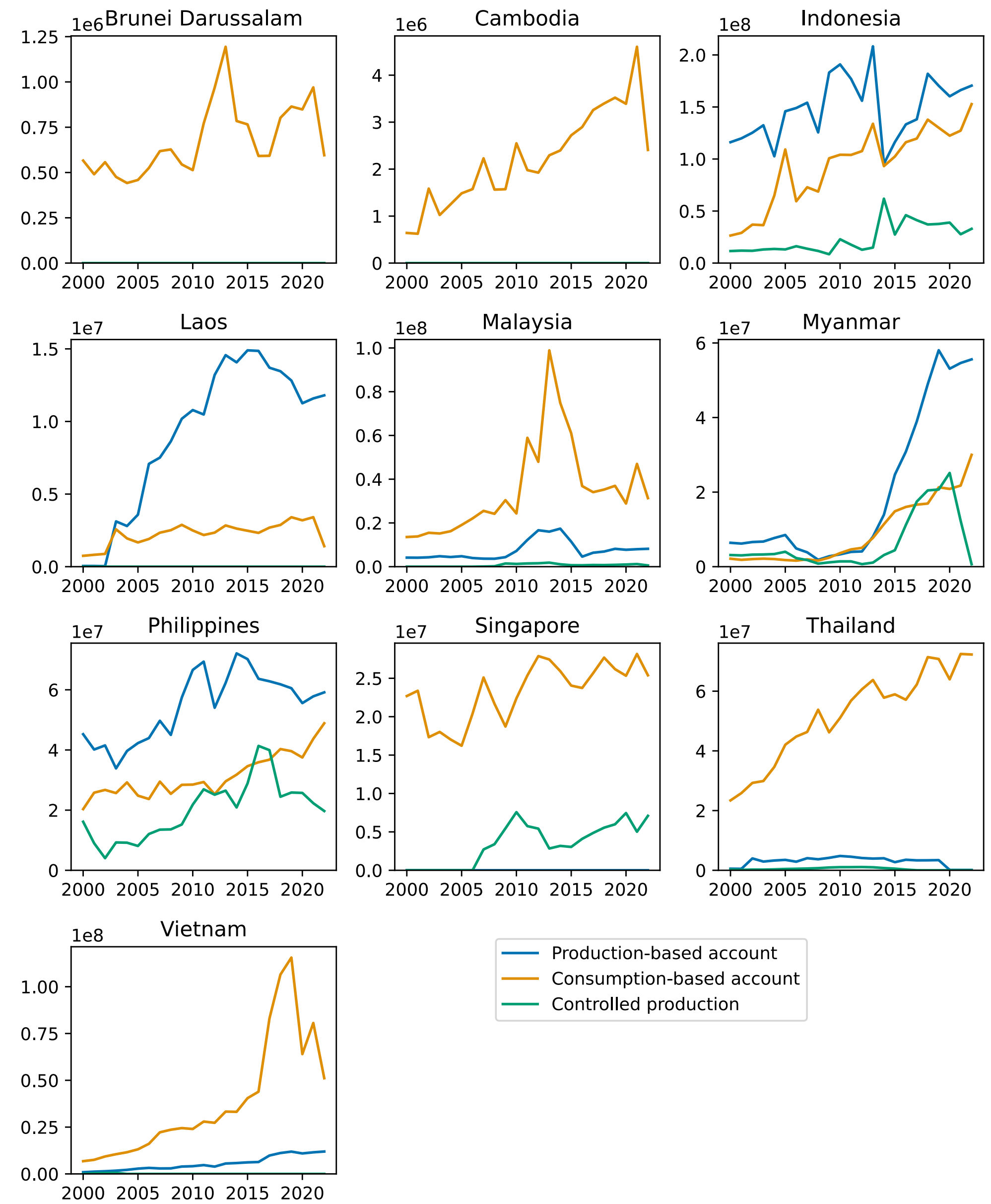


FIGURE 11: PRODUCTION AND CONSUMPTION PLOTS FOR EACH ASEAN MEMBER STATE. COUNTRIES WITHOUT DOMESTIC PRODUCTION SHOW ONLY CONSUMPTION ACCOUNTS.

Vietnam is expected to rise to 124 GW by 2030 (Nguyen et al., 2024). Similarly, Shafie et al. (2018) show that in Malaysia, electricity demand rose from 91.6 GWh in 2007 to 140.2 GWh in 2015; and Nazri et al. (2018) propose that demand is expected to grow at an approximate rate of 4.7% and reach 274 TWh by 2030. The Philippines has also experienced a significant rise in demand, reflected as well in its share increase of prices (Samuel, 2022).

As countries energy demand increase, transitioning to renewable forms of energy is becoming increasingly important, not only for the advancement of the energy transition goals, but also for acquiring energy sufficiency. Even now, the demand for critical minerals has been significantly increasing in the region, leading to an increase in demand in the major economies such as Thailand, Indonesia, Singapore and the Philippines, and an increase in production among mineral rich countries such as Laos, Myanmar, Indonesia and the Philippines. Furthermore, while the control over production remains significantly low, the production and consumption of CMs continues to rise, indicating a high reliance on the region on FDI.

Figure 11 shows the production and consumption plots of critical minerals for each ASEAN Member State. Production based account refers to material extraction in the country, while consumption-based account refers to flow either produced or embodied in the country's final consumption, and controlled production refers to the fraction of the flow that is produced by the country that is owned by domestic capital. The data is derived from the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

It is essential to note that while socio-environmental challenges are less prevalent, challenges also arise with renewable electricity sources, such as hydropower, large-scale wind farms, and solar farms. Vietnam is one of the countries with a larger share of renewable energy generation, with 35% coming from hydro, 10% from solar PV, and 3% from wind (IEA, N.D.). However, these electricity sources also come with environmental challenges such as spatial limitations, land-use conflicts, and resistance from local communities that have blocked the continuous deployment of this renewable form of energy technologies. (Fahim et al., 2023; Chang & Phoumin, 2021).

Despite the vast potential of the region to become a renewable energy hub, significant financial barriers and technological gaps remain obstacles. For instance, Nepal et al (2021) argue that with sufficient investment, energy from hydropower could be a viable source of renewable energy for the region, specifically for countries with suitable topography, such as Lao PDR and Myanmar. Similarly, Lau et al. (2022) demonstrate that bioenergy derived from agricultural waste could be a sustainable and alternative form of energy generation in agricultural economies such as Laos, Cambodia, and Vietnam.

Finally, the challenges are even more pronounced for the ASEAN countries with the lowest levels of socioeconomic development, such as Cambodia, Laos and Brunei. While electricity consumption per capita has increased by 2,427% from 2000 to 2022, the IEA (n.d.) notes that Cambodia still has the second-lowest electrification rate in the region. In the case of the Lao PDR, despite having one of the highest hydropower capacities, exporting energy to Thailand and Vietnam (Phomsoupha, 2012), around 20% of the population still lacks reliable electricity access. Prum et al. (2024) propose that expanding the electricity grid and electrifying rural areas of the country is crucial to increasing the economic development and living standards of communities.

KEY TAKEAWAYS FROM SECTION 3

→ The increased extraction of CM to meet energy transition goals and fulfil the increasing demand comes with significant social, governance, and environmental challenges.

→ Environmental vulnerabilities continue to increase due to the inadequacy of regulatory frameworks. In recent years, ASEAN Member States have made significant efforts to improve their ESG performance; however, due to the voluntary nature of the regulation, adequate protection of communities and ecosystems has not been achieved.

→ Heavy dependency on external investment for the development of the mineral sector exacerbates the geopolitical pressures from China and the West to extract minerals in the fastest possible way while minimising social and environmental concerns.

→ Heavy reliance in fossil fuels, is increasing the risk of a "carbon lock-in" scenario, in which not only current emissions are perpetuated, but investment in renewable energy sources is blocked.

→ Increasing electrification projects such as the Brunei Darussalam-Indonesia-Malaysia-Philippines Power Integration Project (BIMP-PIP) have put the existing electricity infrastructure under increasing demand, making the need for electricity reliability and efficiency and urgent effort.

Conclusion

In this scoping report, we explore the academic and grey literature to provide a knowledge base for understanding the mining capacity and the availability of critical materials in the ASEAN region. The review introduces the ASEAN region, with: Section 1 covering ASEAN the current mining activity and mineral reserves; Section 2 provides an overview of the region's renewable energy potential, calculates the copper demand based on current and future electrification demand, and estimates the material demand of transport decarbonisation; Section 3, discusses the development and environmental issues facing in the ASEAN region in relation to critical minerals and renewable energy development.

Some of the key takeaways from Section 1 are that the ASEAN region is currently undergoing a significant transformation in its mining sector, driven by the increasing demand for the energy transition. While in previous decades, the mining industry primarily focused on non-metallic minerals such as sand and gravel (Emami et al., 2024), ASEAN countries are currently seeking opportunities to develop their critical minerals mining sector along with their manufacturing capacity of batteries, electronics, and renewable energy technologies.

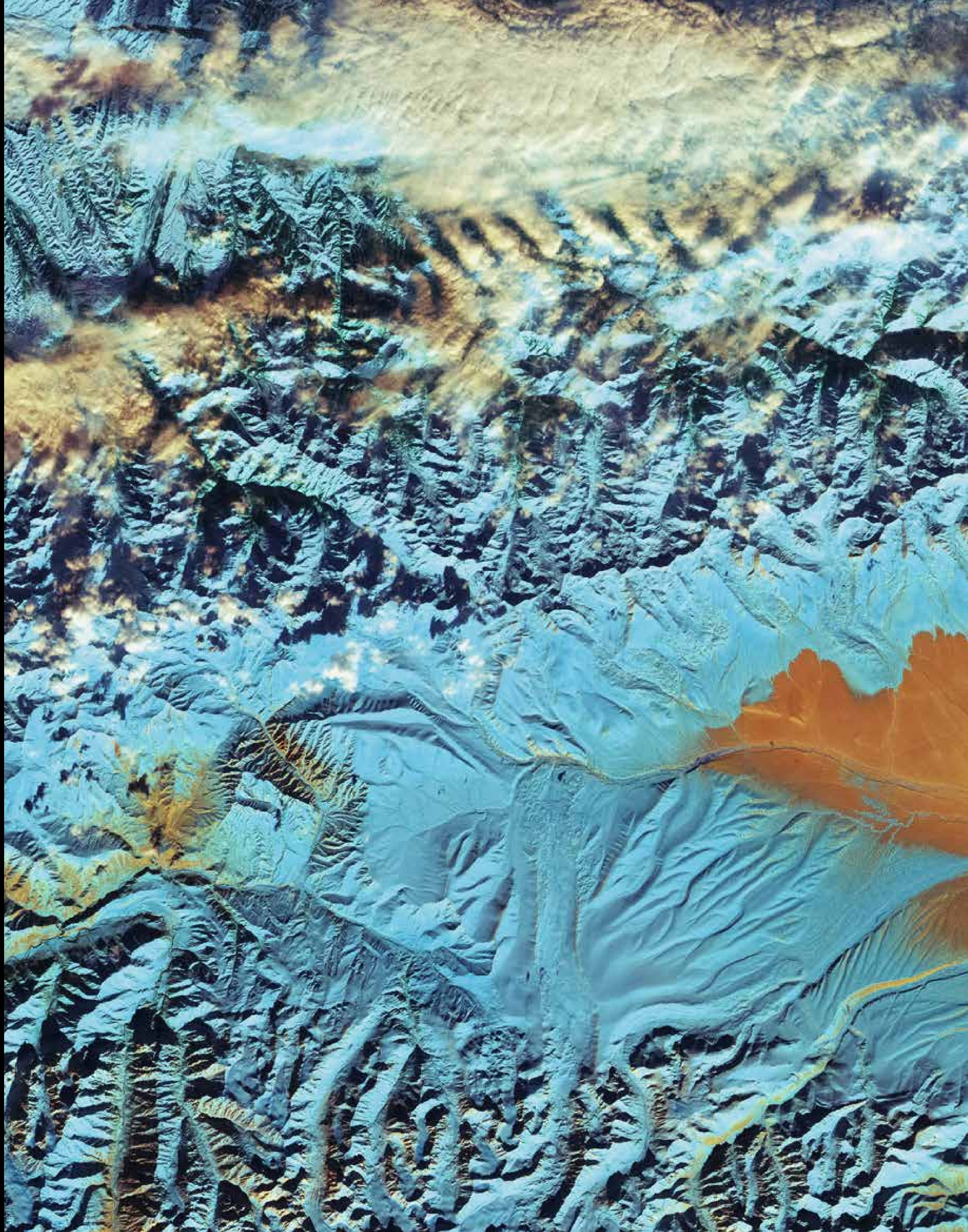
Currently, Indonesia and Myanmar are the ASEAN Member States with the highest mining and processing capacity. While Indonesia is positioning itself as a primary global supplier of nickel and a leading processor of smelted nickel, smelted tin, and ferronickel (IGF, 2023), Myanmar has become China's largest source of REEs, contributing about 14% of the global output (IGF, 2023) (IEA, 2024). While substantial reserves of different CM exist across the region, countries still need to significantly develop their mineral and processing capacity to become significant players. Sankey diagrams and material flows calculations of all ASEAN countries have been included in the Appendix C.
The key takeaway from Section 2 is that as the region continues to grow economically and demographically, electricity demand will also continue to increase. Electricity interconnectors will require substantial resources, including approximately 100,000 tonnes of copper valued at about one billion USD, to implement the planned HVAC and HVDC transmission systems. The transport sector is a major source of greenhouse gas emissions in the ASEAN region. Policies are being introduced to encourage the use of clean transportation, including EVs (electric vehicles). The shift to EVs increases the demand for minerals, such as nickel.

In Section 3, we conclude that while the ASEAN region's clean energy potential is significant, meeting the energy mix targets of expanding renewable energy sources to 23% by 2025 and 31% by 2050 presents significant challenges (Claire & Widyawati, 2023). Some of the barriers include reliance on fossil fuels and increased greenhouse emissions; insufficient electricity infrastructure capacity; and technological gaps.

The increased extraction of CM to meet energy transition goals and fulfil the increasing demand comes with significant social, governance, and environmental challenges (Agusdinata et al., 2022). Loss of livelihoods, rights violations, and inadequate compensation are among the most common social impacts (Astuti et al., 2025). In environmental terms, deforestation is one of the most pressing environmental concerns that comes with increased mining. Impacts are already evident in Indonesia, the country with the most significant mining activity in the ASEAN region, the (Husnah, 2023).

Governance and regulatory frameworks are key to mitigating socio-environmental sustainability issues in CM operations. However, Ding and Beh (2022) show that environmental vulnerabilities continue to increase due to the inadequacy of regulatory frameworks. In recent years, ASEAN Member States have made significant efforts to improve their ESG performance, however, due to the voluntary nature of the regulation, adequate protection of communities and ecosystems has not been achieved(Rizkiand Hartanti, 2021).

Finally, it is important to mention that while the negative impacts of renewable electricity sources are less than those of fossil fuels, spatial limitations, land-use conflicts, and resistance from local communities are challenges that have blocked the continuous deployment of this form of energy (Fahim et al., 2023; Chang & Phoumin, 2021).



Appendix

Appendix A: Abbreviations

AEC: ASEAN Economic Community

AFEC: ASEAN Framework for Energy Cooperation

AIMS: ASEAN Interconnection Masterplan Study

APAEC: ASEAN Plan of Action for Energy Cooperation

APEP: Americas Partnership for Economic Prosperity

APG: ASEAN Power Grid

ASEAN: Association of Southeast Asian Nations

BAU: Business as Usual

BIMP-PIP: Brunei Darussalam-Indonesia-Malaysia-Philippines Power Integration Project

CAGR: Compound Annual Growth Rate

CSR: Corporate Social Responsibility

DMC: Domestic Material Consumption

ESG: Environment, Social and Governance

EV: Electric Vehicle

FDI: Foreign Direct Investment

G7: Group of Seven

GDP: Gross Domestic Product

GHG: Greenhouse Gas

HVAC: High Voltage Alternating Current

HVDC: High Voltage Direct Current

IEA: International Energy Agency

IGF: Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development

IPEF: Indo-Pacific Economic Framework

JETP: Just Energy Transition Partnership

Lao PDR: Lao People's Democratic Republic

LTMS-PIP: Lao PDR-Thailand-Malaysia-Singapore Power Integration Project

NDC: Nationally Determined Contribution

PV: Photovoltaic

REE: Rare Earth Element

WTO: World Trade Organisation

Appendix B: List of Figures and Tables

Appendix C: Metal Ores Footprints of ASEAN Countries in 2022.

INDONESIA

Figure C1: The metal ores footprint of Indonesia in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Indonesia or embodied in Indonesia's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

PHILIPPINES

Figure C2: The Metal ores footprint of the Philippines in 2022 The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in the Philippines or embodied in the Philippines final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

VIET NAM

Figure C3: The metal ores footprint of Viet Nam in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Viet Nam or embodied in Viet Nam's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

MALAYSIA

Figure C4: The metal ores footprint of Malaysia in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Malaysia or embodied in Malaysia's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

THAILAND

Figure C5: The metal ores of Thailand in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Thailand or embodied in Thailand's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

CAMBODIA

Figure C6: The metal ores footprint of Cambodia in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Cambodia or embodied in Cambodia's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

FIG. C1

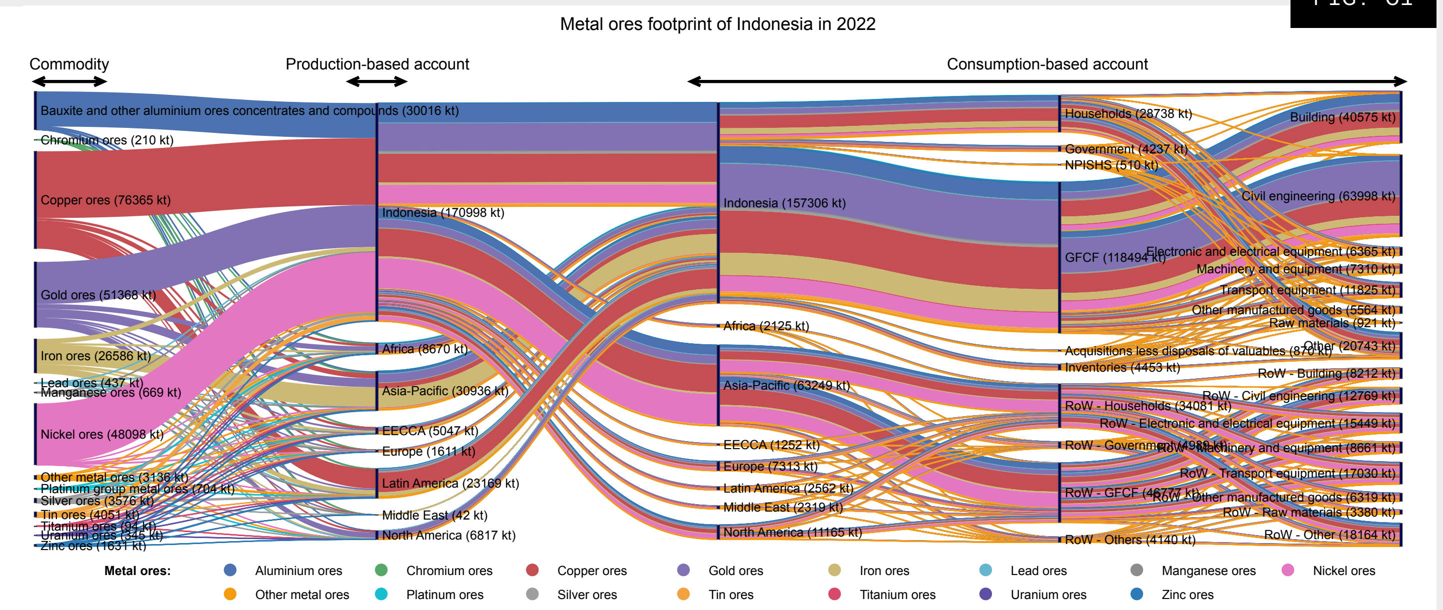


FIG. C2

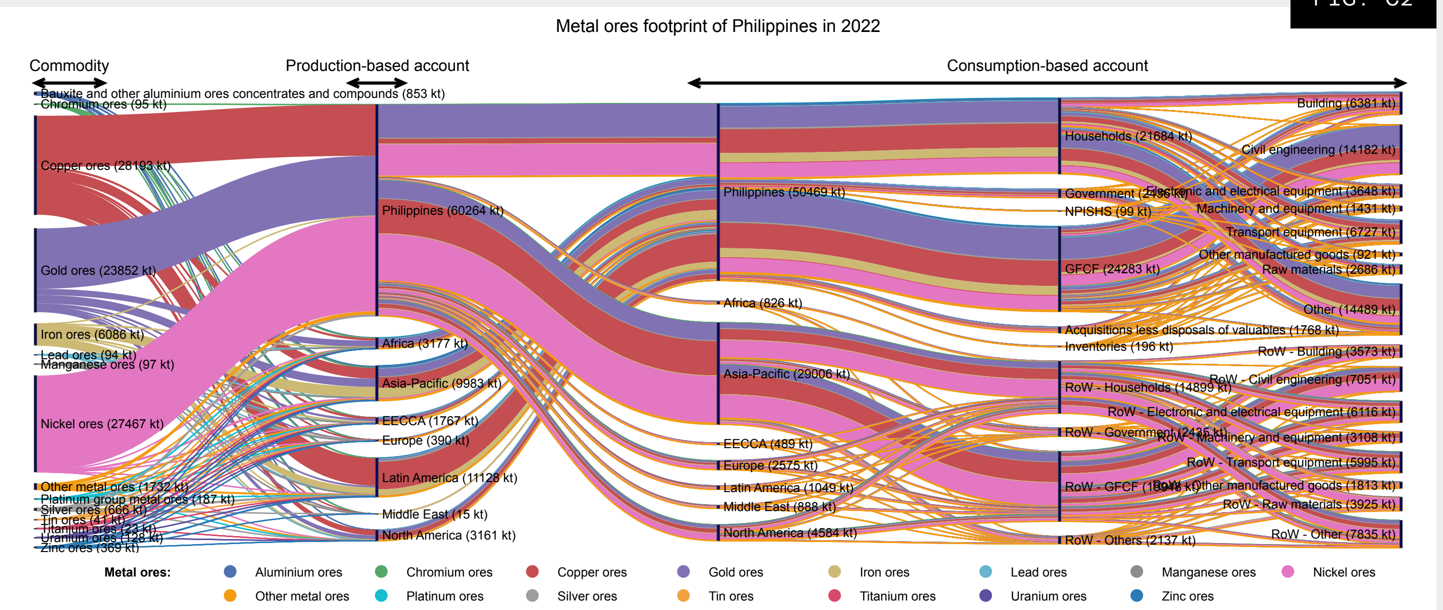


FIG. C3

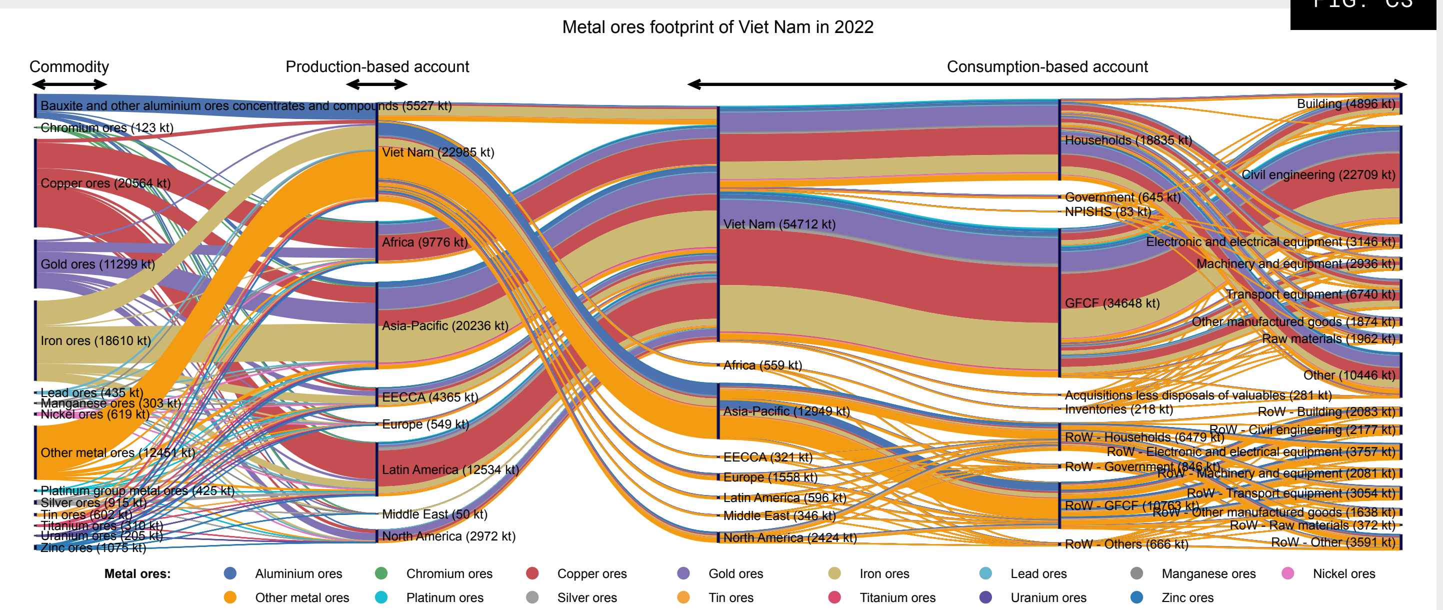


FIG. C4

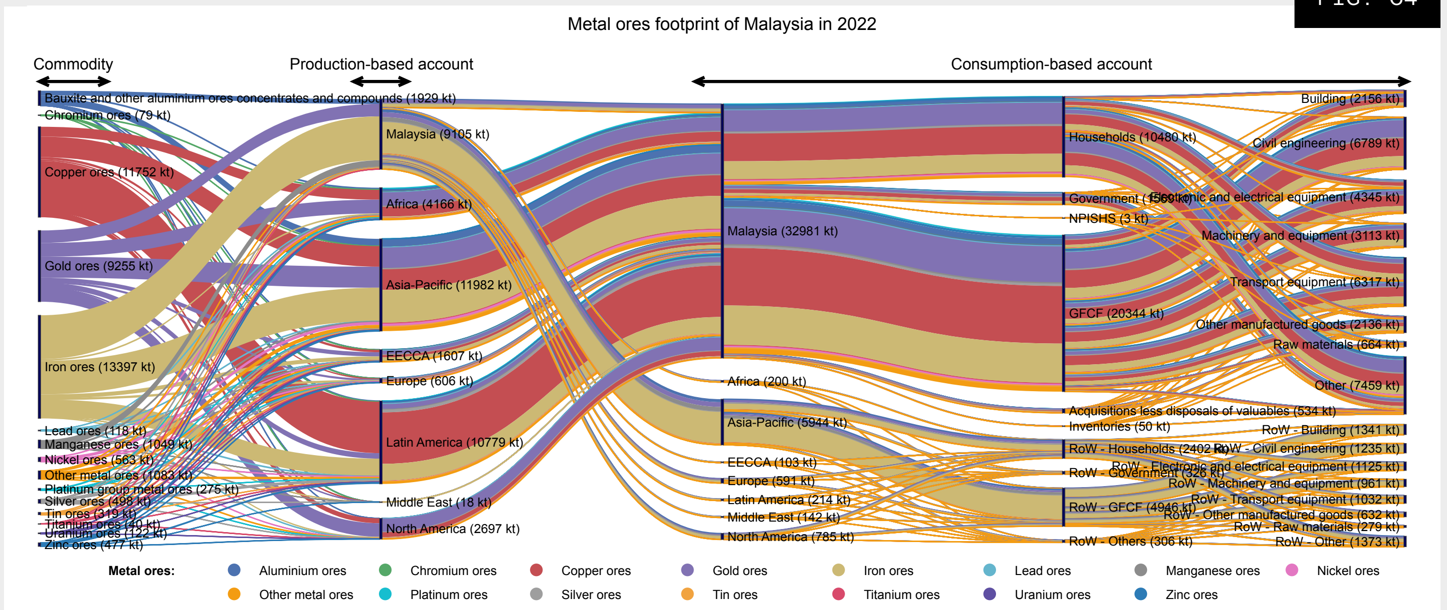


FIG. C5

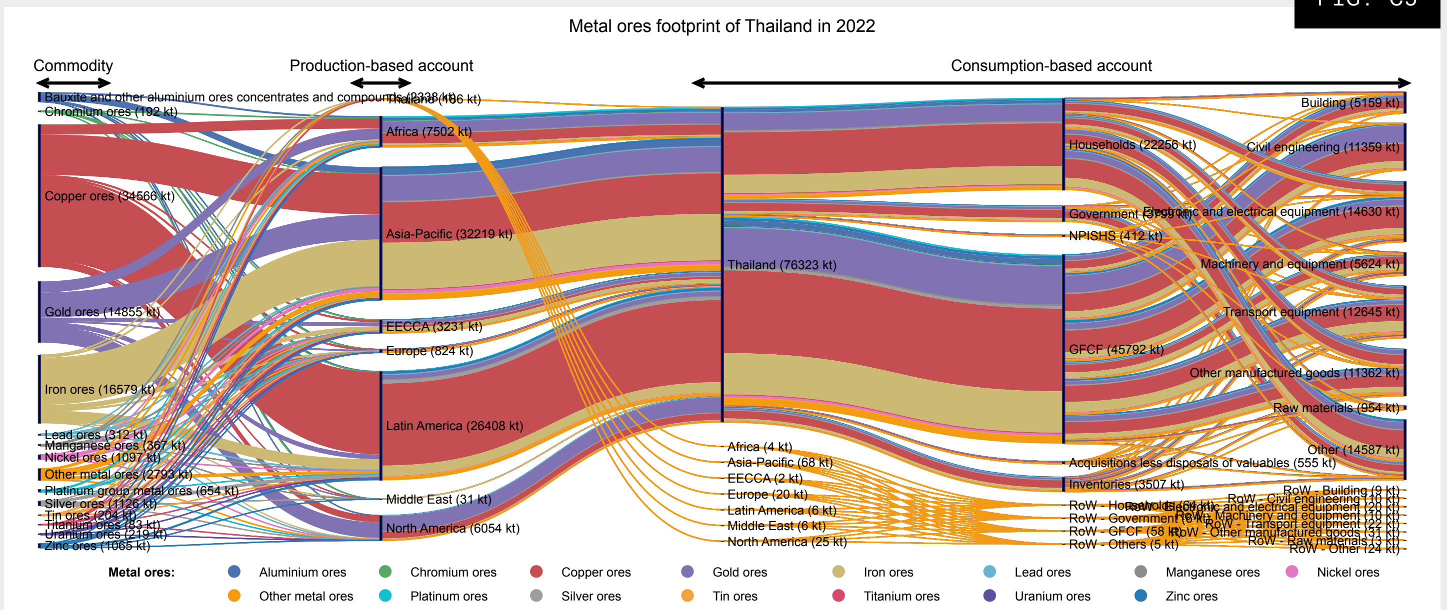
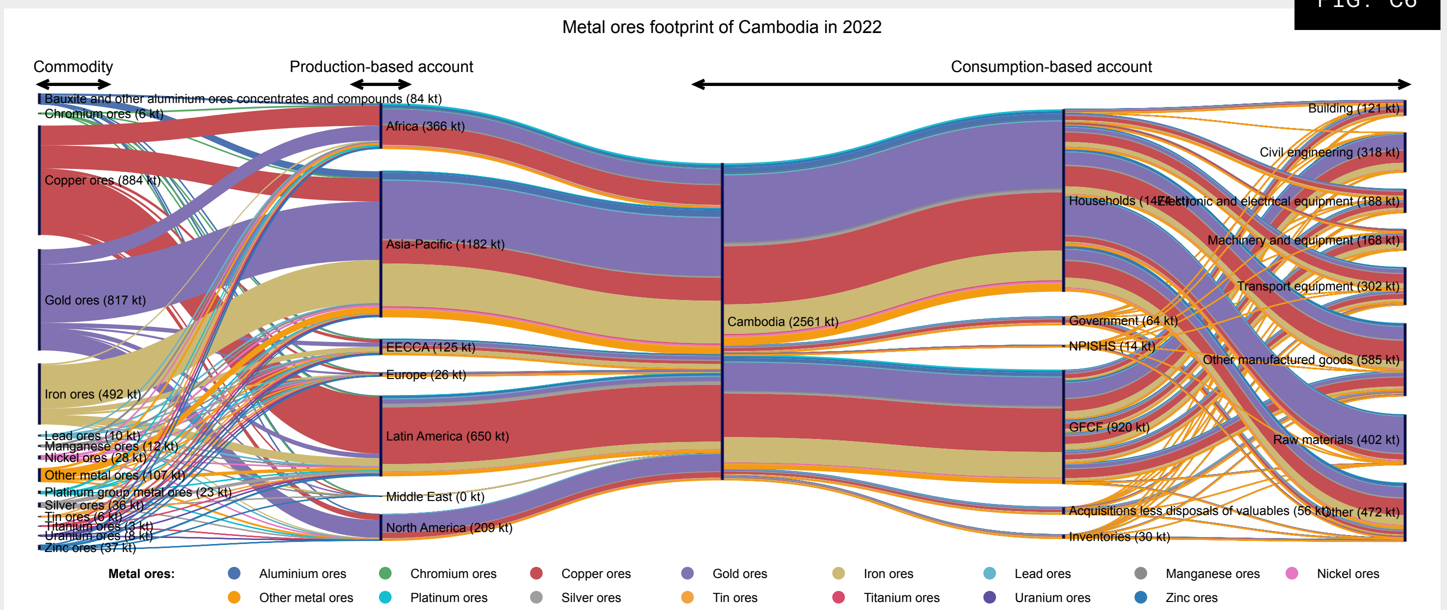


FIG. C6



MYANMAR

Figure C7: The metal ores footprint of Myanmar in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Myanmar or embodied in Myanmar's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

LAO PDR

Figure C8: The metal ores footprint of Lao PDR in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Lao PDR or embodied in Lao PDR's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

BRUNEI DARUSSALAM

Figure C9: The metal ores footprint of Brunei Darussalam in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Brunei Darussalam or embodied in Brunei Darussalam's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

SINGAPORE

Figure C10: The metal ores footprint of Singapore in 2022. The first step corresponds to the commodity, the second step to the production-based accounts (extraction) and the last three steps to the consumption-based account by region, final consumer, and final consumption sector. Any flow represented here is either produced in Singapore or embodied in Singapore's final consumption. The colours correspond to the first step of the diagram. Sankey available online: https://application-sankey-rm.onrender.com/ . We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

FIG. C7

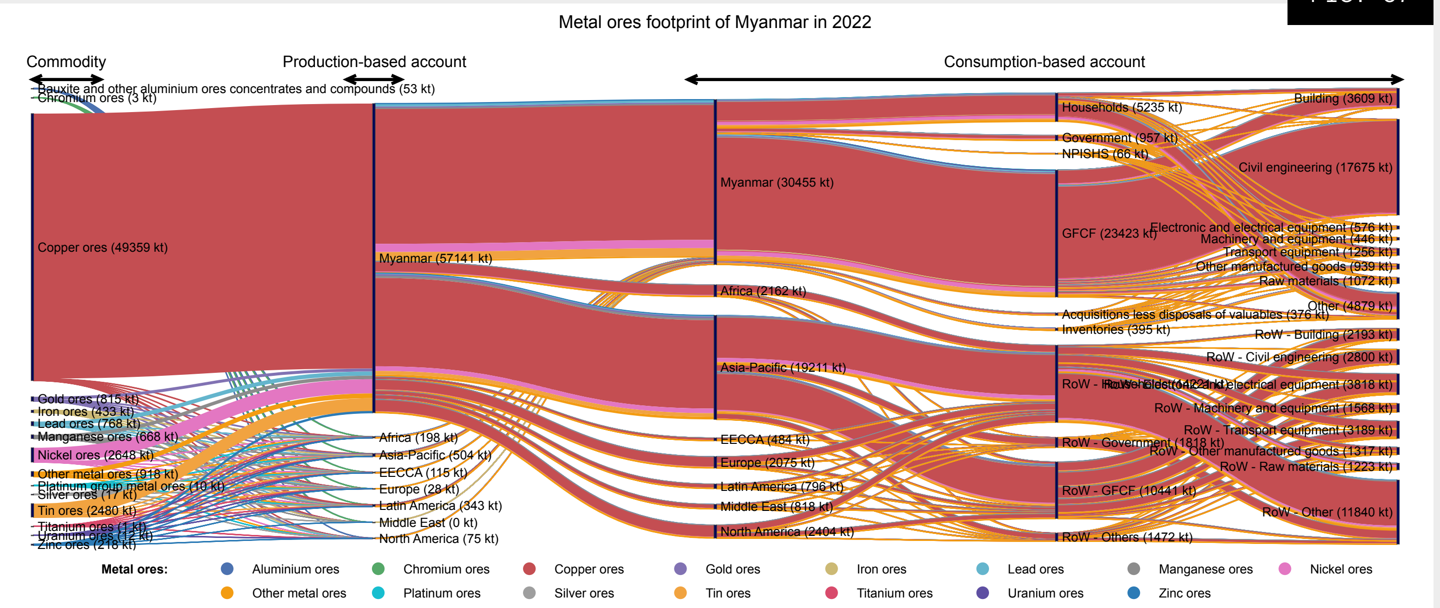


FIG. C8

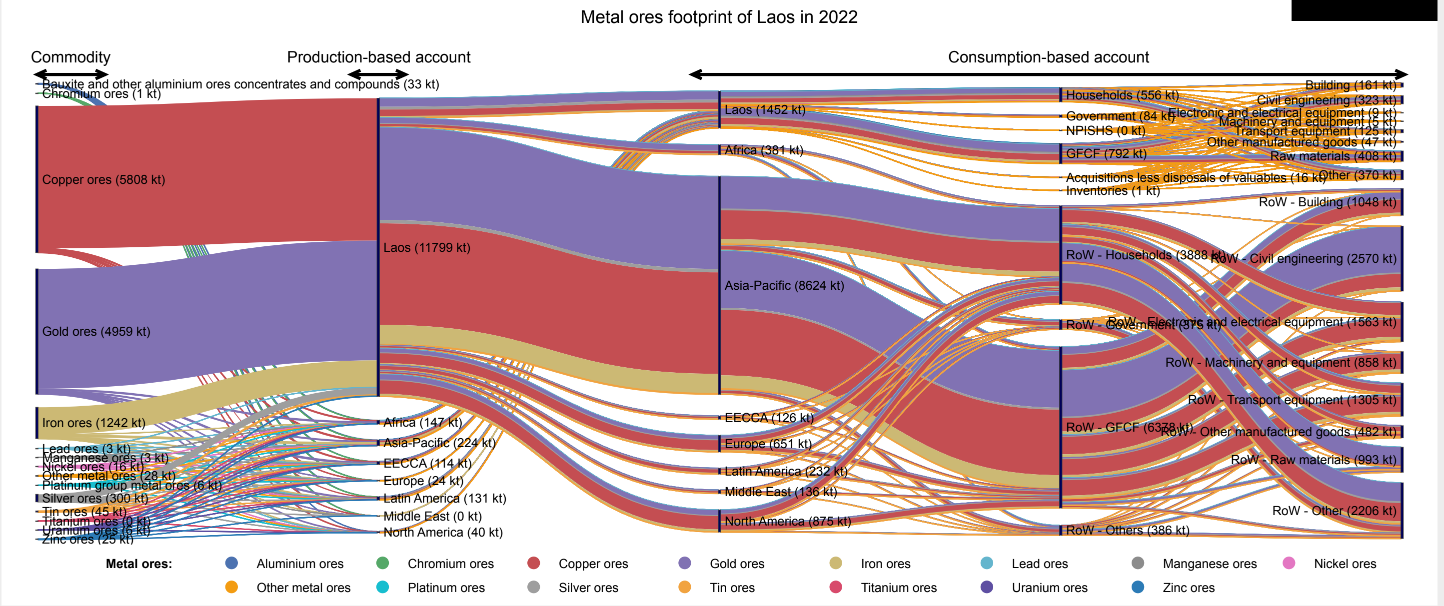


FIG. C9

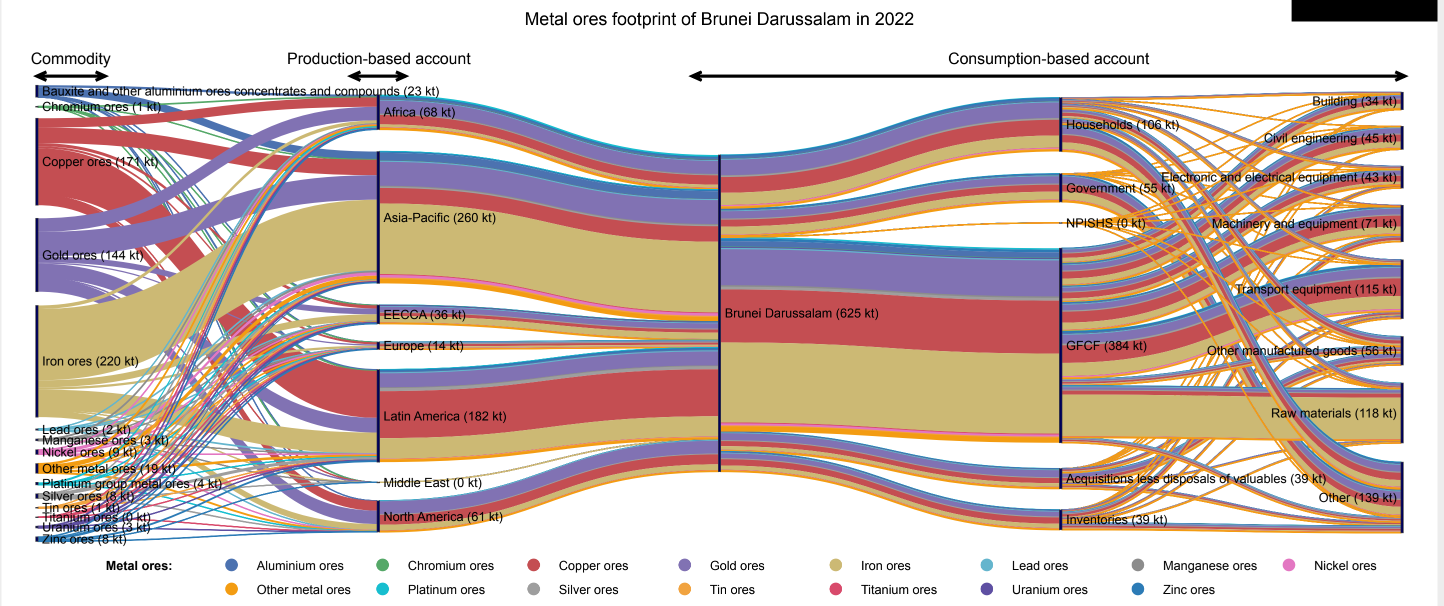
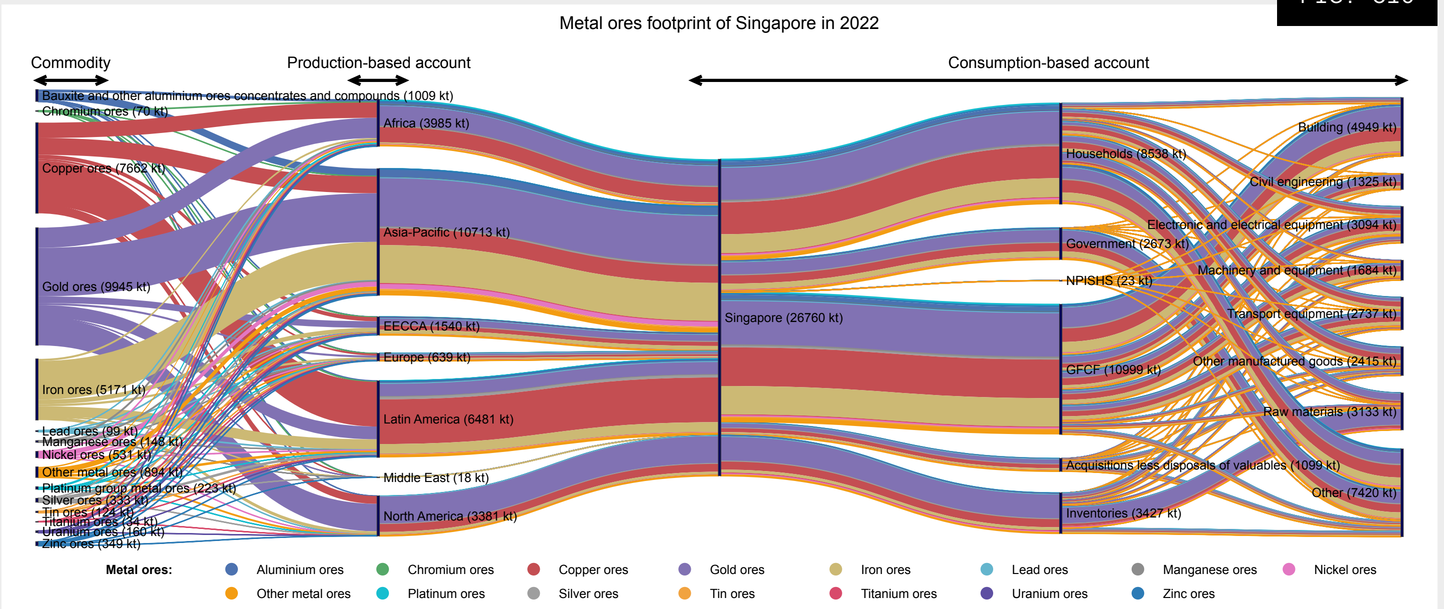


FIG. C10



Appendix D: Electricity Generation

CONNECTION	TRANS-MISSION SYSTEM TYPE*	VOLTAGE (KV)*	LINE CAPACITY (MW)	DISTANCE (KM)	COPPER REQUIRED (KG)
Plentong (Peninsular Malaysia) to Woodlands (Singapore), part of LTMS-PIP (ACE & HAPUA, 2024).	HVDC	230	525* 1,050**	12 (overhead)^ 4 (underground)^	215,040 39,424
Khlong Ngae (Thailand) to Gurun (Peninsular Malaysia) (ACE & HAPUA, 2024).	HVAC	TBC	1,043**	110 (overhead)^	1,971,200
Sarawak (Malaysia)-Peninsular Malaysia (ACE, 2020; ACE & HAPUA, 2024).	HVDC	500	2 x 800* 695**	676 (subsea)*	66,662,656
Telok Gong (Peninsular Malaysia) to Perawang, Sumatra (Indonesia) (ACE, 2024).	HVDC	500	600* 2,130**	234 (subsea)*	2,306,304
Kudat, Sabah (Malaysia) to Palawan (The Philippines), part of BIMP-PIP (ACE, 2020; ACE & HAPUA, 2024).	HVDC	TBC	196*	388 (subsea)^^	3,824,128
Tudan, Sarawak (Malaysia) to Lumut (Brunei Darussalam) (ACE & HAPUA, 2024).	HVAC	275	71**	61-74 (overhead)* 13 (overhead)^	1,093,120-1,326,080
Lawas, Sarawak (Malaysia) to Mengalong, Sabah (Malaysia) (ACE & HAPUA, 2021).	HVAC	275	30-50* 177**	30 (overhead)* 13 (overhead)^	232,960 -537,600
Mae Chan (Thailand) to Ton Pheung (Lao PDR) (ACE & HAPUA, 2024).	HVAC	115/230	5,427**	270 (overhead)^	4,838,400
Nam Ou (Lao PDR) to Dien Bien (Vietnam) (ACE & HAPUA, 2024).	HVAC	220	5,000**	203 (overhead)^	3,637,760
Mae Sot (Thailand) to Myawaddy, Hutgyi (Myanmar) (ACE, 2020; ACE & HAPUA, 2024).	HVAC	230	365* 1,262**	31 (overhead)*	555,520
Lao PDR-Cambodia (ACE & HAPUA, 2024) Ban Hat (Lao PDR) to Kampong Sralao (Cambodia) Ban Hat (Lao PDR) to Preah Vihear (Cambodia).	HVAC	115 500	625**	50 (overhead)^	896,000
Watthana Nakhon 2 (Thailand) to Battambang 2 (Cambodia) (ACE & HAPUA, 2024).	HVAC	230/500	650* 1,315**	112 (overhead)* 300 (overhead)^	2,007,040-5,376,000
Sebatik/Nunukan, North Kalimantan (Indonesia) to Kalumpang/Kalabakan, East Sabah (Malaysia) (ACE, 2024; ACE & HAPUA, 2024).	HVAC	TBC	174**	130 (overhead)^	2,329,600
Singapore to Sumatera (ACE & HAPUA, 2024).	HVDC	250	1, 600* 1,133**	160 (overhead)* 180 (overhead)^ 100 (subsea)* 90 (underground)^	2,867,200-3,225,600 887,040- 985,600
Keng Tung (Myanmar) to Lao PDR (ACE & HAPUA, 2021; ACE & HAPUA, 2024).	HVAC	230	624**	415 (overhead)^^	7,436,800
Java (Indonesia) to Kalimantan (Indonesia) (ACE & HAPUA, 2021; ACE & HAPUA, 2024).	HVDC	TBC	435**	460 (subsea)^^	4,533,760
Sumatra (Indonesia) to Java (Indonesia) (ACE & HAPUA, 2021; ACE & HAPUA, 2024).	HVDC	500	2,600* 10,000**	36 (subsea)^^	354,816
Singapore and Vietnam (ACE, 2024).	HVDC	TBC	1,200*	~1000 (subsea)*	9,856,000
Singapore and Cambodia (ACE, 2024).	HVDC	TBC	1,000*	> 1000 (subsea)*	9,856,000
Australia-Asia Power Link (AAPowerLink) from Darwin (Northern Territory, Australia) to Singapore (Infrastructure Australia, N.D.).	HVDC	TBC	1.75 GW***	4,200 km (subsea)***	41,395,200
Total estimated copper required.					**99,033,088 - 102,303,488**

TABLE D1: COPPER REQUIRED FOR PLANNED MULTI-LATERAL POWER PROJECTS IN THE ASEAN REGION

** As stated in the ACE & HAPUA (2024) ASEAN Power Grid Interconnections Project Profiles report.*

*** As stated in DNV (2024, p. 22) ASEAN Interconnector Study: Taking a Regional Approach to Decarbonisation.*

**** As stated by Infrastructure Australia (N.D.), "Australia-Asia PowerLink".*

^As stated by Ahmed et al. (2017, p. 93), "Investigation into transmission options for cross-border power trading in ASEAN power grid." Energy Policy 108, 91-101.

^^Authors own estimation.

Appendix E: Decarbonisation of Transport

Table E1 shows the subcategories used to classify bulk and critical materials.

Figure E1 shows the material demand for EVs separated as bulk (top) and critical (bottom) materials as shares (left-hand axis) and as totals (right hand axis). Total material demand is expected to be almost two thirds comprised of critical material demand and the rest for bulk materials. Critical material demand is highest for battery-related materials (battery materials and metals).

Figure E2 shows the projected changes in battery chemistries. NMC chemistries which are the industry's best-known in the battery industries, have the largest share of cathode materials. While the substitution of graphite anode materials is eventually expected, these materials are expected to sill dominate battery chemistry until 2045. The use of LFP and other cobalt-free battery chemistries is also projected to expand over time following industry trends.

MATERIAL TYPE	MATERIAL SUBCATEGORY	MATERIAL NAMES
Bulk	Metals & Alloys (non-critical)	Ag, Brass, Bronze, Cast iron, Cd, Fe, Mo, Pb, Steel
	Construction Materials	Aggregate, Asphalt, Bitumen, Cement, Clay, Concrete, Granite, Lime, Sand, Stone wool
	Paints/Coatings	Alkyd paint
	Other Bulk Material	Asbestos, B, Carbon black, Ceramic tile, Clinker, Magnesia, P, Pitch, Se
	Fossil-related compounds	Creosote, Lubricating oil
	Chemical Compounds	Dimethyl carbonate, Ethylene, Ethylene carbonate, Ethylene glycol, Hydrochloric acid, Organic solvent, Propylene glycol, Sodium chloride, Sodium hydroxide, Sulfuric acid
	Fibers & Insulation	Cellulose, CFRP, GFRP, Glass, Glass wool
	Polymers & Plastics	Epoxy resin, Phenolic resin, Polymers, PVC, Synthetic rubber
	Specialty Chemicals	Glyphosate, Refrigerant R134A
	Biological/Natural Materials	Wood
Critical	Metals	Al, Co, Cu, Ni, Pd, Pt, Ru, Ti, V, Zn
	Rare Earth Elements (REEs)	Ce, Dy, Er, Eu, Gd, La, Nd, Pr, Sc, Tb, Y, Yb
	Battery Materials	Graphite, Li, LiFePO4, LiMn2O4, LiPF6, NMC111 oxide, NMC 532 oxide, NMC 622 oxide, NMC 811 oxide
	Metalloids & Non-metals	Ge, Si
	Refractory/High-Performance Materials	Hf, Mg, Mn, Nb, Ta, W, Zircon
	Industrial Use Minerals	Cr
	Other Critical Material	Ga, In, Neodymium oxide, Sa, Sn, Te

TABLE E1: CLASSIFICATION OF TECHNOLOGIES AND MATERIALS USED.

FIG. E1

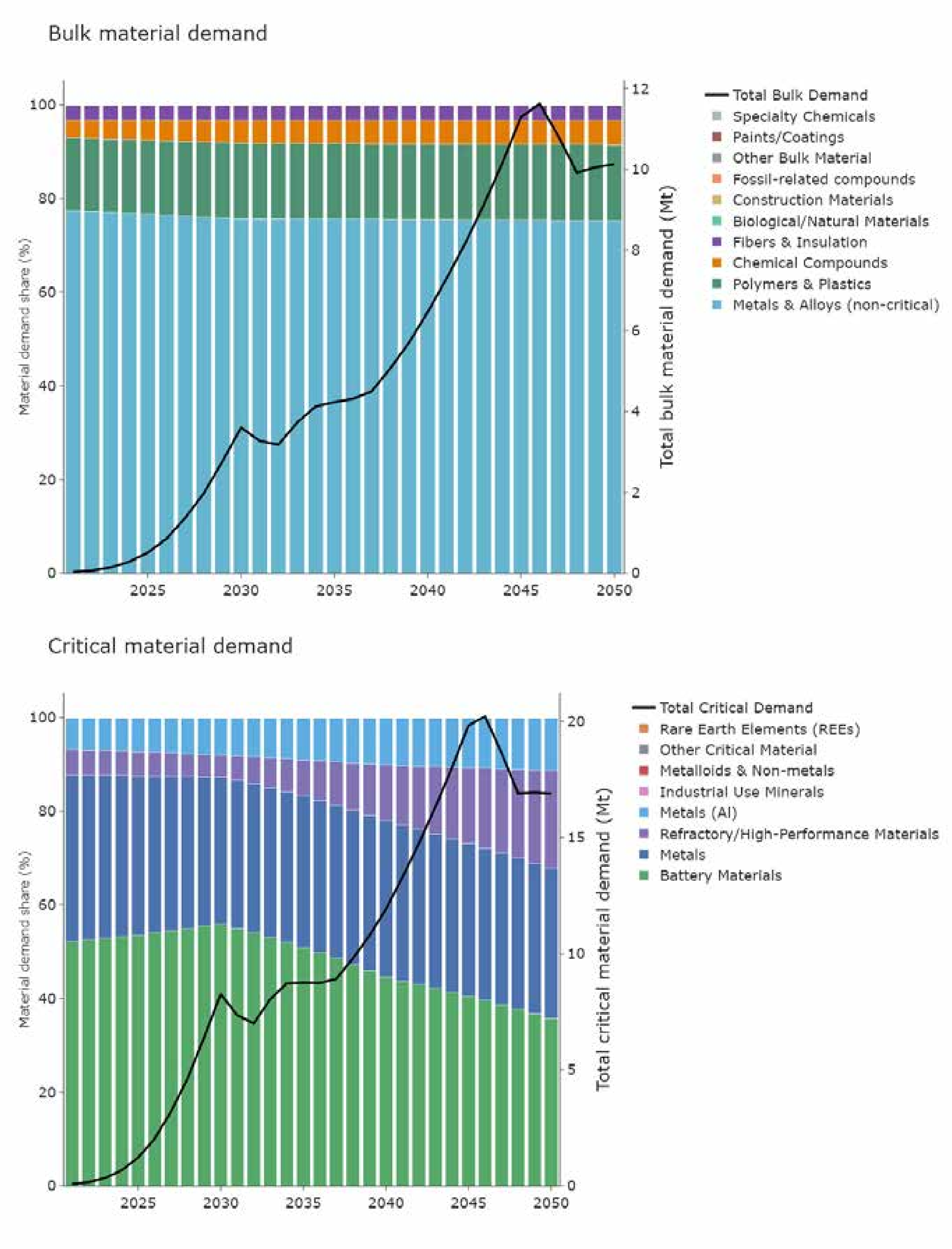


FIGURE E1: MATERIAL DEMAND FOR EVS SEPARATED AS BULK (TOP) AND CRITICAL (BOTTOM) MATERIALS AS SHARES (LEFT-HAND SIDE AXIS) AND AS TOTAL MATERIAL DEMAND (RIGHT-HAND SIDE AXIS)

FIG. E2

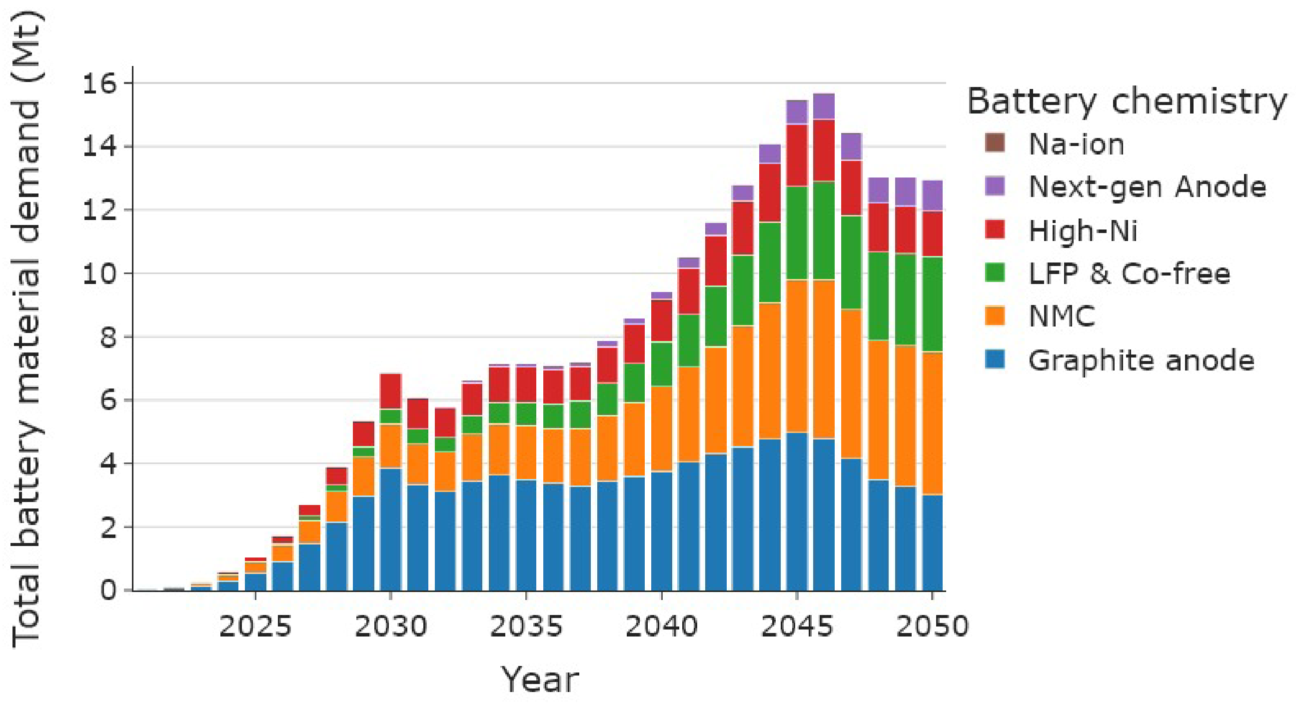


FIGURE E1: MATERIAL DEMAND FOR EVS SEPARATED AS BULK (TOP) AND CRITICAL (BOTTOM) MATERIALS AS SHARES (LEFT-HAND SIDE AXIS) AND AS TOTAL MATERIAL DEMAND (RIGHT-HAND SIDE AXIS)

Appendix F: Countries and technologies for ASEAN demand

Countries and technologies included in the critical mineral demand for the ASEAN region.

	INDONESIA	THAILAND	VIETNAM	ASEAN
Onshore Wind	■	■	■	■
Offshore Wind	■			■
Solar PV	■	■	■	■
Hydro				■
Nuclear	■		■	
Geothermal				■
Solar CSP	■			
Biomass	■	■	■	
Biomass + CCS	■	■	■	
Battery Storage	■			
International Transmission Lines				■
Domestic Transmission Lines				■
Distribution Lines				■

TABLE F1: COUNTRIES INCLUDED IN CRITICAL MINERAL DEMAND MODEL

Appendix G: Production and consumption-based country plots

Figure G1 shows the production and consumption plots for each ASEAN Member State. Production based account refers to material extraction in the country, consumption-based account refers to flow either produced or embodied in the country's final consumption, and controlled production refers to the fraction of the flow that is produced by the country that is owned by domestic capital. We used the Sankey diagrams (Andrieu et al. In prep) based on release 059 of the GLORIA global environmentally extended multi-region input-output (MRIO) database (Lenzen et al. 2021), constructed in the Global MRIO Lab (Lenzen et al. 2017).

FIG. G1

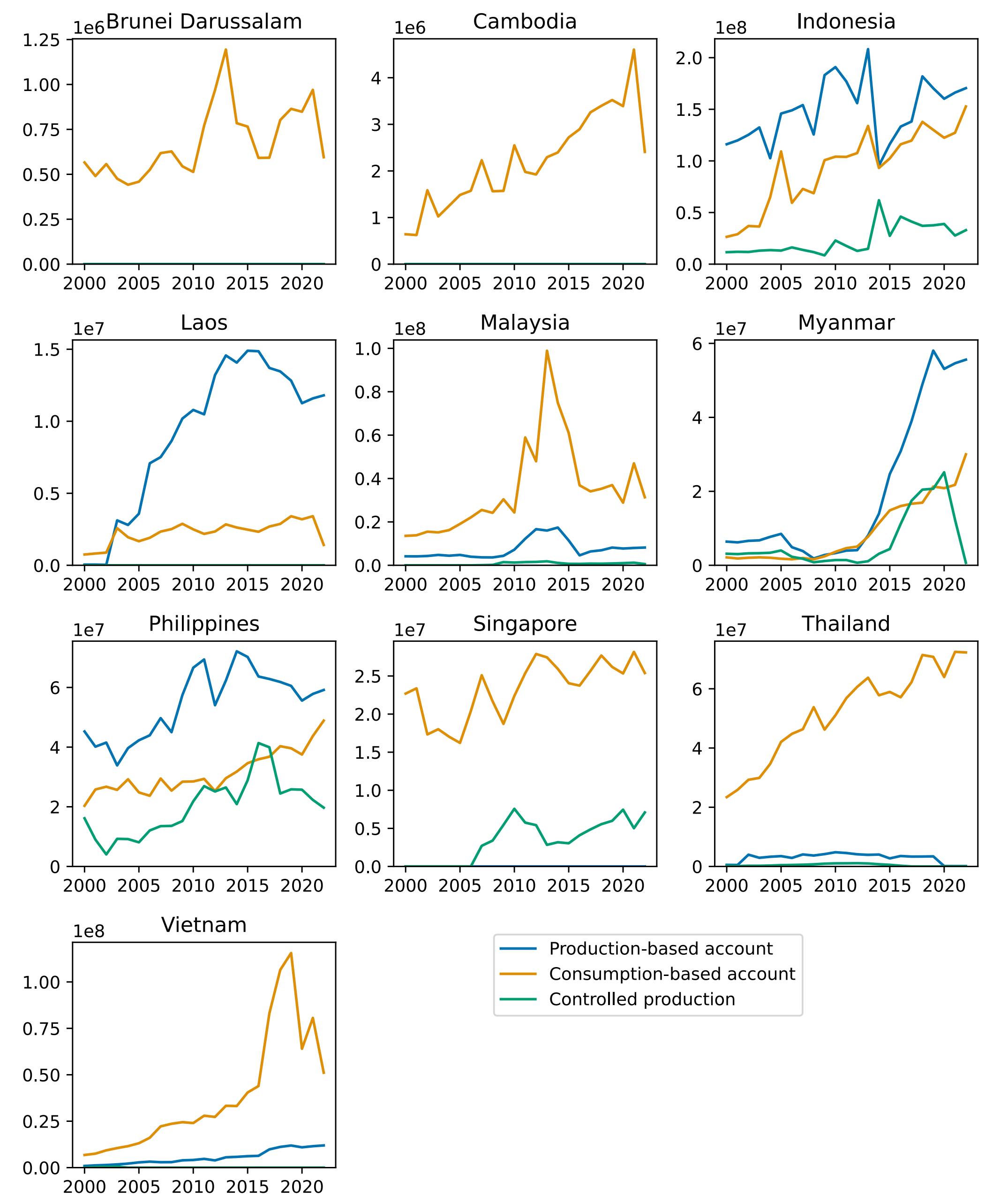


FIGURE G1: PRODUCTION AND CONSUMPTION PLOTS FOR EACH ASEAN MEMBER STATE

REFERENCES

ACE. (2020). (2021-2025) ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II. ASEAN Centre for Energy (ACE), Jakarta. Retrieved from: https://aseanenergy.org/publications/asean-plan-of-action-for-energy-cooperation-apaec-phase-ii-2021-2025/

ACE & HAPUA. (2021). ASEAN Interconnection Masterplan Study (AIMS) III Report. ASEAN Centre for Energy (ACE) & Heads of ASEAN Power Utilities/Authorities (HAPUA). Retrieved from: https://aseanenergy.org/wp-content/uploads/2024/06/01_AIMS-III-Phase-1-and-2_Summary-Report-_Endorsed-AMEM39.pdf

ACE & HAPUA. (2024). ASEAN Power Grid Interconnections Project Profiles. ASEAN Centre for Energy (ACE) & Heads of ASEAN Power Utilities/Authorities (HAPUA) Working Group 2. Retrieved from: https://aseanenergy.org/wp-content/uploads/2024/11/ASEAN-Power-Grid-Interconnections-Project-Profiles.pdf

ACE. (2024). 8th ASEAN Energy Outlook 2023-2050 (AEO8). ASEAN Centre for Energy (ACE), Jakarta. Available for download from https://aseanenergy.org/

Agusdinata, D., Eakin, H., & Liu, W. (2022). Critical minerals for electric vehicles: a telecoupling review. Environmental Research Letters, 17(1), 013005. https://doi.org/10.1088/1748-9326/ac4763

Ahmed, T., Mekhilef, S., Shah, R., & Mithulananthan, N. (2017). "Investigation into transmission options for cross-border power trading in ASEAN power grid." Energy Policy 108, 91-101. https://doi.org/10.1016/j.enpol.2017.05.020

Andrieu, B., Cervantes Barron, K., Heydari, M., Keshavarzzadeh, A., Cullen, J., In prep. https://www.refficiency.org/

Aritenang, A. F. (2017). The potential development effect of ASEAN connectivity: the case of Riau corridor. MIMBAR, Jurnal Sosial Dan Pembangunan, 33(2), 339. https://doi.org/10.29313/mimbar.v33i2.2590

Ambastha, S. K., & Haritash, A. K. (2022). Emission of respirable dust from stone quarrying, potential health effects, and its management. Environmental Science and Pollution Research, 29(5), 6670–6677. https://doi.org/10.1007/s11356-021-16079-4

Amelia, R., Suhardjanto, D., Probohudono, A., & Honggowati, S. (2023). Environmental disclosures in mining companies: are there any stakeholder demands? IOP Conference Series Earth and Environmental Science, 1248(1), 012005. https://doi.org/10.1088/1755-1315/1248/1/012005

Astuti, R., Raman, S., & Yeremia, A. E. (2025). Putting community-centric justice into just transitions from the global south: the case of indonesia's nickel sector. Environmental Research Letters, 20(5), 054020. https://doi.org/10.1088/1748-9326/adc8b9

Bambawale, M. J., D'Agostino, A., & Sovacool, B. K. (2011). Realizing rural electrification in southeast Asia: lessons from Laos. Energy for Sustainable Development, 15(1), 41-48. https://doi.org/10.1016/j.esd.2010.11.001

Budiman, I., Swandaru, A., & Suryadi, B. (2021). The potential contribution of projected ASEAN power grid to emission reduction. https://doi.org/10.21203/rs.3.rs-1141749/v1

Budiono, B. and Virgianita, A. (2024). Indonesia's movement to become the main player in the electric vehicle (ev) market in southeast asia. Asian Journal of Engineering, Social and Health, 3(4), 866-882. https://www.semanticscholar.org/paper/Indonesia%27s-Movement-to-Become-the-Main-Player-in-Budiono-Virgianita/3c44cb44d537f89cf219033aa3549f7504db6a58

Byers, et al. (2022). AR6 Scenarios Database, version 1.1. Zenodo. https://doi.org/10.5281/zenodo.5886911

Cabauatan, R. R. and Tatlonghari, V. M. (2017). Analysing energy consumption in the Philippines using vector error correction. International Social Science Journal, 67(225-226), 137-150. https://doi.org/10.1111/issj.12136

Center for International Law. (2023). ASEAN Leaders Declaration on Developing Regional EV Ecosystem. Retrieved from: https://cil.nus.edu.sg/wp-content/uploads/2023/08/2023-ASEAN-Leaders-Decl-EV-Ecosystem.pdf

Chang, Y. and Phoumin, H. (2021). Harnessing wind energy potential in ASEAN: modelling and policy implications. Sustainability, 13(8), 4279. https://doi.org/10.3390/su13084279

Chen, Q., Wang, B., Ding, W., Liao, Z., Zhang, H., & Zhao, G. (2020). The impact of regional power trade on CO2 emissions in the greater Mekong sub-region. IOP Conference Series: Earth and Environmental Science, 495(1), 012078. https://doi.org/10.1088/1755-1315/495/1/012078

Chen, X. and Mauzerall, D. L. (2021). The expanding coal power fleet in Southeast Asia: implications for future CO2 emissions and electricity generation. Earth's Future, 9(12). https://doi.org/10.1029/2021ef002257

Chen, K. and Zhang, S. (2022). Influence of energy-efficient infrastructure, financial inclusion, and digitalization on ecological sustainability of ASEAN countries. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.1019463

Chinkaka, E., Klinger, J. M., Davis, K. F., & Bianco, F. (2023). "Unexpected expansion of rare-earth element mining activities in the Myanmar–China border region". Remote Sensing, 15(18), 4597. https://doi.org/10.3390/rs15184597

Chongco, S. M. R., Dumlao, N. M., Co, K. J., & Cabauatan, R. R. (2022). The causal relationship of renewable energy and non-renewable energy consumption to the economic growth of the Philippines. Journal of Economics, Finance and Accounting Studies, 4(1), 340-358. https://doi.org/10.32996/jefas.2022.4.1.22

Claire, B. E. and Widyawati, D. (2023). Impact of industrialization and renewable energy on carbon dioxide emission in 9 asean countries. Economic Journal of Emerging Markets, 183-198. https://doi.org/10.20885/ejem.vol15.iss2.art6

Darwis, D. and Wambrauw, M. S. F. (2023). Indonesia's foreign policy in the indo-pacific region in the 2023 ASEAN chair. International Journal of Multidisciplinary Research and Analysis, 06(11). https://doi.org/10.47191/ijmra/v6-i11-23

Dios, M., Souto, J. A., & Casares, J. J. (2013). Experimental development of CO2, SO2 and NOx emission factors for mixed lignite and subbituminous coal-fired power plant. Energy, 53, 40–51. https://doi.org/10.1016/j.energy.2013.02.043

DNV. (2024). ASEAN Interconnector Study: Taking a Regional Approach to Decarbonisation. Retrieved from: https://www.dnv.com/publications/asean-interconnector-study/

Dou, S. and Xu, D. (2022). The security of critical mineral supply chains. Mineral Economics, 36(3), 401-412. https://doi.org/10.1007/s13563-022-00340-4

Economic Outlook Database. International Monetary Fund (IMF). Retrieved from: https://www.imf.org/en/Publications/WEO/weo-database/2023/April/weo-report?c=516,522,536,544,548,518,566,576,578,582,&s=NGDPD,PPPGDP,NGDPDPC,PPPPC,LP,&sy=2021&ey=2028&ssm=0&scsm=1&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

Economic Research Institute for ASEAN and East Asia (ERIA). (2024). Study on an Enabling Agreement amongst Member States for Establishing Multilateral Power Trade and ASEAN Power Grid Institutions. Retrieved from: https://www.eria.org/uploads/Enabling-Agreement-amongst-ASEAN-Member-States.pdf

European Commission. (2023). "Critical Raw Materials: ensuring secure and sustainable supply chains for EU's green and digital future." Retrieved from: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661

Emami, N., Miatto, A., Gheewala, S. H., Soonsawad, N., Nguyen, T. C., Chiu, A. S., & Schandl, H. (2024). Measuring progress toward a circular economy of the ASEAN community. Journal of Industrial Ecology, 29(1), 129-144. https://doi.org/10.1111/jiec.13597

Fahim, K. E., Silva, L. C. D., Hussain, F., Shezan, S. A., & Yassin, H. (2023). An evaluation of ASEAN renewable energy path to carbon neutrality. Sustainability, 15(8), 6961. https://doi.org/10.3390/su15086961

Fikru, M. and Koppera, S. (2024). Public perceptions of mineral criticality and preferences for energy transition strategies in the us. https://doi.org/10.21203/rs.3.rs-4462327/v1

Fong-Sam, Y. (2012). "The Mineral Industry of Viet Nam." In 2010 Mineral Yearbook: Viet Nam; U.S. Geological Survey: Reston, VA, USA. Retreived from: https://scholar.google.com/scholar_lookup?title=The+Mineral+Yearbook:+The+Mineral+Industry+of+Viet+Nam&author=Fong-Sam,+Y.&publication_year=2010

Galelli, S., Dang, T. D., Ng, J. Y., Chowdhury, A. F. M. K., & Arias, M. E. (2022). Opportunities to curb hydrological alterations via dam re-operation in the Mekong. Nature Sustainability, 5(12), 1058–1069. https://doi.org/10.1038/s41893-022-00971-z

Gel, Z., Noza, M., Lin, T., Catacutan, D., Noordwijk, M., Finlayson, R., ... & Khairinissa, A. (2021). State and outlook of agroforestry in ASEAN.. https://doi.org/10.4060/cb7930en

Gödeke, S. (2025). "The white sands of Tutong: A high-quality silica sand deposit from Borneo." Journal of Water and Land Development, 79-86. https://doi.org/10.24425/jwld.2025.153519

Huang, B., Choi, Y., Chng, S., & Neo, H. (2023). Examining policy strategies for electrifying transportation in ASEAN: a steelup framework evaluation. Sustainability, 15(22), 15708. https://doi.org/10.3390/su152215708

Indraswari, R. (2022). ASEAN Centrality: comparative case study of Indonesia leadership. JAS (Journal of ASEAN Studies), 10(1). https://doi.org/10.21512/jas.v10i1.7906

Infrastructure Australia. (N.D.). Australia-Asia Power Link. Australian Government. Retrieved from: https://www.infrastructureaustralia.gov.au/projects/australia-asia-powerlink

International Monetary Fund. (2018). Asean progress towards sustainable development goals and the role of the imf. Policy Papers, 18(054), 1. https://doi.org/10.5089/9781498310208.007

International Monetary Fund. (2024). "Report for Selected Countries and Subjects". IMF. Retrieved from: https://www.imf.org/en/Publications/WEO/weo-database/2023/April/weo-report

International Energy Agency (IEA). (N.D.). "Energy system of Asia Pacific." Retrieved from: https://www.iea.org/regions/asia-pacific

International Energy Agency (IEA). (2023). Decarbonisation Pathways for Southeast Asia. Retrieved from: https://iea.blob.core.windows.net/assets/4d0d7d7d-0ace-4de4-94cf-7c51a0a1517a/DecarbonisationpathwaysforSoutheastAsia.pdf

International Energy Agency (IEA). (2024). Global Critical Minerals Outlook 2024. Retrieved from: https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf

International Energy Agency (IEA). (2024 b). Southeast Asia Energy Outlook 2024. Retrieved from: https://iea.blob.core.windows.net/assets/ac357b64-0020-421c-98d7-f5c468dadb0f/SoutheastAsiaEnergyOutlook2024.pdf

IEA (2024c), Global Critical Minerals Outlook 2024, IEA, Paris https://www.iea.org/reports/global-critical-minerals-outlook-2024, Licence: CC BY 4.0

Intergovernmental Forum (IGF) on Mining, Minerals, Metals and Sustainable Development. (2023). ASEAN-IGF Minerals Cooperation: Scoping study on critical minerals supply chains in ASEAN. Retrieved from: https://www.iisd.org/system/files/2023-05/scoping-study-critical-minerals-asean.pdf

IRENA & ACE. (2022). Renewable energy outlook for ASEAN: Towards a regional energy transition, 2nd edition. International Renewable Energy Agency (IRENA), Abu Dhabi; and ASEAN Centre for Energy, Jakarta. Retrieved from: https://www.irena.org/Publications/2022/Sep/Renewable-Energy-Outlook-for-ASEAN-2nd-edition

Javed, T., Said, F., Zainal, D., & Jalil, A. A. (2024). Circular economy implementation status of selected ASEAN countries. Sage Open, 14(1). https://doi.org/10.1177/21582440231216261

Jones, C. (2019). "A value chain approach to support Southeast Asian economic regionalism." JAS (Journal of ASEAN Studies), 7(1), 40. https://doi.org/10.21512/jas.v7i1.5009

Lau, H. C., Zhang, K., Bokka, H. K., & Ramakrishna, S. (2022). A review of the status of fossil and renewable energies in Southeast Asia and its implications on the decarbonisation of ASEAN. Energies, 15(6), 2152. https://doi.org/10.3390/en15062152

Lèbre, É., Owen, J., Corder, G., Kemp, D., Stringer, M., & Valenta, R. (2019). "Source risks as constraints to future metal supply". Environmental Science & Technology, 53(18), 10571-10579. https://doi.org/10.1021/acs.est.9b02808

Lèbre, É., Stringer, M., Svobodová, K., Owen, J., Kemp, D., Côte, C., ... & Valenta, R. (2020). "The social and environmental complexities of extracting energy transition metals." Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-18661-9

Lenzen, M., A. Geschke, M.D. Abd Rahman, Y. Xiao, J. Fry, R. Reyes, E. Dietzenbacher, S. Inomata, K. Kanemoto, B. Los, D. Moran, H. Schulte in den Bäumen, A. Tukker, T. Walmsley, T. Wiedmann, R. Wood and N. Yamano. (2017). The Global MRIO Lab -charting the world economy. Economic Systems Research 29, 158-186. https://doi.org/10.1080/09535314.2017.1301887

Lenzen, M., A. Geschke, J. West, J. Fry, A. Malik, S. Giljum, L.M.i. Canals, P. Piñero, S. Lutter, T. Wiedmann, M. Li, M. Sevenster, J. Potočnik, I. Teixeira, M.V. Voore, K. Nansai and H. Schandl (2021) Implementing the Material Footprint to measure progress towards SDGs 8 and 12. Nature Sustainability. https://www.nature.com/articles/s41893-021-00811-6

Li, H., Gan, J., Gan, Y., Wang, B., Li, Y., & Jiang, W. (2023). "Coupling mechanism of the concealed rock body and metallogenic structure of the Sarakan gold deposit in Lao PDR investigated using magnetic and electrical methods." Minerals, 13(7), 912. https://doi.org/10.3390/min13070912

Macmac, S. D., Tizon, Z. A., Ocampo, E. S. G., Almendrala, M., & Evidente, R. C. (2023). The future of nuclear power: a Philippine perspective. IOP Conference Series: Earth and Environmental Science, 1199(1), 012033. https://doi.org/10.1088/1755-1315/1199/1/012033

Magnan, A. K., Pörtner, H.-O., Duvat, V. K. E., Garschagen, M., Guinder, V. A., Zommers, Z., Hoegh-Guldberg, O., & Gattuso, J.-P. (2021). Estimating the global risk of anthropogenic climate change. Nature Climate Change, 11(10), 879–885. https://doi.org/10.1038/s41558-021-01156-w

Majkut, J. (2023). "The Inflation Reduction Act: A Race to the Top or Protectionism in High Gear?" Centre for Strategic and International Studies (CSIS). Retrieved from: https://www.csis.org/analysis/inflation-reduction-act-race-top-or-protectionism-high-gear

Ministry of Industry and Trade. (2012). Circular No. 41/2012/TT-BCT of the Ministry of Industry and Trade of December 21, 2012, on Providing the Export of Minerals, Appendix §7. The Ministry of Industry and Trade of the Socialist Republic of Viet Nam. Retrieved from: https://english.luatvietnam.vn/circular-no-41-2012-tt-bct-dated-december-21-2012-of-the-ministry-of-industry-and-trade-providing-the-export-of-minerals-75867-doc1.html

Moody, M. (2013). "Mother Lode: The Untapped Rare Earth Mineral Resources of Vietnam."Defense Technical Information Center. Retrieved from: https://apps.dtic.mil/sti/citations/ADA594225

Nakamura, S. (2011). "Current Trends of Rare Earth Market in Japan." PowerPoint presentation, Critical Metals Investment Symposium, Vancouver, Canada, January 21, 2011.

Nam, C.N. & Bich, T.D. (2016). Thuế Phí Khoáng Sản Hiện Đang Quá Cao. Viet Nam National Coal Mineral Industries Holding Corporation Limited: Hanoi, Viet Nam . Retrieved from: https://vinacomin.vn/vi

Nazri, N., Anuar, S., Basrawi, F., Shukrie, A., & Aishah, S. (2018). Evaluation of potential sites for harnessing tidal energy around coastal area of Malaysia. MATEC Web of Conferences, 225, 06015. https://doi.org/10.1051/matecconf/201822506015

Nepal, R., Phoumin, H., & Khatri, A. (2021). Green technological development and deployment in the association of southeast Asian economies (ASEAN)—at crossroads or roundabout? Sustainability, 13(2), 758. https://doi.org/10.3390/su13020758

Nguyen, T. C., Miatto, A., & Kim, J. (2024). Material services in an emerging economy: Tracking resource utilization in Vietnam's shelter, thermal comfort, and road transportation. Ecological Economics, 220, 108165. https://doi.org/10.1016/j.ecolecon.2024.108165

Nguyen, V. C. N., Dung, H. T., Nguyen, N. S. H., & Nguyen, T. H. (2021). Green technology for sustainable development: practice and experience of renewable energy in Vietnam. Research Nepal Journal of Development Studies, 4(2), 79-92. https://doi.org/10.3126/rnjds.v4i2.42688

Nguyen, M. P., Ponomarenko, T. V., & Nguyễn, N. (2024). Energy transition in Vietnam: a strategic analysis and forecast. Sustainability, 16(5), 1969. https://doi.org/10.3390/su16051969

Nguyen, P., Nguyen, D., & Vu, A. (2024). "Assessing the economic value of copper mineral resources in Ta Phoi area, Lao Aai province." Journal of Mining and Earth Sciences, 65(2), 41-46. https://doi.org/10.46326/jmes.2024.65(2).05

Oo, A., Lv, X., Zaw, K., Htay, T., Binke, S., & Adam, M. (2020). "Ore geology, fluid inclusions, and (H-O-S-Pb) isotope geochemistry of the sediment-hosted antimony mineralization, Lyhamyar Sb deposit, southern Shan plateau, Eastern Myanmar: implications for ore genesis." Minerals, 10(4), 296. https://doi.org/10.3390/min10040296

Øverland, I., Sagbakken, H. F., Chan, H., Merdekawati, M., Suryadi, B., Utama, N. A.& Vakulchuk, R. (2021). The asean climate and energy paradox. Energy and Climate Change, 2, 100019. https://doi.org/10.1016/j.egycc.2020.100019

Pandey, A., Kalidasan, B., Kumar, R. R., Rahman, S., Tyagi, V., Krismadinata, K., ... & Tyagi, S. K. (2022). Solar energy utilization techniques, policies, potentials, progresses, challenges and recommendations in ASEAN countries. Sustainability, 14(18), 11193. https://doi.org/10.3390/su141811193

Paterson, S. (2022). "Supply Chains Are Trying to Diversify. Will ASEAN Step In?" Hinrich Foundation. Retrieved from: https://www.hinrichfoundation.com/research/article/fdi/supply-chains-diversify-asean/

Phomsoupha, X. (2012). Project financing in Laos' hydropower for export of electricity to Thailand. Hydro Nepal: Journal of Water, Energy and Environment, 10, 7-10. https://doi.org/10.3126/hn.v10i0.7096

Phoumin, H., Kimura, F., & Arima, J. (2021). ASEAN's energy transition towards cleaner energy system: energy modelling scenarios and policy implications. Sustainability, 13(5), 2819. https://doi.org/10.3390/su13052819

Prime Minister of Viet Nam. (2011). Decision No. 2427/QD-TTg dated December 22, 2011 of the Prime Minister approving mineral resources strategy to 2020, with a vision toward 2030. The Prime Minister of the Socialist Republic of Viet Nam. Retrieved from: https://english.luatvietnam.vn/decision-no-2427-qd-ttg-dated-december-22-2011-of-the-prime-minister-approving-mineral-resources-strategy-to-2020-with-a-vision-toward-2030-67015-doc1.html

Prime Minister of Viet Nam. (2012). Directive No. 02/CT-TTg 2012 state management for exploration, mining, processing, use and export of minerals. The Prime Minister of the Socialist Republic of Viet Nam. Retrieved from: https://english.luatvietnam.vn/directive-no-02-ct-ttg-dated-january-09-2012-of-the-prime-minister-on-enhancing-the-state-management-for-exploration-mining-processing-use-and-ex-67394-doc1.html

Prum, M., Goh, H. H., Zhang, D., Dai, W., Kurniawan, T. A., & Goh, K. C. (2024). Optimizing hybrid energy systems for remote communities in Asia's least developed countries. Heliyon, 10(8), e29369. https://doi.org/10.1016/j.heliyon.2024.e29369

Roslim, A., Briguglio, A., Kocsis, L., Rahman, F., Bahrein, I., Goeting, S., ... & Razak, H. (2020). "Palaeoenvironmental interpretation of late miocene outcrops (miri and seria formations) along Jalan Tutong in Brunei Darussalam." Bulletin of the Geological Society of Malaysia, 70(1), 39-56. https://doi.org/10.7186/bgsm70202004

Sabado, J. R. F., Albutra, J. M. B., Centino, S. M. P., & Yap, W. B. C. (2022). Determinants of energy consumption: a review of the Philippine energy sector. European Journal of Economic and Financial Research, 6(3). https://doi.org/10.46827/ejefr.v6i3.1323

Samuel, J. (2022). Forecasting electricity consumption in the philippines using arima models. International Journal of Machine Learning and Computing, 12(6). https://doi.org/10.18178/ijmlc.2022.12.6.1112

Sanematsu, K., Moriyama, T., Laochou, S., & Watanabe, Y. (2011). "Mobility of rare earth elements in basalt-derived laterite at the Bolaven plateau, southern Lao PDR." Resource Geology, 61(2), 140-158. https://doi.org/10.1111/j.1751-3928.2011.00155.x

Shafie, S. M., Othman, Z., & Hami, N. (2018). Paddy residue as feedstock in electricity generation: redemption of life cycle emissions and cost analysis. Journal of Technology and Operations Management, 13(Number 1), 55-67. https://doi.org/10.32890/jtom2018.13.1.6

Shi, X. (2016). The future of ASEAN energy mix: a swot analysis. Renewable and Sustainable Energy Reviews, 53, 672-680. https://doi.org/10.1016/j.rser.2015.09.010

Spiegel, S. (2014). "Rural place-making, globalization and the extractive sector: insights from gold mining areas in Kratie and Ratanakiri, Cambodia." Journal of Rural Studies, 36, 300-310. https://doi.org/10.1016/j.jrurstud.2014.09.007

Spiegel, S. (2016). Land and 'space' for regulating artisanal mining in cambodia: visualizing an environmental governance conundrum in contested territory. Land Use Policy, 54, 559-573. https://doi.org/10.1016/j.landusepol.2016.03.015

Sudan, F. K. (2023). Leveraging green bonds to address debt sustainability and economic recovery in South Asia: lessons from EU and ASEAN countries. Regional Economic Development Research, 101-120. https://doi.org/10.37256/redr.4220233543

Sulisnaningrum, E., Mutmainah, S., Priyanto, E., & Chapuzet, A. C. (2023). Environmental taxation and green economics in Southeast Asia. Jurnal Akuntansi Dan Keuangan, 25(1), 17-24. https://doi.org/10.9744/jak.25.1.17-24

Sumitomo Electric. (2016). Catalog: Product and Service for Extra High Voltage System. Sumitomo Electric Industries, Ltd. Retrieved from: https://sumitomoelectric.com/products/high-voltage-cable/hvdc-cable

Soh, W. N., Lau, W. T., Mazlan, N. S., & Tun, Y. L. (2024). Is green always beneficial? assessing the true impact of greenfield investments on green economy---evidence from selected asean countries. International Journal of Academic Research in Business and Social Sciences, 14(5). https://doi.org/10.6007/ijarbss/v14-i5/21408

Tan, H., Ma, H., Li, B., Zhang, X., & Xiao, Y. (2010). "Strontium and Boron isotopic constraint on the marine origin of the Khammuane potash deposits in southeastern Lao PDR." Chinese Science Bulletin, 55(27-28), 3181-3188. https://doi.org/10.1007/s11434-010-4010-x

Tkachenko, O., Crocco, O., Nguyen, L., & Jonathan, V. (2022). "Regional human resource development in ASEAN: An institutional theory perspective." Human Resource Development Review, 21(2), 225-248. https://doi.org/10.1177/15344843221083190

Nguyen, Nhi & Boruff, Bryan & Tonts, Matthew. (2019). The Regulatory Framework and Minerals Development in Vietnam: An Assessment of Challenges and Reform. Sustainability. 11. 4861. 10.3390/su11184861.

Tuan, L., Minh, P., Kien, K., & Duong, D. (2023). "The use of remote sensing technology in geological investigation and mineral detection in Ban Vang area, Kham district, Xieng Khoang province, Lao PDR." Iraqi Geological Journal, 56(1B), 233-245. https://doi.org/10.46717/igj.56.1b.17ms-2023-2-25

Tufail, M., Salam, M., Shakeel, M., & Gohar, A. (2022). Diversified sustainable resource availability by optimizing economic environmental and supply risk factors in Malaysia's power generation mix. International Journal of Energy Economics and Policy, 12(1), 507-516. https://doi.org/10.32479/ijeep.12605

Ufimtseva, A., Li, J., & Shapiro, D. M. (2024). Us critical mineral policies and alliance strategies in an age of geopolitical rivalry. Politics and Governance, 12. https://doi.org/10.17645/pag.8186

United Nations. (1990). Atlas of Mineral Resources of the ESCAP Region, Vol. 6, Viet Nam, 101-103. United Nations Economic and Social Commission for Asia and the Pacific. Retrieved from: https://digitallibrary.un.org/record/113139

U.S. Department of the Interior. (2011). United States Geological Survey Minerals Yearbook 2011: Viet Nam, 28.6. Retrieved from: https://ghdx.healthdata.org/record/united-states-geological-survey-minerals-yearbook-2011

Vakulchuk, R., Øverland, I., & Suryadi, B. (2022). Asean's energy transition: how to attract more investment in renewable energy. Energy, Ecology and Environment, 8(1), 1-16. https://doi.org/10.1007/s40974-022-00261-6

Van Lien, T. & Nguyen, T. G. (2013). "The Assessment of Thorium Resources in Viet Nam." PowerPoint presentation, IAEA Technical Meeting on Thorium Resources and Provinces, Vienna, Austria, September 24, 2013.

Velasco, J. (2023). "Southeast Asian regionalism: An examination of the progress and priorities of ASEAN through its joint communiqués." JAS (Journal of ASEAN Studies), 11(2). https://doi.org/10.21512/jas.v11i2.9402

Verbiest, J. (2013). "Regional cooperation and integration in the Mekong region." Asian Economic Policy Review, 8(1), 148-164. https://doi.org/10.1111/aepr.12015

Verico, K. (2021). "Mega-regionalism in Southeast Asia: single- and dual-track options for ASEAN Member States." Asian Economics Letters, 3(1). https://doi.org/10.46557/001c.27139

Voingpuhakdy, K. (2023). "Strategic resilience in ASEAN: Adapting strategies for changing markets and environments." Journal of Asian Multicultural Research for Economy and Management Study, 4(1), 52-58. https://doi.org/10.47616/jamrems.v4i1.419

Vo, A. T., Vo, D. H., & Le, Q. T. (2019). Co2 emissions, energy consumption, and economic growth: new evidence in the ASEAN countries. Journal of Risk and Financial Management, 12(3), 145. https://doi.org/10.3390/jrfm12030145

Võ, V. C., Nguyen, P. H., Nguyen, L., & Pham, V. (2020). Econometric model for forecasting electricity demand of industry and construction sectors in Vietnam to 2030. Science &Amp; Technology Development Journal - Engineering and Technology, 3(1), First. https://doi.org/10.32508/stdjet.v3i1.646

Vu, T. T. N., Teyssèdre, G., Roy, S. L., Anh, T. T., Trần, T. S., Nguyen, X. T., ... & Nguyễn, Q. V. (2019). The challenges and opportunities for the power transmission grid of Vietnam. European Journal of Electrical Engineering, 21(6), 489-497. https://doi.org/10.18280/ejee.210602

Wang, W., Wang, X., Zhang, B., Wang, Q., Liu, D., Han, Z., ... & Nie, L. (2022). "National-scale geochemical baseline of 69 elements in Lao PDR stream sediments." Minerals, 12(11), 1360. https://doi.org/10.3390/min12111360

Wang, H., Wang, P., Zhang, X., Chen, W.-Q., Tzachor, A., Fishman, T., Schandl, H., Acuto, M., Yang, Y., Lu, Y., Böcher, C., Ma, F., Zhang, C., Yue, Q., Du, T., Liu, J., & Zhu, Y.-G. (2024). Substantial increase in China's manufactured sand supply since 2010. Nature Geoscience, 17(9), 833–836. https://doi.org/10.1038/s41561-024-01501-6

World Bank. (2011). "Viet Nam Development Report 2011: Natural Resource Management." The World Bank: Hanoi, Viet Nam, 2011. Retrieved from: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/509191468320109685/vietnam-development-report-2011-natural-resources-management

Yana, S., Yulisma, A., & Zulfikar, T. (2021). Manfaat sosial ekonomi energi terbarukan:kasus negara-negara asean. Jurnal Serambi Engineering, 7(1). https://doi.org/10.32672/jse.v7i1.3820

Yang, F. and Li, C. (2024). The status quo, dilemma, and transformation path of the carbon neutrality-related policy of the asean. Sustainability, 16(3), 1348. https://doi.org/10.3390/su16031348

Young, S. and Ear, S. (2021). Transnational political economic structures: explaining transnational environmental movements against dams in the lower mekong region. Third World Quarterly, 42(12), 2993-3011. https://doi.org/10.1080/01436597.2021.1984224

Yusoff, N. Y. M., Aris, H., Nasiruddin, W. H. M., Rusli, A. K. C., Yurnaidi, Z., Safrina, R., ... & Rosalia, S. A. (2024). The driving forces behind renewable energy consumption: a comprehensive analysis of key determinants and environmental concerns in asean countries. Environmental Science and Pollution Research, 31(35), 48388-48405. https://doi.org/10.1007/s11356-024-34358-8

Wahab, M. Z. H. and Naim, A. M. (2021). Assessment on the asean standards to support sustainable and responsible investments (SRIS) and green bonds. Journal of Emerging Economies and Islamic Research. https://doi.org/10.24191/jeeir.v9i2.13112

PLEASE CITE AS: CUEVAS VERDIN G, DU PLESSIS L, CULLEN JM. (EDS.) (2025). CRITICAL MINERALS IN THE ASEAN REGION: ASSESSING THE OPPORTUNITIES AND RISKS. UNIVERSITY OF CAMBRIDGE.

DOI: 10.17863/CAM.123365

GET IN TOUCH: CCML-CONTACT@ENG.CAM.AC.UK

RESEARCH IN THIS REPORT IS FUNDED BY CCG, CLIMATE COMPATIBLE GROWTH: HTTPS://CLIMATECOMPATIBLEGROWTH.COM/ABOUT-US/

UNIVERSITY OF CAMBRIDGE

WHO WE ARE

CAMBRIDGE CRITICAL MATERIALS LAB

We believe the energy transition must be equitable and inclusive. That means mineral-rich countries and their communities should benefit fully from their resources. By co-creating information platforms, producing rigorous research, and building tools for better decision-making, we work to strengthen equity in how critical materials are used to ensure no one is left behind.

CAMBRIDGECRITICALMATERIALS.LAB

HOW WE WORK

We combine independent, interdisciplinary research with close collaboration across the Global South to ensure mineral governance is technically sound, socially just, and climate-compatible. By integrating engineering, policy, and social sciences, we create actionable insights that empower governments and communities to defend their rights, advance their interests, and navigate the complex environmental, social, and economic challenges of the energy transition.

OUR TEAM

Blending engineering, policy, and social sciences, our team finds innovative solutions to complex challenges.