**Advance Sustainable Science, Engineering and Technology (ASSET)**
**Vol. 7, No.4, October 2025, pp. 02504010-01 ~ 02504010-036**
**ISSN: 2715-4211 DOI**: https://doi.org/10.26877/asset.v7i4.2005

# Unlocking Indonesia's Critical Minerals for Renewable Energy: Challenges and Pathways to Net-Zero Emissions

**Andrew Cahyo Adhi[1], Nur Widi Priambodo[1], Muchammad[2*], Tony Suryo Utomo[2], Reyhan Kevin Akmal Setia Abdrian[2]**

[1]PLN Research Institute, Kebayoran Baru, 12160, Jakarta, Indonesia

[2]Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Tembalang, Semarang, 50275, Central Java, Indonesia

*m_mad5373@yahoo.com

**Abstract**. Indonesia holds a pivotal role in the global renewable energy (RE) transition due to its abundant reserves of critical minerals like nickel, cobalt, and rare earth elements (REEs). However, a significant gap exists between these resources and the technologies needed to leverage them, highlighting supply chain vulnerabilities. This qualitative, exploratory-descriptive study integrates Life Cycle Assessment (LCA), criticality matrix analysis, and value chain mapping to examine Indonesia's mineral supply chains, sustainability, and Local Content (TKDN) policies. The findings reveal that despite its mineral wealth, Indonesia's inadequate management capacity complicates the achievement of TKDN goals and exposes supply chain deficiencies. The research advocates for developing downstream industries, adopting sustainable mining practices, and international collaboration. Policy recommendations include simplifying regulations, fostering innovation, and embracing circular economy principles, providing Indonesia with a strategic framework for its energy transformation.

**Keywords**: Critical raw materials, Energy transition, Net-zero policy, Resource governance, Supply chain resilience

***(Received 2025-05-15, Revised 2025-07-29, Accepted 2025-08-17, Available Online by 2025-08-28)***

## 1. Introduction

Climate change has emerged as a critical global threat, posing severe risks to food security by disrupting climatic stability, altering precipitation patterns, increasing the frequency and intensity of extreme weather events, and accelerating sea-level rise. Environmental alterations diminish agricultural productivity and jeopardize coastal employment. The repercussions are particularly severe in regions that are already vulnerable, such as archipelagic and low-lying nations. Climate-related alterations are engendering unprecedented challenges, particularly in agriculture, fisheries, and water resource management. These regions are directly impacted by erratic precipitation, prolonged droughts, and frequent extreme weather phenomena. [1-3]. No location is impervious to climatic variability, as it impacts food systems globally. This underscores the urgent necessity for comprehensive mitigation and adaptation strategies immediately. This phenomenon has created unprecedented challenges across sectors, particularly in agriculture, fisheries, and water resources, which are directly affected by unpredictable rainfall, prolonged droughts, and increased frequency of extreme weather events. The interconnectedness of climate variability and global food systems signifies that no region remains unaffected, reinforcing the urgent need for comprehensive climate mitigation and adaptation strategies [4-6]. In response, international cooperation has intensified, with Indonesia actively supporting climate action through its commitment to the Paris Agreement, which aims to limit global temperature increases to below 2°C, ideally 1.5°C. This reflects Indonesia's alignment with global efforts to prevent catastrophic environmental and socio-economic consequences arising from unmitigated climate change. As one of the world's largest archipelagic nations with significant natural resources and biodiversity, Indonesia plays a pivotal role in global environmental governance [7-8]. Indonesia ratified the agreement through Law No. 16/2016 and pledged to reduce greenhouse gas (GHG) emissions by 31.89% unconditionally by 2030, and up to 43.20% with international support. These targets are part of Indonesia's Enhanced Nationally Determined Contributions (NDCs), which incorporate strategies in land use, energy transition, and sustainable development. The commitment illustrates Indonesia's proactive stance in integrating climate action into national development agendas while recognizing the necessity of global solidarity and support, particularly in finance and technology transfer, to meet its more ambitious emission reduction goals [9-11]. Reinforcing this commitment, Indonesia declared its intention to achieve Net-Zero Emissions by 2060 or earlier at COP-26 in 2021. This milestone declaration indicates a paradigm shift in Indonesia's climate policy orientation toward long-term decarbonization and sustainable development. Achieving net-zero emissions will require structural transformations across sectors such as energy, transportation, industry, and land use, highlighting the government's resolve in building a green economy [12-16]. Indonesia submitted its Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) to the UNFCCC, detailing its plans to peak emissions by 2030 and transition toward a climate-resilient future [17-20].

Indonesia possesses substantial strategic potential to capitalize on its vast reserves of critical minerals—particularly copper, nickel, and aluminum—which serve as essential inputs for national industrial development and the acceleration of low-carbon technologies. These minerals are indispensable for manufacturing key components of renewable energy systems, including wind turbine generators, photovoltaic solar cells, and energy storage batteries. Leveraging this mineral wealth not only supports domestic value creation and green economic growth but also positions Indonesia as a pivotal player in the global clean energy transition [21-22]. However, challenges remain in optimizing their use amid rising global demand, especially for critical minerals like gallium and scandium used in healthcare. According to the IEA, the global shift to sustainable energy will double mineral demand by 2040. Despite this, Indonesia's mining sector faces safety issues and uneven extraction, with limited use of minerals like bauxite and vanadium. In 2021 alone, 93 mining accidents caused 11 deaths. Moreover, the integration of these minerals into the renewable energy sector is limited, as 84% of Indonesia's energy still came from fossil fuels that year, with only 14% of renewable targets met by 2020. Strengthening safety, refining extraction methods, fostering international partnerships, and increasing investment in clean energy are essential for a resilient, low-carbon future [23-27].

Despite Indonesia's robust policy framework to accelerate energy transition and net-zero emissions by 2060, there remains a significant knowledge gap regarding the alignment between domestic critical mineral availability and technological pathways for renewable energy deployment. Most existing studies focus on sectoral mineral potentials or policy analysis but fail to integrate a sustainability science lens with techno-economic considerations of mineral supply chains for low-carbon technologies [28-33]. This study addresses the existing research gap by evaluating the readiness of Indonesia's critical mineral resources in supporting the deployment of renewable energy technologies within the framework of the national net-zero emission strategy. The research provides a novel contribution by integrating material criticality mapping specific to low-carbon technologies, analyzing the sustainability and resilience of mineral supply chains, and assessing localization strategies—particularly the Local Component Level (TKDN)—through an innovation and policy-oriented lens. Drawing from life-cycle analysis, global supply chain risk modeling, and criticality assessment frameworks, this study delivers a strategic synthesis that bridges natural resource governance with energy system innovation. The interdisciplinary approach adopted in this study positions critical minerals not merely as industrial commodities, but as essential enablers in the transformation toward a sustainable and sovereign energy future for Indonesia.

## 2. Literature Review

### *2.1 The Role of Critical Minerals in Renewable Energy*

Renewable energy plays a vital role in addressing climate change and achieving the Sustainable Development Goals (SDGs), particularly in clean energy and climate action. Although global renewable energy capacity grew significantly from 923 GW in 2004 to 2,588 GW in 2019, its development heavily depends on critical minerals such as nickel, cobalt, copper, lithium, and rare earth elements. The shift from fossil fuels to technologies like solar, wind, electric vehicles, and hydrogen has intensified demand for these minerals, transforming the mining and metals sectors with new challenges and opportunities. Low-carbon technologies in power generation and transportation require far more metals than fossil fuel systems—solar and wind plants, for example, use up to 300% more metals than gas plants. This necessitates a stable supply of both abundant and specialty minerals. Moreover, factors like lifecycle emissions, mineral types, and sourcing practices influence the carbon footprint of these technologies, emphasizing the need for efficient and sustainable resource use in the transition to clean energy [34-38].

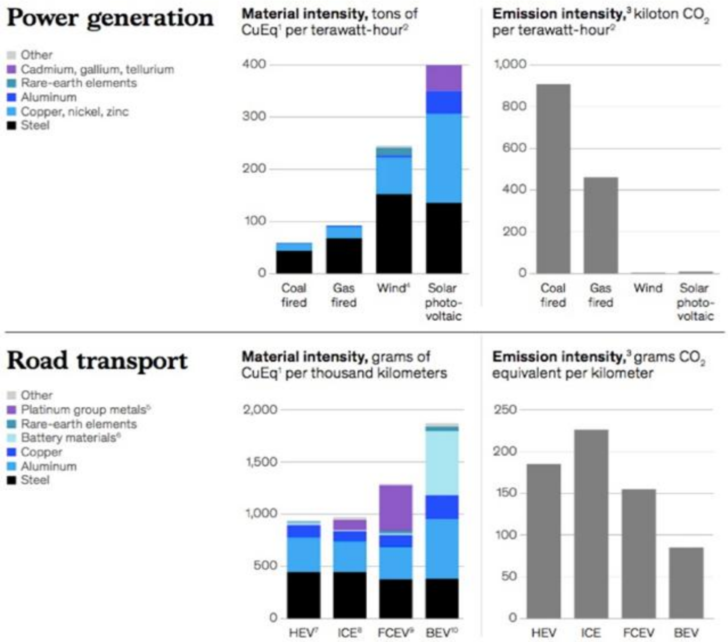



**Figure 1.** Critical mineral intensity in power generation and land transportation [39]

Geothermal and hydropower are key components of sustainable energy development. Geothermal energy harnesses the Earth’s internal heat from deep rock layers, often accessed by drilling into subterranean water reservoirs. This energy source, driven by the planet's geothermal gradient, is continuous, low-emission, and cost-effective. While more reliable than solar or wind, geothermal systems face material challenges due to corrosive conditions. To combat corrosion, high-nickel alloys like Alloy 625 and C-276, and stainless steels such as 316L and 304L, are used, though no universal material suits all due to varying brine compositions, requiring ongoing research. Hydropower, on the other hand, converts water flow into electricity using turbines and generators. By 2020, global capacity reached 1,308 GW and is projected to grow 60% by 2050. Turbines made from fiberglass and stainless steel are supported by systems using zinc for cooling, corrosion resistance, and electrical protection. Both energy sources are essential in achieving long-term sustainability and energy security [40-45].

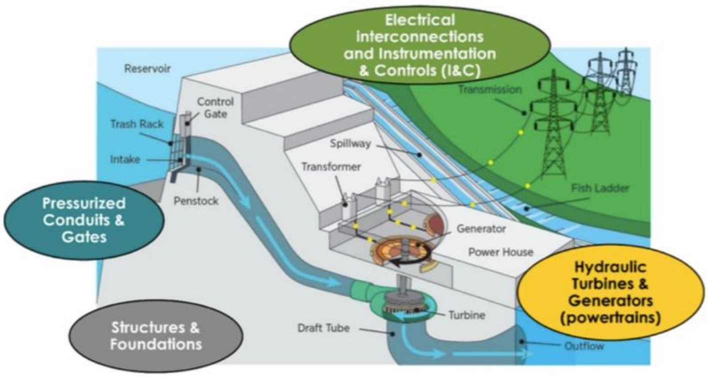



**Figure 2.** Hydropower application scheme [46]

Biomass energy, derived from organic materials and animal waste, is converted into heat, power, and biofuels using materials like stainless steel and nickel alloys to resist corrosion during processing. Common grades include 304(L), 316(L), and duplex types such as 2205 and 2507, while copper is crucial for plant growth and bioenergy production. Aluminum, serving as an eco-friendly energy storage medium, and zinc, essential for biodiesel synthesis through catalytic processes, also play key roles. In parallel, energy networks—among the world's most complex systems—must ensure reliable electricity distribution while supporting growing electric vehicle usage. Structural materials like steel protect infrastructure, while copper and aluminum act as main conductors. Though aluminum is more corrosion-prone, it is a lighter, more cost-effective conductor, whereas copper offers superior conductivity and is ideal for indoor wiring. Electrical steel, used in transformers and motors, provides enhanced magnetic properties, ensuring efficient power transmission and generation in a sustainable energy future [47-51].

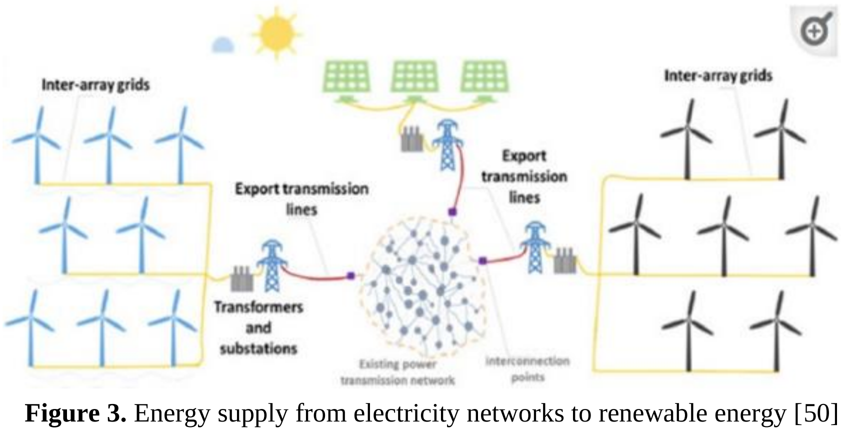
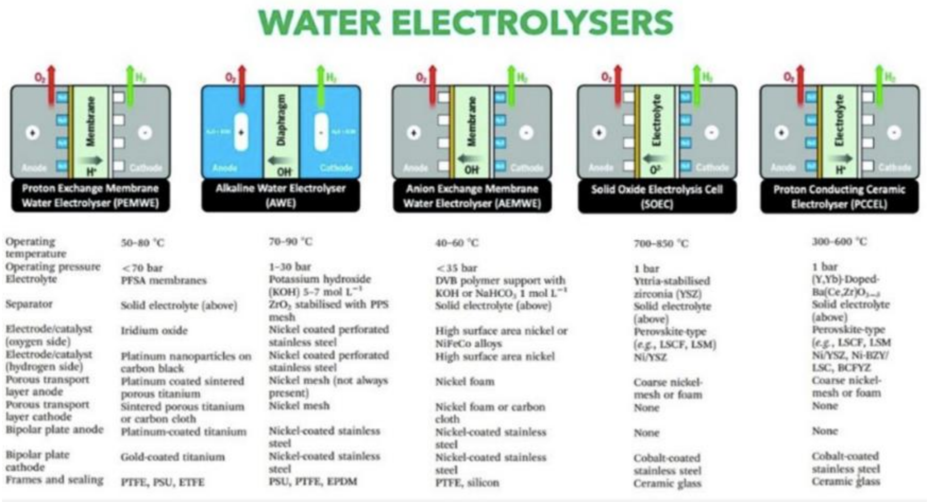



**Figure 3.** Energy supply from electricity networks to renewable energy [50]

Concentrated solar power (CSP) systems use mirrors to focus sunlight onto a receiver that heats fluid to drive a turbine or engine for power generation. Beyond electricity, CSP is also applied in industries like food processing, chemical manufacturing, and desalination. Materials such as stainless steel are favored for their resistance to corrosion and high temperatures, while copper provides excellent electrical and thermal conductivity for precision components. Aluminum boosts heat collection due to its strength, reflectivity, and lightness, and nickel enhances the durability of steel alloys under harsh conditions. Hydrogen, a key to carbon neutrality, is projected to exceed 500 MTA in demand by 2050. Its production via SMR, electrolysis, or biomass gasification relies on critical minerals like platinum, iridium, nickel, and rare earth elements. Green hydrogen, produced using water electrolyzers like PEMWE, AWE, AEMWE, and SOEC, faces barriers including high costs and mineral scarcity.

Advancing hydrogen technology and improving mineral recycling are essential to scaling production sustainably and minimizing environmental impact [52-54].




| | PEMWE | AWE | AEMWE | SOEC | PCCEL |
|---|---|---|---|---|---|
| Operating temperature | 50–80 °C | 70–90 °C | 40–60 °C | 700–850 °C | 300–600 °C |
| Operating pressure | <70 bar | 1–30 bar | <35 bar | 1 bar | 1 bar |
| Electrolyte | PFSA membranes | Potassium hydroxide (KOH) 5–7 mol L$^{-1}$ | DVB polymer support with KOH or $NaHCO_3$ 1 mol L$^{-1}$ | Yttria-stabilised zirconia (YSZ) | (Y,Yb)-Doped-Ba(Ce,Zr)$O_{3-\delta}$ |
| Separator | Solid electrolyte (above) | $ZrO_2$ stabilised with PPS mesh | Solid electrolyte (above) | Solid electrolyte (above) | Solid electrolyte (above) |
| Electrode/catalyst (oxygen side) | Iridium oxide | Nickel coated perforated stainless steel | High surface area nickel or NiFeCo alloys | Perovskite-type (e.g., LSCF, LSM) | Perovskite-type (e.g., LSCF, LSM |
| Electrode/catalyst (hydrogen side) | Platinum nanoparticles on carbon black | Nickel coated perforated stainless steel | High surface area nickel | Ni/YSZ | Ni/YSZ, Ni-BZY/LSC, BCFYZ |
| Porous transport layer anode | Platinum coated sintered porous titanium | Nickel mesh (not always present) | Nickel foam | Coarse nickel-mesh or foam | Coarse nickel-mesh or foam |
| Porous transport layer cathode | Sintered porous titanium or carbon cloth | Nickel mesh | Nickel foam or carbon cloth | None | None |
| Bipolar plate anode | Platinum-coated titanium | Nickel-coated stainless steel | Nickel-coated stainless steel | None | None |
| Bipolar plate cathode | Gold-coated titanium | Nickel-coated stainless steel | Nickel-coated stainless steel | Cobalt-coated stainless steel | Cobalt-coated stainless steel |
| Frames and sealing | PTFE, PSU, ETFE | PSU, PTFE, EPDM | PTFE, silicon | Ceramic glass | Ceramic glass |

**Figure 4.** Types of water electrolysis [116]

Wind turbines generate electricity by converting wind's kinetic energy into mechanical motion through aerodynamic blade forces that drive a rotor and generator. They are built using materials like copper, aluminum, steel, fiberglass, and iron, with zinc used to prevent corrosion. Permanent magnets containing neodymium, praseodymium, dysprosium, and terbium increase turbine efficiency, while sturdy steel towers ensure stability. Copper is crucial for improving energy efficiency and reducing $CO_2$ emissions in wind systems. In solar technology, copper and silver are heavily used, with silver comprising about 10% of solar module costs. Monocrystalline silicon and emerging technologies like perovskite/silicon cells offer higher efficiency but increase mineral demand, particularly for silver. Future scenarios suggest rising global needs for aluminum, cadmium, copper, and silver, alongside thin-film technologies elevating demand for germanium and tellurium. Solar panel supports rely on aluminum and stainless steel for strength and corrosion resistance. Minerals like silicon, indium, gallium, selenium, and tellurium are also essential for improving solar cell conductivity and performance [55-57].

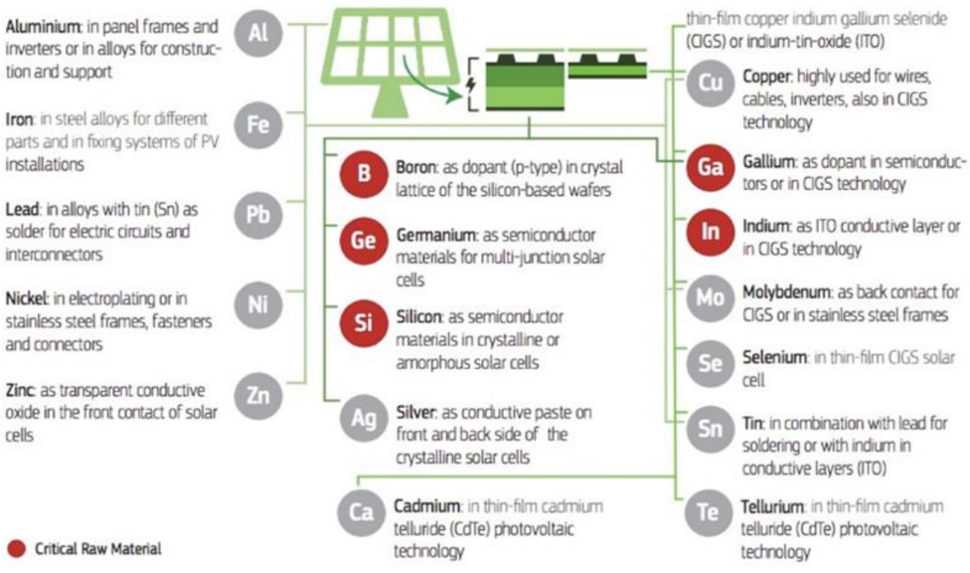



**Figure 5.** The role of critical minerals in photovoltaics [58]

Batteries are vital for electric vehicles (EVs), with their size and capacity shaped by energy consumption, which ranges from 100 to 300 Wh/km. By 2030, battery material demand could reach 14 million tons. Key materials include copper, aluminum, graphite, lithium, cobalt, and nickel, the latter three comprising about 20% of a battery's mass. EV battery cells feature an anode (graphite or silicon), cathode (nickel, manganese, or cobalt), electrolyte, and aluminum casing. Aluminum use in EVs is expected to rise to 233 kg per vehicle by 2026. Rare earth metals such as terbium, dysprosium, praseodymium, and neodymium enhance electric motor efficiency under high heat. Fuel cells, a clean alternative to combustion, convert hydrogen or other fuels into electricity with only heat and water as emissions. These systems rely on materials like platinum-nickel catalysts, aluminum, stainless steel, and various oxides and rare earths to boost performance and durability. As these technologies evolve, they support sustainable energy in transport, power, and industry [59-62].

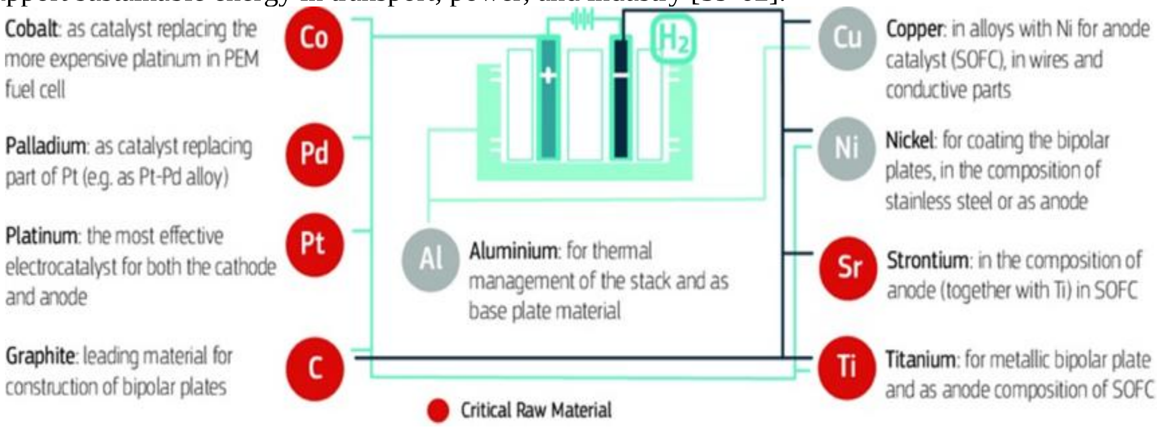



**Figure 6.** The role of critical minerals in fuel cells [63]

*2.2 Availability of Critical Minerals in Indonesia*

Indonesia recognizes 47 critical minerals under Ministerial Decree No. 296.K/MB.01/MEM.B/2023, with high demand in sectors like health, security, and renewable energy. While the country mines lithium, nickel, and steel, it still imports aluminum—valued at $5.9 million USD from Angola in 2022. Currently, 21 essential minerals are especially needed in technology related to renewable energy.

**Table 1** Critical Mineral Classification

| No | Critical Mineral Types of Usefulness in RE Technology | No | Critical Mineral Types of Usefulness in RE Technology |
|---|---|---|---|
| 1 | Aluminum | 12 | Nickel |
| 2 | Iron | 13 | Silver |
| 3 | Dysprosium | 14 | Platinum |
| 4 | Gallium | 15 | Praseodymium |
| 5 | Graphite | 16 | Zinc |
| 6 | Iridium | 17 | Silica |
| 7 | Cadmium | 18 | Tellurium |
| 8 | Cobalt | 19 | Copper |
| 9 | Lithium | 20 | Terbium |
| 10 | Manganese | 21 | Uranium |
| 11 | Neodymium | | |

Iron, the fourth most abundant element in Earth's crust, is crucial for new and renewable energy (NRE) technologies like wind and gas turbines. Indonesia holds substantial iron reserves 1 billion tons projected and 13 billion tons of total resources mainly found in South Kalimantan's Yiwan Mine and other regions like Southeast Sulawesi and North Maluku. A single wind turbine requires around 1,500 tons of iron ore, while a gas turbine needs about 300 tons. With its vast iron resources, Indonesia has the potential to produce up to 8.6 million wind turbines or 43.3 million gas turbines, significantly supporting its renewable energy goals [64-65].

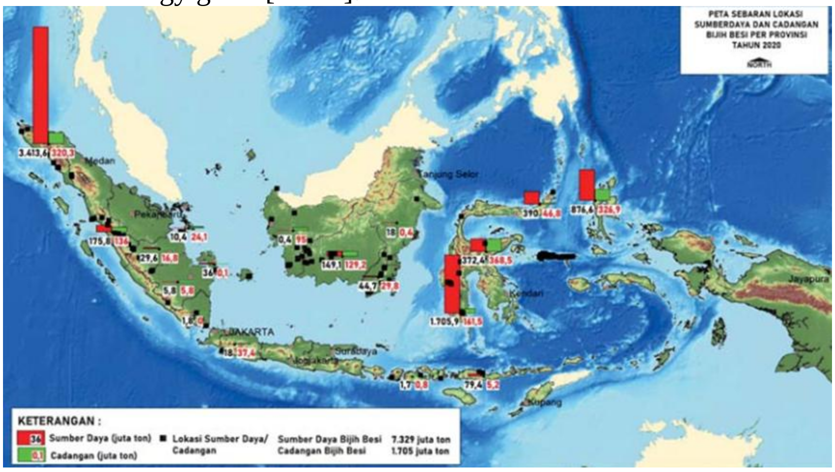



**Figure 7.** Distribution of Iron Ore per Province in Indonesia in 2020 [66]

Indonesia, the world’s seventh-largest copper producer, saw a production decline from 941,000 metric tons in 2022 to 840,000 in 2023, yet still holds strong potential for advancing renewable energy technologies like solar panels and wind turbines. With current output, Indonesia can support the creation of approximately 330,000 solar panels, 308,000 onshore wind turbines, and 115,000 offshore wind turbines, largely supplied by the Grasberg Mine in Papua and other regional mines. Although not a top global aluminum producer, Indonesia’s bauxite and alumina resources have grown, reaching 1.8 billion tons by 2020. This positions the country to manufacture about 85 million solar panels, based on the alumina requirement of 21 tons per megawatt, bolstering its role in the renewable energy sector [67-69].

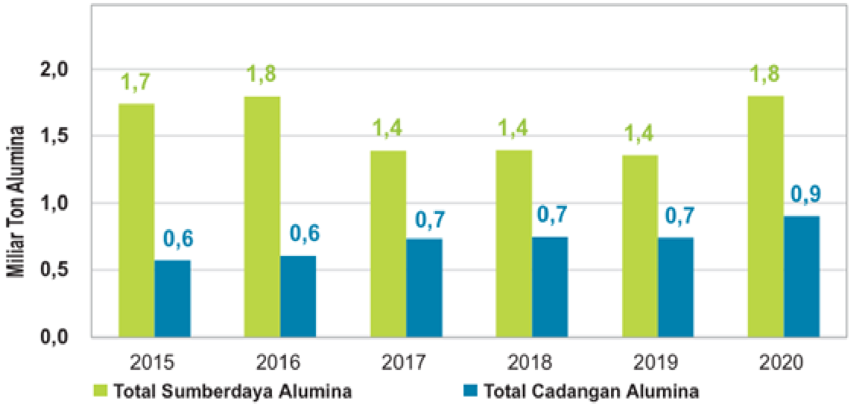



**Figure 8.** Total Resources and Reserves of Alumina in Indonesia [66]

Indonesia, the world’s top nickel producer in 2023 with 1.8 million metric tons, significantly contributes to renewable energy (RE) technologies such as solar panels and wind turbines. Despite a decline in reserves since 2019, current production enables the potential construction of 7.5 million offshore wind turbines, 4.5 million onshore turbines, and 1.8 billion solar panels. Meanwhile, Indonesia's zinc reserves 57.9 million tons of ore and 2.3 million tons of metal are concentrated in areas like Dairi, North Sumatra, and represent 1% of global reserves. These resources support RE growth, particularly through the use of zinc in technologies like CIGS solar cells and EV components [70].


**Figure 9.** Distribution of Zinc Resources and Reserves in Indonesia [71]

Bangka Belitung holds 180,323 tons of monazite, a source of rare earth metals such as dysprosium, terbium, neodymium, and praseodymium key components in permanent magnets used in electric vehicles, electronics, aviation, and energy-efficient lighting. These elements are vital for technological advancement, and the government is urged to optimize their utilization. Additionally, Indonesia possesses vast silicon resources, especially silica sand, with over 400 million tons in total and 79 million tons in reserves, mainly located in Banda Aceh, Bangka, Belitung, and Bengkulu. In 2022, Indonesia produced 1.1 million tons of silica sand, sufficient to manufacture around 253,000 solar panels.

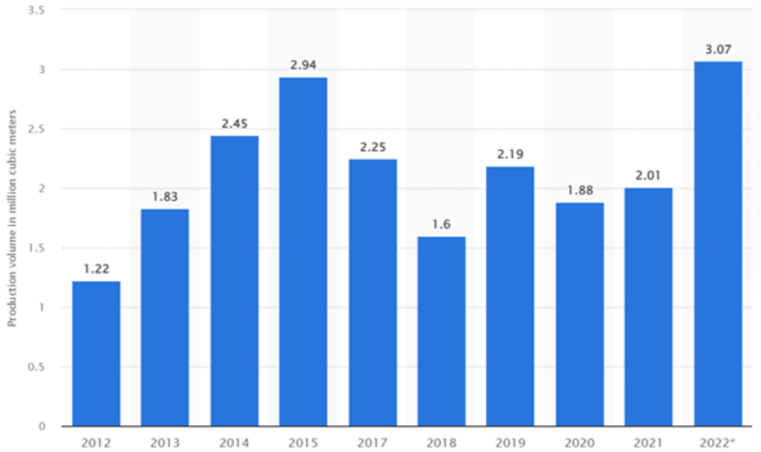



**Figure 10.** Indonesia's Annual Silica Sand Production 2012 – 2022 [72]

Indonesia holds significant potential for the development of renewable energy through its abundant critical minerals, including cobalt, graphite, and manganese. Cobalt, often found alongside nickel and copper, has ore reserves of 449.08 million tons and metal reserves of 258,746 tons, mainly located in North Maluku and Southeast Sulawesi. In 2023, Indonesia produced 17,000 tons of cobalt, supporting the potential production of up to 2.5 million electric vehicles and 8.5 million lithium-ion batteries. Graphite, found in Payakumbuh, West Sumatra, has an indicated resource of around 14 million tons and is used in various applications such as battery electrodes and lightweight composite materials. Meanwhile, manganese sourced from regions such as South Kalimantan, West Java, and Yogyakarta has reserves of up to 108 million tons of ore and 49 million tons of metal. This mineral availability enables the construction of up to 169,000 wind turbines, supporting Indonesia's clean energy transition [73-74].


**Figure 11.** Indonesia's Manganese Resources and Reserves [74]

Silver (Ag) and cadmium (Cd) are two critical metals with significant but differing roles in technology and renewable energy. Silver, prized for its conductivity and ductility, is widely used in electronics, jewelry, and solar panels. Indonesia holds vast silver ore resources—over 10 billion tons—and metal reserves of 11,000 tons, yet annual production remains limited, peaking at 487.8 tons in 2019. Major silver mines include Grasberg (Papua), Martabe (North Sumatra), and Tujuh Bukit (East Java), which, if fully optimized, could support the deployment of approximately 833 million 1-GW solar panels. In contrast, cadmium is a toxic heavy metal found primarily as a byproduct of zinc ore processing, such as sphalerite and greenockite. Although cadmium deposits in Indonesia are not widely distributed, the metal remains important for applications like nickel-cadmium batteries due to its unique electrochemical properties [75-76].

**Figure 12.** Cadmium Ore [76]

Gallium (Ga) and iridium (Ir) are two critical yet scarce metals essential to advanced technologies. Gallium, found as an impurity in bauxite, zinc, and aluminum ores, is notable for its low melting point and is used in thermostats, thermometers, transistors, and diodes. Indonesia previously exported bauxite rich in gallium, especially to Japan, but since 2014 has mandated domestic processing, enabling gallium production with high economic value around five times the price of gold. However, only about 10% of bauxite-derived materials are used for gallium in LED and semiconductor applications. In contrast, iridium—an extremely rare and corrosion-resistant transition metal occurs in nickel and platinum ores and is critical for semiconductors, catalysts, electrodes, medical equipment, and cancer treatment. Despite its high utility, Indonesia lacks dedicated iridium mining, relying entirely on imports, with global supplies mainly sourced from Canada, Russia, and South Africa.

**Figure 13.** (a) Galium Ore [77] (b) Iridium Ore [78]

Lithium (Li) and platinum (Pt) are essential minerals for advancing modern technology and renewable energy. Lithium, an alkali metal primarily found in granite, pegmatite, and minerals such as spodumene and lepidolite, is vital for lithium-ion batteries used in electronics and electric vehicles. Although Indonesia currently lacks sufficient mining and processing capabilities and relies on imports, the government plans to develop domestic production by constructing a 30,000-ton lithium carbonate plant and a 50,000-ton lithium hydroxide facility. These facilities aim to exploit lithium reserves in regions such as Bangka Belitung, Aceh, and Sumatra to reduce import dependency. In contrast, platinum, a precious metal present in nickel, copper, and palladium ores, is highly valued for its strength, conductivity, and corrosion resistance. It is used in jewelry, electronics, catalysts, and laboratory tools. With estimated reserves of 114 million tons as of 2021, Indonesia has significant potential to become a major global platinum producer. Realizing this potential requires strategic investment and enhanced extraction efforts, particularly in areas like Martapura and Bengkalis.

**Figure 14.** (a) Lihtium Ore [79] (b) Paltinum Ore [80]

Tellurium (Te) and uranium (U) are two strategically important minerals with growing relevance in modern technology and energy sectors. Tellurium, a metalloid primarily obtained as a byproduct of copper and tin mining, is used extensively in photovoltaic solar panels, fire-resistant magnesium alloys, stainless steel, and semiconductor devices such as diodes and infrared sensors. Despite its critical applications, tellurium is produced in minimal quantities in Indonesia, and its resource potential remains unclear, necessitating further exploration and evaluation. On the other hand, uranium, a radioactive element found in minerals like carnallite and uraninite, serves as the primary fuel for nuclear reactors that currently generate about 10% of global electricity through nuclear fission. Although Indonesia possesses approximately 13,503 tons of uranium reserves as of 2021, these are limited and dispersed across several regions, including the Riau Islands, Kalimantan, Sulawesi, Sumatra, Papua, and Bangka Belitung. Unlocking the full potential of these resources will require sustained research and development to support national energy security and technological progress.

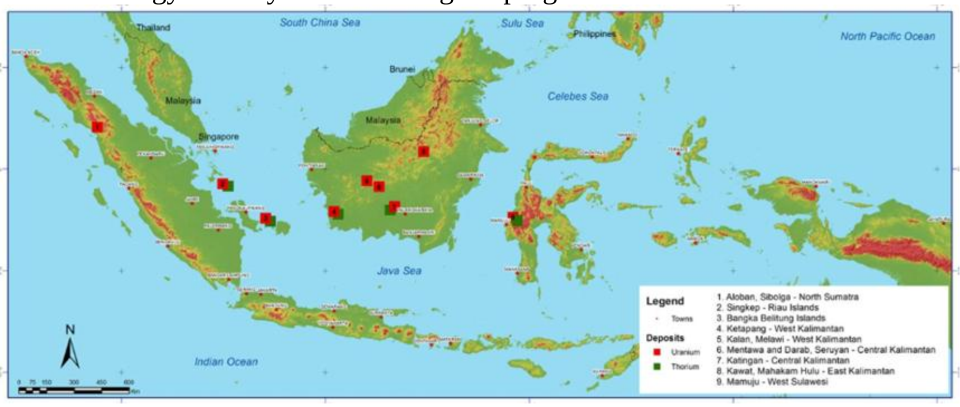



**Figure 15.** Distribution of Uranium and Thorium Minerals in Indonesia as of 2021 [81]

*2.3 Local Component Level (TKDN) for Renewable Energy Development Using Critical Minerals*

The Local Component Level (TKDN) represents the proportion of local content in goods, services, or both, and serves as a strategic initiative by the Indonesian government to strengthen industrial infrastructure and support domestic enterprises [82]. As part of this effort, TKDN encourages greater use of locally produced products. In alignment with the Ministry of Energy and Mineral Resources (KESDM) Regulation No. 16 of 2020 on the Strategic Plan 2020–2024, Indonesia's installed renewable energy capacity reached 10,300.7 MW by 2019, marking a 21% increase since 2015, as shown in Table 2.

**Table 2** The development of installed capacity of renewable energy plants

| Type | Achievement of Renewable Energy Electricity Supply (MW) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 | 2019 |
| Geothermal Power Plant | 1,438 | 1,533 | 1,808 | 1,948 | 2,131 |
| Bioenergy Power Plant | 1,742 | 1,783 | 1,857 | 1,883 | 1,890 |
| Hydro and Micro-hydro Power Plant | 5,277 | 5,621 | 5,658 | 5,742 | 5,976 |
| Solar Power Plant | 33 | 44 | 52 | 73 | 146 |
| Wind Power Plant | 1 | 1 | 1 | 144 | 154 |
| Hybrid Power Plant | 4 | 4 | 4 | 4 | 4 |
| Ocean Current Power Plant | 0 | 0 | 0 | 0 | 0 |
| Total | 8,496 | 8,986 | 9,380 | 9,793 | 10,301 |

The Photovoltaic Solar Energy System (SESF), commonly known as a Photovoltaic Solar Power Plant (PLTS) or solar module, is utilized not just for rural electrification projects but also for applications such as area and street lighting, as well as powering places of worship. Rooftop solar power plants and other solar power installations are being utilized increasingly regularly. Figureure 16 demonstrates that PLTS's installed capacity surged by 335% from 2015 to 2019, attaining 145.81 MW.


**Figure 16** Development of installed capacity of solar power plants (PLTS) [83]

Figureure 16 highlights TKDN percentage requirements based on Regulation No. 04/M-Ind/Per/2/2017 for Solar Power Plants (PLTS). However, Indonesia's local industry struggles to meet these standards due to high production costs and limited capabilities. The TKDN requirement for PLTS can reach 65%, while the minimum target is 40.50%, hindering investment viability. In 2023, Indonesia only reached USD 1.1 billion in renewable energy (RE) investment, falling short of its USD 1.7 billion goal. Most local manufacturers produce only 450 Wp solar modules, with only one making 560 Wp, while 21 factories rely on imported solar cells. Locally made modules are also 30% - 45% more expensive than imported ones. Meanwhile, geothermal energy remains a government priority, though only 4.7% (1,343.5 MW) of Indonesia’s 28,994 MW potential about 40% of the world’s reserves has been utilized, covering various resource categories including hypothetical, speculative, and proven reserves [84].

Local Content Requirement (TKDN) refers to the ratio of domestic components contained within goods and services. For goods, it encompasses domestically sourced raw materials, design, and manufacturing processes. For services, it includes local labor, equipment, software, and supporting facilities. In the context of geothermal power plants (PLTP), TKDN calculations cover major components such as steam turbines, steam systems, generators, electrical systems, and civil structures. In addition, it also accounts for services including consultancy, engineering, procurement, and construction (EPC), testing, training, and other supporting activities. The minimum TKDN requirements are stipulated under Regulation of the Ministry of Industry No. 54/M-IND/PER/3/2012 [85-86].

**Table 3** Minimum local component level (TKDN) for geothermal power plant (PLTP)

| Geothermal Power Plant (PLTP) | Geothermal Power Plant Scale | | | | |
|---|---|---|---|---|---|
| | up to 5 MW | 5-10 MW | 10-60 MW | 60-100 MW | >110 MW |
| Goods | 31.30% | 21% | 15.70% | 16.30% | 16% |
| Service | 89.18% | 82.30% | 74.10% | 60.10% | 58.40% |
| Goods and Service | 42% | 40.45% | 33.24% | 29.21% | 28.95% |

Despite the minimum TKDN requirements for geothermal power plants (PLTP) set by Ministerial Regulation No. 54/2012 (Table 3), project implementation faces challenges. In Bengkulu, TKDN regulations—particularly those involving turbines have delayed 600 MW projects in Kepahiang and Lebong. As a result, JICA withdrew its funding, citing a mismatch between TKDN mandates and procurement guidelines. Overall, geothermal development remains difficult due to complex technical standards that often require foreign investment to proceed effectively [87].

**Table 4** Minimum local component level (TKDN) for hydro and micro-hydro power plant

| Hydro Power Plant (PLTP) | Hydro Power Plant Scale | | | |
|---|---|---|---|---|
| | 15 MW | 15-50 MW | 50-150 MW | >150 MW |
| Goods | 64.20% | 49.84% | 48.11% | 47.82% |
| Service | 86.06% | 55.54% | 51.10% | 46.98% |
| Goods and Service | 71% | 51.60% | 49.00% | 47.60% |

The table referenced outlines the minimum Domestic Component Level (TKDN) for hydropower and micro-hydro power plants (PLTA and PLTMH) as stipulated in Ministerial Regulation No. 54/M-IND/PER/3/2012. By December 2023, PT Kayan Hydro Energy (KHE) achieved an 80% TKDN for the Kayan hydropower project, leveraging abundant local resources in Kalimantan, while two micro-hydro plants PLTM Lambur and PLTM Aek Sibundong were successfully commissioned in 2022. However, other projects such as PLTA Bakaru 1 and 2, PLTA Upper Cisokan PS, and several smaller hydro facilities still face hurdles in meeting TKDN requirements. Meanwhile, bioenergy has emerged as a promising contributor to Indonesia's renewable energy mix, accounting for 7.7% in 2023, with biodiesel production reaching 12.3 million kg, saving over 122 trillion rupiahs and reducing 132 million tons of greenhouse gas emissions. Despite this progress, bioenergy development is constrained by logistical limitations, sustainability concerns, and a lack of incentives, particularly for non-palm-based biofuels. Regulation No. 9 of 2023 by MESDM seeks to address these barriers, including procurement inefficiencies and transportation challenges [88-90].

### *2.4 Strategies to secure critical mineral supplies*

The restricted availability and crucial role of vital minerals have made securing their supply a global concern, as identified in the World Bank's 2020 study, which highlights this issue as a barrier to economic development. Indonesia has responded with a collaborative strategy involving government, industry, and academia to stabilize mineral supply chains. At the 2021 international trade conference in Jakarta, the Minister of Trade reaffirmed Indonesia's commitment to regional cooperation in this area.

Indonesia’s strategies are divided into domestic and international efforts. Domestically, the government is focused on critical mineral classification, downstream processing regulation, technological innovation to reduce emissions, better resource utilization, and repurposing coal waste. Internationally, Indonesia, like other countries, is working to boost domestic production, diversify supply sources, and expand recycling. China has moved toward self-sufficiency by investing in overseas mining and enhancing local recycling, while Japan emphasizes partnerships with key mineral-producing countries like Australia and Indonesia to secure supplies for its manufacturing and technology sectors. Figureures 5.8 and 17 underscore Japan’s reliance on these international sources for vital minerals [91-94].

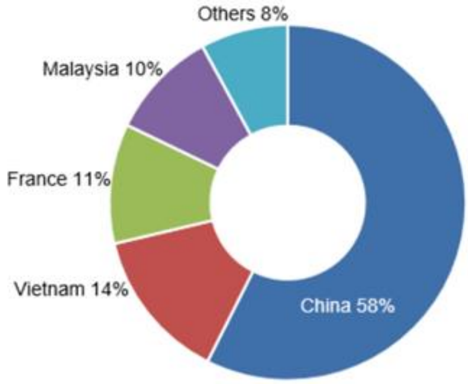



**Figure 17.** Japan's Dependence on Critical Minerals Supply Countries [94]

As fossil fuel reserves diminish and their adverse impacts become increasingly apparent, the role of renewable energy has grown more critical. Meeting global energy needs requires a thorough understanding of efficient and effective renewable energy strategies. This section examines the approaches adopted by Indonesia and other nations, with a particular focus on identifying strategies most suitable for PLN, Indonesia’s state-owned electricity utility, to ensure a sustainable energy supply. Indonesia, with its high geothermal potential due to subsurface heat, ranks as the world's second-largest producer of geothermal power, generating 2,418 MW as of 2023. However, only 11% of its geothermal resources had been utilized by 2018, leaving significant untapped capacity [95-96].

To stimulate development, the government enacted Law No. 21 of 2014 on Geothermal Energy and PLN plays a crucial role in supporting such projects. One key challenge is PLN’s lengthy and complex process for finalizing Power Purchase Agreements (PPAs), which hinders investment; thus, streamlining negotiations would significantly aid project acceleration. In addition to geothermal, hydropower represents another major renewable source. Derived from the mechanical energy of flowing water, hydropower remains one of the most widely used renewable technologies worldwide. Between 2017 and 2021, global hydroelectric capacity expanded rapidly, with the East Asia and Pacific region leading in installed capacity for nearly five consecutive years [97-98].

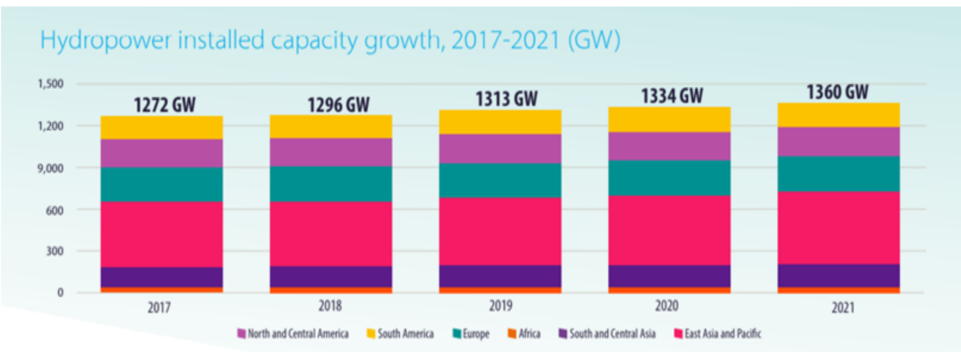



**Figure 18.** Growth in Installed Electricity Capacity in Each Region of the World in 2017-2021 [99]

Indonesia remains underutilized in its hydroelectric potential, despite East Asia and the Pacific leading in hydropower capacity from 2017 to 2021. In 2023, Indonesia's projected hydropower potential reached 76.09 GW, yet only about 5.28 GW (6.9%) has been realized. This shortfall stems from high investment costs, lengthy permitting processes, land-use challenges, forested hydropower sites, and poor water quality. To overcome these barriers, PLN and the government must revise investment strategies to attract investors, simplify permitting procedures, and promote equitable development of hydropower across all viable regions, while ensuring adherence to Environmental Impact Assessments (Amdal). Additionally, rather than focusing solely on large-scale projects, hydropower plants can be designed to meet local energy needs, optimizing land use [100-103].

Meanwhile, nuclear energy, sourced from the fission of atomic nuclei, remains a significant contributor to global electricity, supplying around 10% of the total energy mix, with 361,105 MW of installed capacity as of 2022. Although Indonesia holds approximately 70,000 tons of $U_3O_8$, categorized into measured, indicated, inferred, and hypothetical resources, it has yet to build a nuclear power plant (NPP). However, plans are underway, with PLN expected to play a key role in establishing the country's first NPP by 2030 in coordination with the Ministry of Energy and Mineral Resources (ESDM) and the Nuclear Energy Council (MTN). Concurrently, bioenergy sourced from biomass such as agricultural waste, forestry residues, grasses, food waste, and microalgae represents another growing renewable energy option. It is commonly used to blend or replace fossil fuels and generate electricity through biomass power plants (PLTBm), offering a sustainable pathway within Indonesia's energy transition [104-107].

**Table 5** Top Biofuel-Producing Nations by 2022

| Nations | Biofuel Production (Thousand Barrels of Oil per Day) |
|---|---|
| United States | 728 |
| Brazil | 409 |
| Indonesia | 174 |
| China | 66 |
| Germany | 62 |
| Argentina | 45 |
| India | 43 |
| Netherlands | 39 |
| Thailand | 36 |
| France | 35 |

In 2022, Indonesia positioned itself as the world's third-largest biofuel producer, underscoring the government's strong commitment to transitioning from fossil fuels to renewable energy through its mandatory Biofuel (BBN) program. However, challenges persist in advancing B40, D100, and Bioavtur fuels, along with infrastructure development for the "Merah Putih" catalyst, palm oil-based gasoline, natural gas (BBG), and electric vehicles. Despite achieving a total biomass power plant (PLTBm) capacity of 1,856.6 MW in 2018—214.6 MW on-grid and 1,643.9 MW off-grid—Indonesia did not rank among the top 10 countries for installed PLTBm capacity in 2022. Globally, PLTBm capacity reached 26,060 MW, with Brazil leading at 12,688 MW. To enhance bioenergy utilization, the Indonesian government has launched several market-based initiatives, such as co-firing coal plants (PLTU) with biomass, supporting captive power plant electricity sales to PLN through the Excess Power scheme, converting diesel plants to Crude Palm Oil-fueled plants (PLTBn-CPO), and developing Waste-to-Energy (PLTSa) and agro-industrial waste power plants. These efforts are reinforced by state budget support (APBN) and more accessible financing [108-109].

Meanwhile, electricity transmission from producers to end users continues to evolve with growing global demand. Based on World Energy & Climate Statistics, global power generation grew by 2.3% in 2022 compared to 2021—slower than the 5.7% increase seen the year prior. In 2021, Indonesia produced

308,661 GWh of electricity, ranking sixth in the Asia-Pacific region. This reflects the country's consistent upward trend in electricity generation since 2000, signifying its rising energy demand and production capacity [110-112].

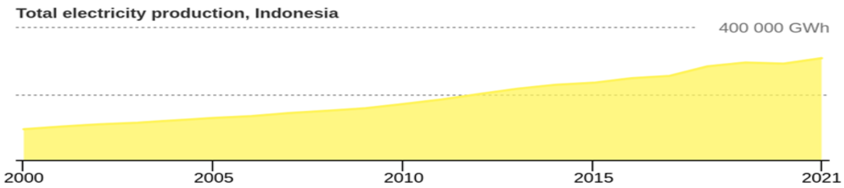



**Figure 19.** Total Electricity Production in Indonesia 2000 – 2021[113].

Despite annual increases in energy generation, Indonesia remains heavily reliant on fossil fuels, particularly coal, which accounted for 61.5% of electricity production in 2021. To mitigate this dependency, the government has adopted strategies such as boosting renewable energy deployment, implementing carbon taxes and trading schemes, cofiring coal plants, decommissioning outdated coal-fired units, and developing Carbon Capture and Storage (CCS) systems. In alignment with its environmental commitments, Indonesia aims to reduce carbon emissions by 29% independently and up to 41% with international support by 2030. In the realm of emerging technologies, fuel cells which convert hydrogen and oxygen into electricity via electrochemical reactions are increasingly being used globally. South Korea's Shinincheon Bitdream Fuel Cell Power Plant exemplifies this trend, boasting a capacity of 78.96 MW and generating 700 GWh annually. In Indonesia, although fuel cell adoption is still nascent, the establishment of the Indonesia Association Fuel Cell and Hydrogen Energy (INAFHE) by BPPT reflects growing national interest. INAFHE brings together key institutions like LIPI, BATAN, ESDM, academia, and private sectors to accelerate development in this field [114-116].

Indonesia also holds vast potential for Concentrated Solar Power (CSP) due to its abundant sunlight, though environmental constraints such as the need for expansive flat land and consistent solar radiation pose obstacles. CSP, which focuses sunlight using mirrors or lenses to produce heat for electricity, is still in the R&D stage domestically. Nonetheless, the Ministry of Energy and Mineral Resources targets a 23% renewable energy share by 2025, with CSP seen as a key contributor. This technology is also linked to mineral resource strategies due to its reliance on specific critical materials. Additionally, hydrogen is gaining attention as a clean alternative to fossil fuels, though like electricity, it is a secondary energy carrier. Global interest in low-emission hydrogen projects is rising, with potential output estimated at 38 metric tons per year by 2030. Indonesia has made strides in this area, as PT Aneka Gas Industri (AGI) has launched the country's first green hydrogen plant using water electrolysis. Moreover, PT PLN (Persero) inaugurated a pilot Green Hydrogen Plant and Hydrogen Refueling Station at the Kamojang Geothermal Power Plant on February 21, marking a significant milestone in Indonesia's hydrogen infrastructure development [117-121].


**Figure 20.** The First Officially Operating Hydrogen Filling Station [121]

Wind energy converts wind's kinetic energy into electricity using turbines with rotating blades that drive generators. Wind is caused by air pressure differences, and its speed is affected by the Coriolis effect, sunlight, and geography. Applications range from traditional milling sails to modern wind farms and bladeless turbines.Wind energy converts wind's kinetic energy into electricity using turbines with rotating blades that drive generators. Wind is caused by air pressure differences, and its speed is affected by the Coriolis effect, sunlight, and geography. Applications range from traditional milling sails to modern wind farms and bladeless turbines. [122].

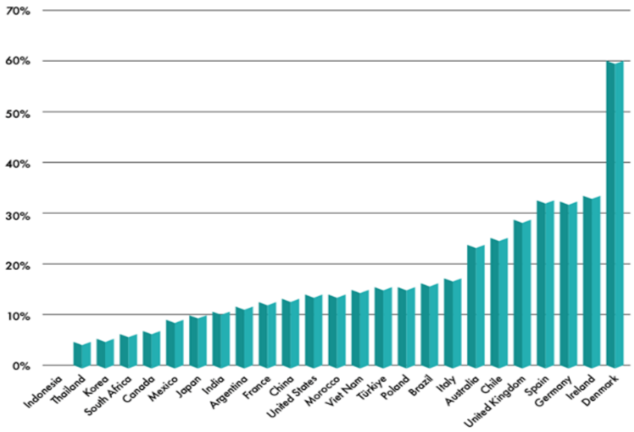



**Figure 21.** Total Wind Energy System and Capacity Factor between China and the United States [123]

Data shows that Thailand leads in renewable energy ownership, with Indonesia following. However, Indonesia faces challenges in wind energy implementation due to its uneven terrain and the specific wind speeds needed for turbines. In contrast, solar photovoltaics (PV) which use semiconductors to convert sunlight into electricity are gaining global prominence due to declining costs. Indonesia has played a role in the global rise of PV technology, as seen in large-scale projects like the Desert Sunlight Solar Farm in the U.S., which generates 550 MW of power across 1,600 hectares [124-125].

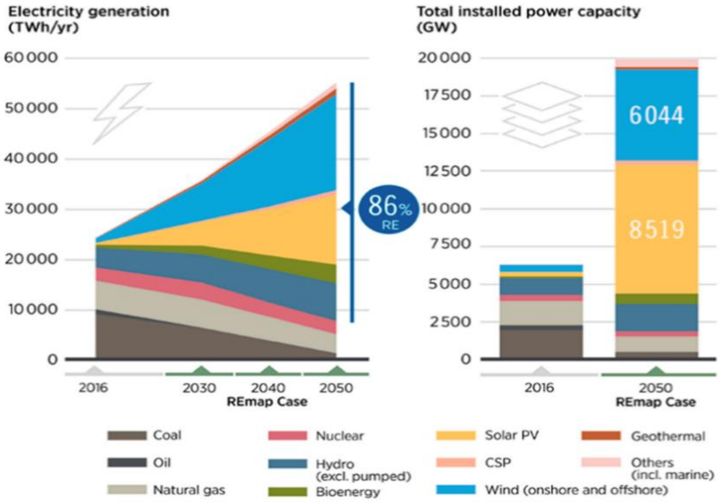



**Figure 22.** Contribution of energy sources, both electricity generation and total installed electricity capacity globally in 2050 [126]

Although solar energy currently contributes only 3.6% to global electricity production, its adoption is rapidly increasing, accounting for 31% of new renewable energy capacity in 2022. Global solar power capacity grew significantly across 235 countries and regions from 2021 to 2022, with projections indicating that by 2050, solar photovoltaic (PV) technology could supply 25% of global electricity. Europe led this growth in 2022 with an installed capacity of 225,478 MW. Despite this global momentum, Indonesia remains behind, with only 271.6 MW of installed solar capacity in 2022 far below the national target of 893.3 MW. The Ministry of Energy and Mineral Resources aims to increase rooftop solar capacity to 3,600 MW by 2025. Meanwhile, the electric vehicle (EV) market continues to expand, with 14 million EVs sold globally in 2023a 35% rise from 2022. China led with 8.1 million sales, followed by the U.S. with 1.4 million, driven by tax incentives and revised regulations. In Indonesia, the EV sector is gaining traction through strong government policy and investor interest. Despite comprising only 0.1% of the automotive market in 2020, Indonesia's resource wealth and industrial growth position it as a future EV hub, though obstacles like high costs and limited charging infrastructure must still be overcome [127-130].

### *2.5 Renewable Energy Technology Considerations*

Indonesia's energy sustainability hinges on harnessing local resources for renewable energy (RE) development, supported by policies that encourage research and innovative technology deployment. Key minerals such as nickel, cobalt, and copper are crucial in advancing toward sustainable energy by enhancing energy independence, reducing greenhouse gas emissions, and diversifying the national energy mix. Nickel, vital for lithium-ion batteries used in electric vehicles and energy storage systems, is abundant in Sulawesi, which holds around 80% of the world's nickel reserves. Although its utilization in battery production is still limited, usage is rapidly growing alongside the rising demand for electric vehicles and renewable technologies. Similarly, cobalt primarily sourced from Halmahera Island is used in lithium-ion batteries for both energy storage and electric vehicles. While its current application in Indonesia remains constrained, cobalt presents significant potential to accelerate the development of electric vehicle infrastructure and renewable energy systems [131-132].

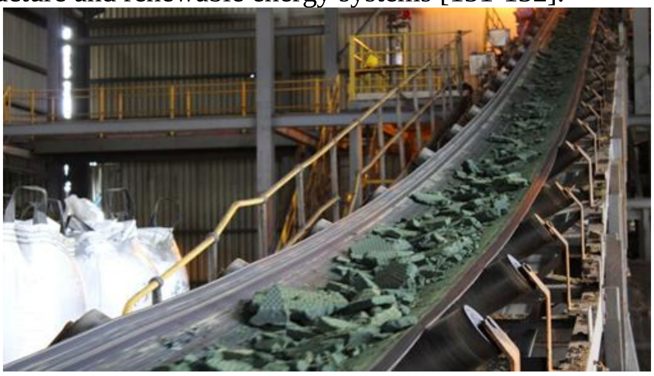


**Figure 23.** Cobalt production yield in batteries [133]

Indonesia possesses substantial mineral reserves that play a crucial role in the development of renewable energy technologies. The country is estimated to have around 800,000 tons of tin, primarily located in the Bangka and Belitung Islands, which is used in solder and electronic components for solar panels, wind turbines, and control systems, although its utilization remains limited. Additionally, Indonesia holds significant copper reserves, particularly in Papua and West Nusa Tenggara, home to the Grasberg mine one of the largest copper mines in the world. Copper is essential for renewable energy technologies as it is used in batteries, electrical wiring, and various components of solar and wind energy systems. While copper has been employed in some renewable energy applications in Indonesia, its widespread use must be enhanced to support domestic clean energy infrastructure and innovation [133-135].

**Figure 24.** Tin Production in the RI Market [134]

## 3. Methods

This study adopts a qualitative, exploratory-descriptive research design to assess Indonesia's readiness in leveraging its critical mineral resources for renewable energy (RE) technology and net-zero transition. The methodological approach integrates multiple analytical frameworks to enhance both strategic depth and policy relevance. First, a Life Cycle Assessment (LCA) is employed to evaluate the environmental impact of critical mineral use across various RE technologies. Second, a criticality matrix is utilized to map the supply risk and economic importance of key minerals in Indonesia's context, drawing upon internationally recognized indicators. Third, a value chain analysis is conducted to examine the domestic mineral development trajectory from upstream extraction to downstream industrial application, including the evaluation of local content (TKDN) requirements. Fourth, a resource typology framework is applied to classify Indonesia's mineral endowment based on geological availability, processing readiness, and strategic potential. These approaches are complemented by SWOT analysis and stakeholder benchmarking to contextualize national strategies within broader global energy transition trends. Data is sourced from peer-reviewed literature, government publications, and global databases, ensuring robust triangulation and empirical grounding. This comprehensive methodology provides a structured basis for generating policy-relevant insights on enhancing critical mineral governance in support of Indonesia's renewable energy ambitions. The flowchart in the Figureure 25 depicts the research methodology for Phase 1, which is structured into three sequential stages. The first stage involves identifying and classifying critical minerals relevant to renewable energy (RE) technologies. The second stage focuses on analyzing Indonesia's mineral potential and evaluating its readiness to support national net-zero emission targets. The third stage encompasses the assessment of localization strategies (TKDN) and the formulation of strategic policy recommendations. Throughout these stages, a data triangulation approach is employed by integrating information from multiple sources, including government institutions, international organizations, and peer-reviewed academic journals, to ensure the robustness and validity of the research findings.

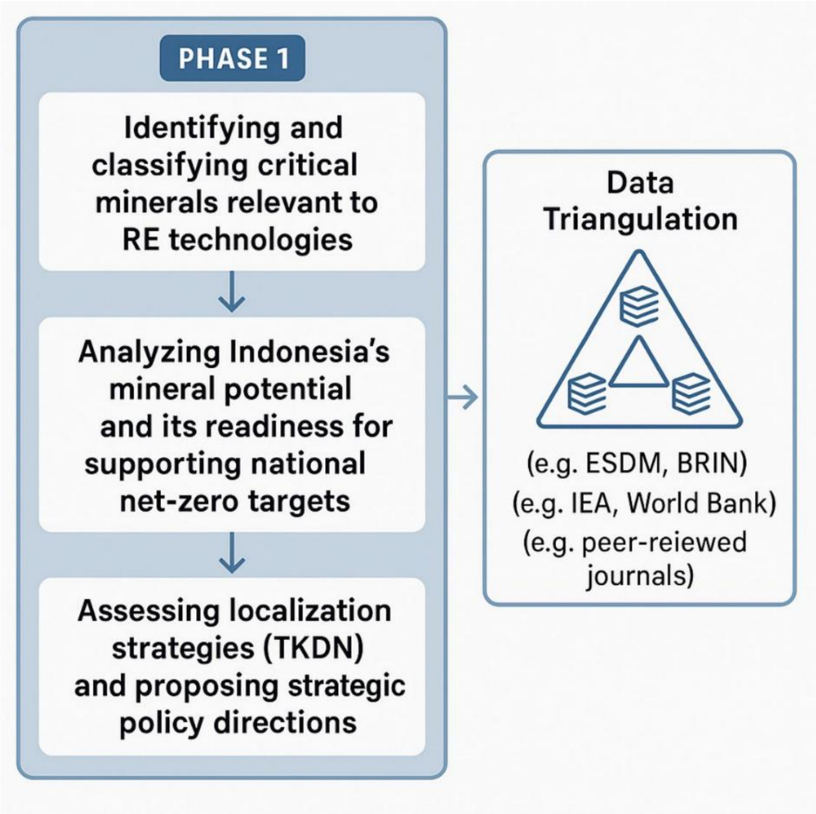



**Figure 25.** Flowchart of the research

## 4. Result and Discussions

### *4.1 Results*

In Figureure 26 shown the SWOT analysis highlights Indonesia's abundant reserves of critical minerals such as nickel, cobalt, copper, and rare earth elements, supported by national regulations and strong government commitment to energy transition and green economy initiatives. However, the sector faces challenges including limited downstream processing capacity, low technological readiness, and difficulties in meeting Local Content Requirements (TKDN), which hinder investment and industrial growth. Opportunities arise from growing global demand for renewable energy minerals driven by electric vehicles, solar PV, wind energy, and energy storage technologies, positioning Indonesia to become a key player in battery manufacturing and the clean energy value chain. Nonetheless, threats such as global price volatility, environmental and social risks, and geopolitical tensions may restrict access to technology and markets. Strategic policies are needed to enhance Indonesia's competitiveness and promote sustainable development in the critical minerals sector.

**Figure 26.** SWOT analysis of critical raw materials

Table 6 summarizes the critical mineral value chain for renewable energy technologies, outlining each stage from extraction to end-of-life and recycling. The extraction stage involves mining essential minerals, which can cause significant environmental impacts such as deforestation and water contamination. Processing and refining transform raw minerals into usable components but are associated with high energy use and chemical waste risks. Manufacturing uses these processed minerals to produce renewable energy components, with considerations for emissions, resource efficiency, and local content (TKDN). Deployment and operation integrate these technologies into infrastructure, where operational emissions are low but depend on mineral types. Finally, end-of-life and recycling focus on waste management and mineral recovery, though Indonesia currently has limited recycling capacity, underscoring the need for enhanced circular economy practices.

**Table 6** Life cycle analysis of critical raw materials

| Stage | Description | Environmental Considerations |
|---|---|---|
| **Extraction** | Mining of critical minerals such as nickel, cobalt, bauxite, copper, and rare earth elements from domestic reserves. | Deforestation, land degradation, biodiversity loss, water contamination. |
| **Processing & Refining** | Smelting, separation, and purification of raw minerals into usable components for RE technology (e.g., battery-grade nickel, refined silicon). | High energy consumption, emissions, chemical waste disposal risks. |
| **Manufacturing** | Use of processed minerals in components of solar PV, | Emissions from manufacturing, resource efficiency, |

| | | | |
|---|---|---|---|
| | | wind turbines, EV batteries, fuel cells, etc. | TKDN (local content) impact. |
| **Deployment & Operation** | | Integration into national infrastructure (e.g., solar farms, EV fleets, wind plants). | Operational emissions (low), durability and efficiency influenced by mineral type. |
| **End-of-Life & Recycling** | | Decommissioning, waste handling, and recycling/recovery of valuable minerals (e.g., lithium, cobalt, copper). | Low recycling capacity in Indonesia; potential circular economy benefits. |

Table 7 shown the Indonesia's renewable energy (RE) value chain, spanning from mineral extraction to end-use deployment, reflects both strategic advantages and critical constraints. The upstream stage, encompassing exploration and mining, demonstrates Indonesia's strong position due to its abundant reserves of critical minerals such as nickel, bauxite, copper, and rare earth elements (REEs). However, this stage faces challenges, including environmental degradation risks, safety concerns, and social resistance from local communities, which could hinder sustainable resource exploitation.

In the midstream stage, which involves processing and refining, Indonesia has made progress in developing domestic smelting capacities, yet significant gaps persist. The reliance on energy-intensive technologies and difficulties in meeting Local Content Requirements (TKDN) constrain the sector's growth. Meanwhile, the downstream manufacturing of RE components—such as battery cells, solar panels, and electric vehicle (EV) parts—remains underdeveloped due to technological dependence on imports and limited economies of scale, undermining Indonesia's potential to establish a competitive industrial base.

The deployment phase, including the construction of RE facilities like solar power plants (PLTS) and wind farms (PLTB), shows gradual improvement, supported by state-owned enterprises (e.g., PLN) and national energy transition targets. Nevertheless, financing limitations and regulatory inefficiencies delay project implementation. Finally, the end-of-life and recycling segment remains nascent, with only pilot-scale initiatives in place. The absence of comprehensive circular economy systems and low public awareness further impede progress in recovering critical materials from used RE technologies. Addressing these constraints through policy reforms, technological investments, and international collaboration will be pivotal for Indonesia to fully leverage its mineral wealth for a sustainable energy future.

**Table 7** Value chain analysis from mineral to renewable energy deployment

| Stage | Key Activities | Indonesia's Position | Constraints |
|---|---|---|---|
| **Upstream (Exploration & Mining)** | Survey, licensing, extraction of raw minerals | Strong: abundant reserves (nickel, bauxite, copper, REEs) | Environmental and safety concerns, community resistance |
| **Midstream (Processing & Refining)** | Smelting, purification, conversion to intermediate industrial forms | Developing: growing domestic smelters | Technology gaps, energy-intensive, TKDN challenges |

| | | | |
|---|---|---|---|
| **Downstream (Manufacturing)** | Component production: battery cells, solar panels, EV parts | Weak: limited industrial base for RE components | Dependence on imported tech, low economies of scale |
| **Deployment** | Construction of RE facilities (PLTS, PLTBm, EV infrastructure, etc.) | Improving: PLN & national targets in place | Funding gaps, regulatory bottlenecks |
| **End-of-Life & Recycling** | Collection, separation, recovery of critical materials from used RE tech | Nascent: pilot-scale recycling only | Low public awareness, lack of circular systems |

Table 8 present the Indonesia's mineral resources exhibit varying degrees of development readiness across a clear classification spectrum. Proven reserves like Grasberg's copper and Morowali's nickel are actively exploited, while probable reserves such as Bangka Belitung's rare earth elements require further validation. The country also holds inferred resources (e.g., Kalimantan's uranium) needing exploration investment, along with speculative potential in lithium deposits that could bolster future mineral supply chains. Notably absent are formal strategic stockpiles, representing both a policy gap and opportunity for securing critical minerals. This resource typology reveals Indonesia's immediate strengths and future potential in the global minerals market. While established mines currently drive economic value, underdeveloped inferred and speculative resources - particularly those relevant to renewable energy technologies - demand systematic exploration and assessment. The absence of strategic stockpiles highlights an area for policy innovation to enhance mineral security as global demand for critical resources intensifies, especially for energy transition applications.

**Table 8** Typology of resources classification of Indonesia’s mineral assets

| Resource Type | Definition | Examples in Indonesia | Status |
|---|---|---|---|
| **Proven Reserves** | Economically mineable resources with confirmed quantity and quality | Grasberg (Copper), Morowali (Nickel), Halmahera (Cobalt) | Actively exploited |
| **Probable Reserves** | Resources with reasonable economic confidence but less certainty | Monazite (REE) in Bangka Belitung, Zinc in Sumatra | Partially explored |
| **Inferred Resources** | Estimated based on limited geological evidence | Uranium (in Kalimantan, Papua), Gallium | Not actively developed |
| **Speculative Resources** | Presumed to exist based on regional geology, not yet confirmed | Lithium (Bangka, Sumatra), Tellurium | Targeted for future exploration |

| | | | |
|---|---|---|---|
| **Strategic Stockpiles** | Reserves maintained for long-term industrial or energy security needs | Not formally developed in RI policy | Potential area for policy development |

Figureure 27 show the criticality matrix for a strategic evaluation of Indonesia's mineral resources based on their importance to renewable energy (RE) technologies and associated supply risks. Minerals such as silicon, copper, cobalt, and rare earth elements (REEs) are positioned as highly critical, reflecting their indispensable role in manufacturing solar panels, wind turbines, batteries, and other RE components. These resources score notably high on both axes—demonstrating significant technological importance (4.5–5.0 on the scale) and elevated supply risk (3.0–5.0), the latter stemming from geopolitical dependencies, concentrated production, or environmental extraction challenges. In contrast, bauxite (aluminum) exhibits lower criticality, with moderate importance (scoring 1.0–3.0) to RE technologies and relatively stable supply risks (1.0–3.0). This disparity underscores the varying degrees of strategic value among Indonesia's mineral assets, with high-criticality minerals requiring prioritized policy attention to secure supply chains. The matrix further highlights potential vulnerabilities, particularly for cobalt and REEs, where global demand surges and export restrictions could disrupt domestic RE ambitions.

To mitigate these risks, Indonesia must adopt integrated strategies, including diversified sourcing, investment in domestic processing, and international partnerships. The criticality framework not only identifies immediate priorities but also guides long-term mineral governance to support the nation's energy transition. Future research should expand this analysis to include socio-environmental factors, ensuring sustainable resource management aligns with RE deployment goals.

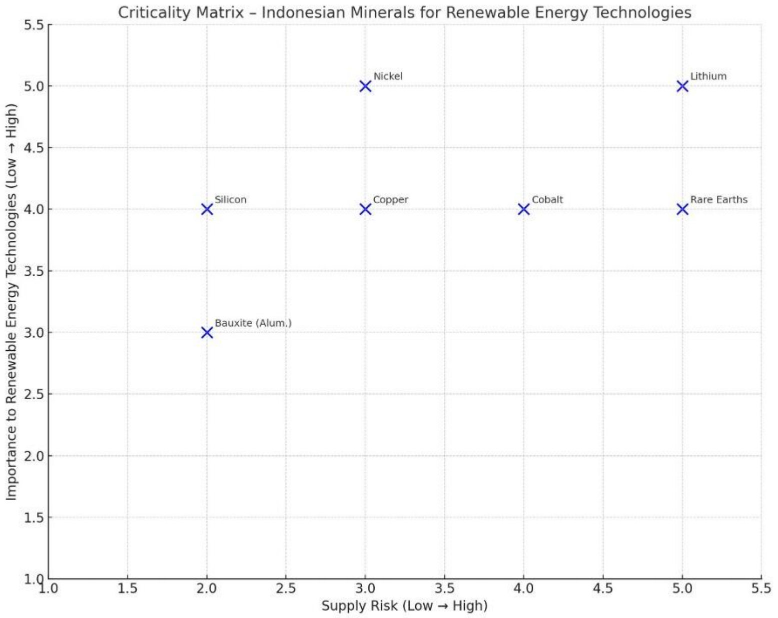



**Figure 27.** Indonesian criticality matrix for minerals in renewable energy technologies

Table 9-10 provides a structured overview of Indonesia’s readiness and strategic pathways in managing critical mineral resources for renewable energy development. The Scenario Planning, outlines three future-oriented scenarios—Optimistic, Baseline, and Pessimistic—based on varying degrees of policy success, market stability, and technological integration. Each scenario is analyzed in terms of its projected impact on mineral demand, local content (TKDN) targets, and the corresponding policy implications. For instance, under the Optimistic scenario, the demand for critical minerals is expected to rise sharply due to accelerated deployment of RE technologies and electric vehicles, necessitating strong downstream integration and international cooperation. Conversely, the Pessimistic scenario warns of increased risks stemming from weak governance, supply chain disruptions, and socio-environmental conflicts, which would hinder Indonesia's energy transition.

The Stakeholder Mapping, identifies and categorizes key actors involved in Indonesia's critical mineral governance. It details the roles, interest levels, and influence of each stakeholder, including government ministries, PLN, mining companies, research institutions, local communities, and international investors. High-influence entities such as the Ministry of Energy and Mineral Resources (ESDM), the Ministry of Industry, and PLN are central to regulatory development, industrial policy, and infrastructure implementation. Meanwhile, non-state actors like environmental NGOs and local communities, although less influential, play a crucial role in ensuring sustainable and socially accepted mineral practices. This mapping provides a foundational understanding for multi-stakeholder coordination and policy alignment, essential for achieving a resilient and inclusive mineral supply chain aligned with Indonesia's net-zero ambition.

**Table 9** Scenario plannings

| Scenario | Description | Impact on Mineral Demand | Policy Implication | TKDN (Local Content) Target |
|---|---|---|---|---|
| Optimistic | High global demand, successful downstream integration, strong international cooperation, and environmental safeguards in place. | Very High (Rapid expansion of RE tech and EVs) | Incentivize R&D, strengthen circular economy, secure long-term international agreements. | ≥60% |
| Baseline (Current Trajectory) | Moderate growth in renewable deployment, partial success in local content and mineral processing. | Moderate (Gradual RE implementation) | Maintain steady investment and improve governance mechanisms. | 40–50% |
| Pessimistic | Global market volatility, weak domestic policies, high environmental and social opposition. | Low (Delays in RE development) | Reform regulations, mitigate social/environmental risks, diversify sourcing. | <30% |

**Table 10** Stakeholders mapping

| Stakeholder | Role | Interest Level | Influence Level |
|---|---|---|---|
| Ministry of Energy and Mineral Resources (ESDM) | Policy formulation, regulatory oversight, mineral classification | High | High |
| Ministry of Industry | Industrial policy, TKDN regulation, downstream industry development | High | High |
| PLN (State Electricity Company) | Deployment of RE infrastructure, power purchase agreements | High | High |

| | | | |
|---|---|---|---|
| Private Mining Companies | Mineral extraction, processing, export operations | High | High |
| Research Institutions & Universities | Conduct studies, provide innovation and technical recommendations | Medium | Medium |
| Local Governments | Permit issuance, regional mineral planning and development | Medium | Medium |
| Environmental NGOs | Monitoring sustainability, advocacy, community engagement | High | Medium |
| Foreign Investors | Capital and technology investment in RE and mineral processing | High | High |
| Local Communities | Resource stewardship, land access, social license to operate | High | Medium |

### *4.1 Discussion*

The study underscores Indonesia's pivotal role in the global renewable energy (RE) transition, leveraging its abundant critical minerals to achieve net-zero emissions by 2060. Indonesia's vast reserves of nickel, cobalt, copper, and rare earth elements (REEs) position it as a key player in supplying materials essential for RE technologies, such as solar panels, wind turbines, and lithium-ion batteries. However, the paper reveals a significant gap between the country's mineral potential and its capacity to harness these resources effectively. Despite being the world's top nickel producer, Indonesia's local content (TKDN) requirements remain unmet due to technological limitations and high production costs. This disconnect highlights the urgent need for strategic policies to bridge the gap between resource availability and industrial capability. A critical issue identified is the low integration of domestic minerals into RE technologies. For instance, while Indonesia produces 1.8 million metric tons of nickel annually, its utilization in battery manufacturing is minimal, with most raw materials exported. This trend not only limits economic value addition but also exacerbates dependency on foreign technology. The paper emphasizes the importance of downstream industrial development to enhance TKDN and reduce reliance on imports. Strengthening local processing capabilities and fostering innovation in mineral refining could transform Indonesia from a raw material exporter to a hub for high-value RE components, aligning with global sustainability goals.

The environmental and social impacts of mineral exploration present another layer of complexity. Mining accidents, deforestation, and water contamination pose significant risks, undermining the sustainability of Indonesia's RE ambitions. The study calls for stringent regulations and sustainable mining practices to mitigate these effects. For example, adopting circular economy principles, such as recycling critical minerals from end-of-life products, could reduce environmental degradation while securing supply chains. Balancing economic growth with ecological preservation is paramount to ensuring long-term viability and gaining public support for RE projects. International collaboration emerges as a key strategy to address supply chain vulnerabilities. The paper cites China's self-sufficiency model and Japan's partnerships with mineral-rich nations as benchmarks. Indonesia could leverage similar alliances to access advanced technologies, diversify supply sources, and stabilize prices amid global market volatility. Regional cooperation within ASEAN and frameworks like the Indo-Pacific

Economic Framework (IPEF) could further enhance resource security and trade resilience. Such partnerships must prioritize equitable benefits to avoid neo-colonial exploitation of Indonesia's mineral wealth.

The study also highlights disparities in RE technology adoption across sectors. Geothermal and hydropower dominate Indonesia's RE capacity, yet solar and wind energy lag due to infrastructural and regulatory hurdles. For instance, solar PV installation reached only 270.1 MW in 2023, far below the 893.3 MW target. Streamlining power purchase agreements (PPAs), incentivizing investments, and simplifying permitting processes are recommended to accelerate deployment. Tailoring solutions to regional conditions—such as optimizing wind farms in high-wind areas and solar plants in sun-rich regions—could maximize efficiency and resource use. Policy coherence is another critical challenge. While Indonesia has robust frameworks like the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR), implementation gaps persist. Conflicting regulations, such as TKDN mandates delaying geothermal projects, deter investors. The paper advocates for harmonizing policies across ministries and enhancing stakeholder coordination. A unified approach, involving government, industry, and academia, is essential to align mineral governance with RE targets and ensure policy effectiveness.

The role of state-owned enterprises (SOEs) like PLN is pivotal in driving the energy transition. PLN's initiatives, such as co-firing biomass in coal plants and piloting green hydrogen projects, demonstrate progress. However, the study notes that SOEs face financial and operational constraints, necessitating public-private partnerships (PPPs) and international funding. Mobilizing green finance and de-risking investments through guarantees could unlock capital for large-scale RE projects, ensuring Indonesia meets its 23% RE share target by 2025.

Finally, this research underscores the need for continuous research and development (R&D) to innovate RE technologies suited to Indonesia's resource profile. Investing in R&D for lithium extraction, rare earth processing, and advanced battery systems could position Indonesia as a leader in the global RE market. Coupled with education and workforce training, such efforts would build domestic expertise and reduce technological dependence. The study concludes that Indonesia's path to net-zero emissions hinges on a holistic strategy—integrating resource management, policy reform, international cooperation, and sustainable practices—to transform its mineral wealth into a catalyst for a resilient, low-carbon future.

### *4.2 Recommendation*

1. Enhance Downstream Processing and Local Content (TKDN) Requirements

To maximize the economic and technological benefits of Indonesia’s critical minerals, the government must prioritize downstream industrial development. Strengthening local processing capabilities for minerals like nickel, cobalt, and rare earth elements (REEs) will reduce reliance on raw material exports and increase the Local Component Level (TKDN) in renewable energy (RE) technologies. Policies should incentivize domestic manufacturing of high-value components, such as lithium-ion batteries and solar panels, while addressing barriers like high production costs and technological gaps through targeted subsidies and R&D investments.

2. Adopt Sustainable Mining Practices and Circular Economy Principles

Given the environmental and social risks associated with mineral extraction, Indonesia must enforce stringent regulations to mitigate deforestation, water contamination, and mining accidents. Implementing circular economy strategies—such as recycling critical minerals from end-of-life RE technologies—can reduce environmental degradation and secure supply chains. Collaboration with international organizations to adopt best practices in sustainable mining and resource management will further align Indonesia’s mineral sector with global sustainability goals.

3. Strengthen International and Regional Collaborations

To mitigate supply chain vulnerabilities, Indonesia should pursue strategic partnerships with mineral-rich nations and technology leaders, such as Japan and China. Frameworks like the Indo-Pacific Economic Forum (IPEF) can facilitate knowledge transfer, diversify supply sources, and stabilize prices amid global market volatility. Regional cooperation within ASEAN should also be leveraged to harmonize policies, share expertise, and attract foreign investment while ensuring equitable benefits for Indonesia's mineral resources.

4. Streamline Policy Implementation and Stakeholder Coordination

Despite robust frameworks like the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR), conflicting regulations—such as TKDN mandates delaying geothermal projects—hinder progress. A unified approach involving the Ministry of Energy and Mineral Resources (ESDM), PLN, and private sectors is essential to harmonize policies, simplify permitting processes, and accelerate RE deployment. Establishing a dedicated task force for RE project management can improve coordination and resolve bottlenecks in power purchase agreements (PPAs) and financing.

5. Invest in Research, Innovation, and Workforce Development

Continuous R&D is critical to advancing RE technologies tailored to Indonesia's resource profile, such as lithium extraction and rare earth processing. Funding for universities and research institutions should be increased to foster innovation in battery systems, solar PV efficiency, and hydrogen technologies. Concurrently, vocational training programs must be expanded to build domestic expertise, reducing dependence on foreign technology and ensuring a skilled workforce for Indonesia's energy transition. By integrating these measures, Indonesia can transform its mineral wealth into a cornerstone of a resilient, low-carbon future.

## 5. Conclusions

This comprehensive study highlights Indonesia's strategic position in the global renewable energy transition, emphasizing the critical role of its abundant mineral resources—including nickel, cobalt, copper, and rare earth elements (REEs)—in achieving the nation's net-zero emissions target by 2060. The research reveals that while Indonesia possesses significant reserves of these essential minerals, their full potential remains underutilized due to several key challenges. These include the persistent gap in local content (TKDN) requirements for renewable energy technologies, which stems from limited downstream processing capabilities, high production costs, and technological dependencies on foreign imports. Additionally, the environmental and social impacts of mineral extraction, such as deforestation, water contamination, and mining accidents, pose significant risks that must be mitigated through stringent regulations and sustainable practices. The findings further demonstrate that Indonesia's current reliance on raw material exports, rather than high-value-added manufacturing, constrains its ability to capitalize on the growing global demand for RE technologies. To address these issues, the study advocates for a multi-faceted approach, including enhanced downstream industrial development, the adoption of circular economy principles for mineral recycling, and stronger international partnerships to diversify supply chains and stabilize market volatility. Policy coherence across government agencies, streamlined permitting processes, and increased investment in research and workforce development are also identified as critical enablers for advancing Indonesia's renewable energy sector. By implementing these strategic recommendations, Indonesia can transition from a resource exporter to a leader in sustainable energy technology, ensuring long-term economic growth, environmental preservation, and energy security. This transformation will not only support the nation's climate commitments but also position it as a key player in the global clean energy landscape, fostering innovation and resilience in the face of evolving energy demands.

**Acknowledgements**

Gratitude is extended to all parties who have supported the completion of this study. Appreciation is directed to the Ministry of Energy and Mineral Resources (ESDM) and PT PLN (Persero) for providing essential data and initiatives supporting Indonesia's energy transition. Thanks are also conveyed to academic institutions, industry experts, and the Indonesia Association Fuel Cell and Hydrogen Energy

(INAFHE) for their contributions to the advancement of renewable energy technologies and the management of critical mineral resources. The "Critical Mineral Supply Study for Renewable Energy Technology (RE) in Achieving Net Zero Emission in Indonesia" served as a valuable reference throughout the review. Acknowledgement is due to all national and international stakeholders whose collaboration in research, sustainable exploration, recycling technology, and policy development has played a significant role in promoting a resilient and sustainable energy future for Indonesia.

## References

[1] K. Fuji, A. Suppasri, P. Kwanchai, E. Lahcene, and F. Imamura, "Assessing future tsunami hazards from Japan trench coupling with sea level rise impact on economic risks using an input–output table," *International Journal of Disaster Risk Reduction*, vol. 104, p. 104286, Feb. 2024, doi: 10.1016/j.ijdrr.2024.104286.

[2] R. Martyr-Koller, A. Thomas, C.-F. Schleussner, A. Nauels, and T. Lissner, "Loss and damage implications of sea-level rise on Small Island Developing States," *Current Opinion in Environmental Sustainability*, vol. 50, pp. 245–259, Jun. 2021, doi: 10.1016/j.cosust.2021.05.001.

[3] M. A. Karegar, T. H. Dixon, R. Malservisi, J. Kusche, and S. E. Engelhart, "Nuisance Flooding and Relative Sea-Level Rise: the Importance of Present-Day Land Motion," *Scientific Reports*, vol. 7, no. 1, Sep. 2017, doi: 10.1038/s41598-017-11544-y.

[4] D. Majumder, S. Saha, M. a. S. Chandran, and S. K. Bal, "Prospects of Modified Plant Micro-Climate in global Climate change Research," in *Advances in global change research*, 2024, pp. 285–324. doi: 10.1007/978-981-99-7935-6_11.

[5] B. Pentz and N. Klenk, "Will climate change degrade the efficacy of marine resource management policies?," *Marine Policy*, vol. 148, p. 105462, Dec. 2022, doi: 10.1016/j.marpol.2022.105462.

[6] H. K. Lotze, A. Bryndum-Buchholz, and D. G. Boyce, "Effects of climate change on food production (fishing)," in *Elsevier eBooks*, 2021, pp. 205–231. doi: 10.1016/b978-0-12-822373-4.00017-3.

[7] F. Sidik, A. Lawrence, T. Wagey, F. Zamzani, and C. E. Lovelock, "Blue carbon: A new paradigm of mangrove conservation and management in Indonesia," *Marine Policy*, vol. 147, p. 105388, Nov. 2022, doi: 10.1016/j.marpol.2022.105388.

[8] U. Muawanah, Z. Salim, and A. E. Nugroho, "Toward sustainable ocean governance: research for inclusive and equitable development in Indonesia," in *Edward Elgar Publishing eBooks*, 2025, pp. 215–228. doi: 10.4337/9781035325757.00030.

[9] N. Novita *et al.*, "Natural climate solutions in Indonesia: wetlands are the key to achieve Indonesia's national climate commitment," *Environmental Research Letters*, vol. 17, no. 11, p. 114045, Nov. 2022, doi: 10.1088/1748-9326/ac9e0a.

[10] L. Tacconi, R. J. Rodrigues, and A. Maryudi, "Law enforcement and deforestation: Lessons for Indonesia from Brazil," *Forest Policy and Economics*, vol. 108, p. 101943, Jun. 2019, doi: 10.1016/j.forpol.2019.05.029.

[11] K. Handayani and T. Filatova, "Greening energy supply in the light of SDGs and Covid-19," *IOP Conference Series Earth and Environmental Science*, vol. 753, no. 1, p. 012035, May 2021, doi: 10.1088/1755-1315/753/1/012035.

[12] Y. I. Siregar, "Pathways towards net-zero emissions in Indonesia's energy sector," *Energy*, vol. 308, p. 133014, Aug. 2024, doi: 10.1016/j.energy.2024.133014.

[13] T. C. Bond, D. G. Streets, K. F. Yarber, S. M. Nelson, J. Woo, and Z. Klimont, "A technology-based global inventory of black and organic carbon emissions from combustion," *Journal of Geophysical Research Atmospheres*, vol. 109, no. D14, Jul. 2004, doi: 10.1029/2003jd003697.

[14] A. Massagony, R. Pandit, and B. White, "Political economy of energy policy in Indonesia towards net zero emissions by 2060," *Energy Sustainable Development/Energy for Sustainable*

*Development*, vol. 88, p. 101757, May 2025, doi: 10.1016/j.esd.2025.101757.

[15] Y. Arwadi, A. Torku, M. O. Tetteh, and F. K. Bondinuba, "Strategies to optimise project management implementation in the delivery of renewable energy projects in Indonesia," *Buildings*, vol. 15, no. 7, p. 1049, Mar. 2025, doi: 10.3390/buildings15071049.

[16] A. Alwahab, P. T. Maharani, W. O. M. N. K, L. O. Ahmad, A. Alimin, and A. Zaeni, "Optimization of Biogas Liquid Waste from Livestock Manure as a Source of Renewable Energy through Microbial Fuel Cell (MFC) Technology," *Advance Sustainable Science Engineering and Technology*, vol. 6, no. 2, p. 0240202, Mar. 2024, doi: 10.26877/asset.v6i2.17931.

[17] "BRIN - Badan Riset Dan Inovasi Nasional." 2021. BRIN - Badan Riset Dan Inovasi Nasional. https://www.brin.go.id/news/110603/indonesia-targetkan-pencapain-net-zero-emission-pada-2060

[18] "Kemenkeu RI." 2023. https://www.kemenkeu.go.id/informasi-publik/publikasi/berita-utama/Ini-Komitmen-Indonesia-Mencapai-Net-Zero-Emission.

[19] Kementrian PPN. 2022. "Pembangunan Rendah Karbon Indonesia & Net-Zero Emission Menuju Ekonomi Hijau." Power Point. Slide show. Https://Iesr.or.Id/. https://iesr.or.id/wp-content/uploads/2021/05/Final-Dir-LH-IESR-Net-Zero-Emission_V1.pdf.

[20] "Net Zero Emission Indonesia 2060: Langkah Menuju Ekonomi Sirkular." 2022. Waste4change.Com. August 19, 2022. https://waste4change.com/blog/net-zero-emission-indonesia-2060-menuju-ekonomi-sirkular/.

[21] M. F. Ibrahim, "Feasibility Study of solar power generation system for public street lighting," *Advance Sustainable Science Engineering and Technology*, vol. 4, no. 2, p. 0220207, Nov. 2022, doi: 10.26877/asset.v4i2.13378.

[22] R. Firdaus and M. Ariandi, "Utilization of Heat from Geothermal Well Pipes as Electricity for Road Lighting Based on The Internet of Things," *Advance Sustainable Science Engineering and Technology*, vol. 5, no. 1, p. 0230106, Apr. 2023, doi: 10.26877/asset.v5i1.14980.

[23] "ESDM: Mineral Kritis Punya Peran Vital Pada Transisi Energi." 2023. https://validnews.id/ekonomi/esdm-mineral-kritis-punya-peran-vital-pada-transisi-energi.

[24] "Teknologi Baterai Berbasis Mineral Kritis Untuk Kendaraan Listrik." 2024. ESDM. https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-ebtke/teknologi-baterai-berbasis-mineral-kritis-untuk-kendaraan-listrik.

[25] Faizal, Mohammad. 2024. "Badan Geologi Ungkap Keberadaan 47 Mineral Kritis Berharga Di Indonesia." *SINDOnews Ekbis*, January 20, 2024. https://ekbis.sindonews.com/read/1302995/34/badan-geologi-ungkap-keberadaan-47-mineral-kritis-berharga-di-indonesia-1705730514.

[26] Haryanto, Imam. 2020. "REGULATION OF FOREIGN INVESTMENTS IN THE DEVELOPMENT OF NEW RENEWABLE ENERGY (EBT) IN INDONESIA." *Veteran Law Review* 3 (1): 12. https://doi.org/10.35586/velrev.v3i1.1458.

[27] "Bigger Share Given to Renewables in 2021-2030 Electricity Procurement Plan." 2022. ESDM. https://www.esdm.go.id/en/berita-unit/directorate-general-of-electricity/ruptl-2021-2030-diterbitkan-porsi-ebt-diperbesar.

[28] L. A. Attílio, "Impact of critical mineral prices on energy transition," *Applied Energy*, vol. 377, p. 124688, Oct. 2024, doi: 10.1016/j.apenergy.2024.124688.

[29] Md. M. Islam, K. Sohag, S. O. Mamman, and H. Herdhayinta, "Response of Indonesian mineral supply to global renewable energy generation: Analysis based on gravity model approach," *Geoscience Frontiers*, vol. 15, no. 4, p. 101658, Jun. 2023, doi: 10.1016/j.gsf.2023.101658.

[30] A. Işıldar, E. D. Van Hullebusch, and D. Huisingh, *Critical materials and sustainability transition*. 2023. doi: 10.1201/9781003218920.

[31] M. Adrian, E. P. Purnomo, A. Enrici, and T. Khairunnisa, "Energy transition towards renewable energy in Indonesia," *Heritage and Sustainable Development ISSN 2712-0554*, vol. 5, no. 1, pp. 107–118, May 2023, doi: 10.37868/hsd.v5i1.108.

[32] I. D. Qurbani, R. J. Heffron, and A. T. S. Rifano, “Justice and critical mineral development in Indonesia and across ASEAN,” *The Extractive Industries and Society*, vol. 8, no. 1, pp. 355–362, Dec. 2020, doi: 10.1016/j.exis.2020.11.017.
[33] E. Aramendia, P. E. Brockway, P. G. Taylor, and J. B. Norman, “Exploring the effects of mineral depletion on renewable energy technologies net energy returns,” *Energy*, vol. 290, p. 130112, Dec. 2023, doi: 10.1016/j.energy.2023.130112.
[34] “Transforming Our World: The 2030 Agenda for Sustainable Development.” 2018. In *Springer eBooks*. https://doi.org/10.1891/9780826190123.ap02.
[35] NJ MED. 2024. “World Top 20 Project.” Educate Every Child on the Planet: The World Top 20 Project. June 26, 2024. https://www.worldtop20.org/.
[36] Zheng, Mingbo, Gen-Fu Feng, Chyi-Lu Jang, and Chun-Ping Chang. 2021. “Terrorism and Green Innovation in Renewable Energy.” *Energy Economics* 104 (November): 105695. https://doi.org/10.1016/j.eneco.2021.105695.
[37] De Koning, Arjan, René Kleijn, Gjalt Huppes, Benjamin Sprecher, Guus Van Engelen, and Arnold Tukker. 2017. “Metal Supply Constraints for a Low-carbon Economy?” *Resources Conservation and Recycling* 129 (November): 202–8. https://doi.org/10.1016/j.resconrec.2017.10.040.
[38] Klimenko, V.V., S.V. Ratner, and A.G. Tereshin. 2021. “Constraints Imposed by Key-material Resources on Renewable Energy Development.” *Renewable and Sustainable Energy Reviews* 144 (April): 111011. https://doi.org/10.1016/j.rser.2021.111011.
[39] “The Raw-materials Challenge: How the Metals and Mining Sector Will Be at the Core of Enabling the Energy Transition.” 2022. McKinsey & Company. January 10, 2022. https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-raw-materials-challenge-how-the-metals-and-mining-sector-will-be-at-the-core-of-enabling-the-energy-transition.
[40] Kabeyi, Moses Jeremiah Barasa, and Oludolapo Akanni Olanrewaju. 2022. “Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply.” *Frontiers in Energy Research* 9 (March). https://doi.org/10.3389/fenrg.2021.743114.
[41] Turcotte, Donald L., and Gerald Schubert. 2002. *Geodynamics*. https://doi.org/10.1017/cbo9780511807442.
[42] *Hot rocks - Geothermal and the role of nickel*. (2021.). https://nickelinstitute.org/en/blog/2021/august/hot-rocks-geothermal-and-the-role-of-nickel/#:~:text=as%20Alloy%20625%20(N06625)%2C,specific%20high%20corrosivity%20geothermal%20operations
[43] Quaranta, Emanuele, and Peter Davies. 2021. “Emerging and Innovative Materials for Hydropower Engineering Applications: Turbines, Bearings, Sealing, Dams and Waterways, and Ocean Power.” *Engineering* 8 (September): 148–58. https://doi.org/10.1016/j.eng.2021.06.025.
[44] International Hydropower Association. 2020. “hydropower status report sector trends and insights.” IHA Central Office.
[45] Myshkin, N.K. 2000. “Friction Transfer Film Formation in Boundary Lubrication.” *Wear* 245 (1–2): 116–24. https://doi.org/10.1016/s0043-1648(00)00472-5.
[46] “Types of Hydropower Plants.” 2024. Energy.Gov. https://www.energy.gov/eere/water/types-hydropower-plants.
[47] Coleman, M, and J Stanturf. 2006. “Biomass Feedstock Production Systems: Economic and Environmental Benefits.” *Biomass and Bioenergy* 30 (8–9): 693–95. https://doi.org/10.1016/j.biombioe.2006.04.003.
[48] KCI Media Group. 2024. “Bioenergy: An Important and Growing Industry for Stainless Steel.” Stainless Steel World. January 8, 2024. https://stainless-steel-world.net/bioenergy-an-important-and-growing-industry-for-stainless-steel/.
[49] Weldeslase, Mebrhit Gebreyohanes, Natei Ermias Benti, Mekonnen Abebayehu Desta, and Yedilfana Setarge Mekonnen. 2023. “Maximizing Biodiesel Production From Waste Cooking

Oil With Lime-based Zinc-doped CaO Using Response Surface Methodology." *Scientific Reports* 13 (1). https://doi.org/10.1038/s41598-023-30961-w.
[50] Tong, Colin. 2018. *Introduction to Materials for Advanced Energy Systems*. *Springer eBooks*. https://doi.org/10.1007/978-3-319-98002-7.
[51] De Naoum, Kat, and Rebecca Piccoli. 2025. "All About Electrical Steel." Xometry. March 14, 2025. https://www.xometry.com/resources/materials/electrical-steel/.
[52] Administrator. 2024. "Stainless Steel Sections in Solar Power Plants." Montanstahl. July 22, 2024. https://www.montanstahl.com/blog/stainless-steel-sections-solar-power-plants/.
[53] Eikeng, Erik, Ashkan Makhsoos, and Bruno G. Pollet. 2024. "Critical and Strategic Raw Materials for Electrolysers, Fuel Cells, Metal Hydrides and Hydrogen Separation Technologies." *International Journal of Hydrogen Energy* 71 (May): 433–64. https://doi.org/10.1016/j.ijhydene.2024.05.096.
[54] "Wind Turbine." 2024. https://www.enelgreenpower.com/learning-hub/renewable-energies/wind-energy/wind-turbine.
[55] "Renewable Energy." 2024. International Copper Association. https://internationalcopper.org/policy-focus/climate-environment/renewable-energy/#:~:text=Because%20copper%20is%20a%20highly,energy%20needed%20to%20produce%20electricity.
[56] Bellini, Emiliano. 2021. "Silver Accounts for 10% of PV Module Costs." Pv Magazine International. March 4, 2021. https://www.pv-magazine.com/2021/03/04/silver-currently-accounts-for-10-of-pv-module-costs.
[57] "How Much Silver Is Needed for the Solar Panel Industry? – Resource World Magazine." 2024. https://resourceworld.com/how-much-silver-is-needed-for-the-solar-panel-industry.
[58] "DocsRoom - European Commission." 2024. https://ec.europa.eu/docsroom/documents/42881.
[59] "EV Database." 2024. EV Database. https://ev-database.org/cheatsheet/energy-consumption-electric-car.
[60] Seedigital. 2023. "Electric Vehicles | Rare Earth Metals | Victory Metals Australia." Victory Metals. July 4, 2023. https://www.victorymetalsaustralia.com/rare-earth-metals-electric-vehicles/.
[61] Mahmoodzadeh, Fatemeh, Nahid Navidjouy, Saber Alizadeh, and Mostafa Rahimnejad. 2023. "Investigation of Microbial Fuel Cell Performance Based on the Nickel Thin Film Modified Electrodes." *Scientific Reports* 13 (1). https://doi.org/10.1038/s41598-023-48290-3.
[62] Spiegel, R.J. 2004. "Platinum and Fuel Cells." *Transportation Research Part D Transport and Environment* 9 (5): 357–71. https://doi.org/10.1016/j.trd.2004.07.001.
[63] Hool, Alessandra, Christoph Helbig, and Gijsbert Wierink. 2023. "Challenges and Opportunities of the European Critical Raw Materials Act." *Mineral* Economics 37 (3): 661–68. https://doi.org/10.1007/s13563-023-00394-y.
[64] "Keputusan Menteri Energi dan Sumber Daya Mineral No. 301.K/MB.01/MEM.B/2022." 2022. Menteri Energi dan Sumber Daya Mineral Republik Indonesia. https://jdih.esdm.go.id/common/dokumen-external/Salinan%20Kepmen%20ESDM%20Nomor%20301%20RPMBN%202022%20sd%202027. pdf.
[65] Lloyd, Jay. 2022. "The Hard Math of Minerals." Issues in Science and Technology. July 15, 2022. https://issues.org/environmental-economic-costs-minerals-solar-wind-batteries-mills/.
[66] "Grand Strategy Mineral dan Batubara." 2021. Direktorat Jenderal Mineral dan Batubara Kementrian ESDM. https://www.minerba.esdm.go.id/upload/ebook/20220329144756.pdf.
[67] "Mineral Commodity Summaries 2023." 2023. https://doi.org/10.3133/mcs2023.
[68] "Visualized: How Much Metal is Used in Clean Energy Technology?" 2023. Https://Www.Visualcapitalist.Com/. September 8, 2023. https://www.visualcapitalist.com/sp/visualized-how-much-metal-is-used-in-clean-energy-technology/.

[69] "Aluminium in Solar An enabler and consumer of European solar energy." 2022. European Aluminium. https://european-aluminium.eu/wp-content/uploads/2022/10/european-aluminium_aluminium-in-solar_position-paper.pdf.
[70] "Mineral Commodity Summaries 2024." 2024. https://doi.org/10.3133/mcs2024.
[71] "Peluang Investasi Timbal dan Seng Indonesia." 2023. Kementerian Energi dan Sumber Daya Mineral Republik Indonesia. https://www.esdm.go.id/assets/media/content/content-peluang-komoditas-timbal-dan-seng-indonesia.pdf.
[72] "Neodymium Stone, Part of the Rare Earth Group, the World's Strongest Magnetic Ore Used in the Technology Industry Stock Photo | Adobe Stock." 2021. Adobe Stock. https://stock.adobe.com/id/images/neodymium-stone-part-of-the-rare-earth-group-the-world-s-strongest-magnetic-ore-used-in-the-technology-industry/408335208.
[73] Calvo, Guiomar, and Alicia Valero. 2021. "Strategic Mineral Resources: Availability and Future Estimations for the Renewable Energy Sector." *Environmental Development* 41 (April): 100640. https://doi.org/10.1016/j.envdev.2021.100640.
[74] "Peluang Investasi Mangan di Indonesia." 2023. KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL REPUBLIK INDONESIA. https://www.esdm.go.id/assets/media/content/content-peluang-investasi-mangan-indonesia.pdf.
[75] L, Jennifer. 2024. "Silver'S Crucial Role in Achieving a Net Zero World." Carbon Credits. April 9, 2024. https://carboncredits.com/silvers-crucial-role-in-achieving-a-net-zero-world/#:~:text=Based%20on%20BloombergNEF's%20estimate%20of,demand%20based%20on%20trend%20projections.
[76] Japardi, Johan. 2021. "Kadmium Dalam Baterai Isi Ulang Halaman 1 - Kompasiana.com." *KOMPASIANA*, July 17, 2021. https://www.kompasiana.com/johan0501/60f32bf070de05372d64da92/kadmium-dalam-baterai-isi-ulang.
[77] Azizah, Rosi Nur. 2022. "Unik! Logam Galium Meleleh Saat Dipegang." *Kumparan*, February 11, 2022. https://kumparan.com/rosinurazizahrna/unik-logam-galium-meleleh-saat-dipegang-1xUE1XPjoAZ.
[78] Lukyani, Lulu. 2023. "Apa Itu Iridium Yang Disebut Lebih Mahal Dari Emas?" *KOMPAS.com*, December 28, 2023. https://www.kompas.com/sains/read/2023/12/28/180000123/apa-itu-iridium-yang-disebut-lebih-mahal-dari-emas-#:~:text=Faktanya%2C%20iridium%20adalah%20unsur%20paling%20tahan%20korosi%20dalam%20Tabel%20Periodik.&text=Per%2028%20Desember%202023%2C%20harga,Rp%2032%20juta%20per%20ons.
[79] Wilser, Jeff. 2023. "A More Plentiful Metal." *Time*, October 24, 2023. https://time.com/collection/best-inventions-2023/6324126/li-metal-lithium-metal-production-process/.
[80] Jabbar, Gamma Abdul. 2023. "[Mineral] Platina (Platinum) | Pt – Menginspirasi Mengenal Bumi." August 27, 2023. https://belajargeologi.com/mineral-platina-platinum-pt/.
[81] Syaeful, H, I G Sukadana, Y S B Susilo, F D Indrastomo, A G Muhammad, and None Ngadenin. 2021. "Uranium Exploration, Deposit and Resources: The Key of Nuclear Power Plant Development Program in Indonesia." *Journal of Physics Conference Series* 2048 (1): 012003. https://doi.org/10.1088/1742-6596/2048/1/012003.
[82] "Inilah Jenis Tingkat Komponen Dalam Negeri (TKDN) Yang Harus Anda Ketahui | Easybiz Bagian Dari Hukumonline Untuk Izin Usaha, Pendirian Usaha, Dan Kewajiban Pelaporan Usaha." 2024. https://www.easybiz.id/inilah-jenis-tingkat-komponen-dalam-negeri-tkdn-yang-harus-anda-ketahui#:~:text=Layanan%20OSS%20RBA-,Tingkat%20Komponen%20Dalam%20Negeri%20(TKDN)%20adalah%20besaran%20kandungan%20dalam%20negeri,negeri%20dan%20memperkuat%20struktur%20Industri.

[83] "Peraturan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 16 Tahun 2020." 2020. Menteri Energi dan Sumber Daya Mineral Republik Indonesia. https://www.minerba.esdm.go.id/upload/file_menu/20201110163100.pdf.
[84] Tv, Cnbc Indonesia. 2021. "AESI Sebut Aturan TKDN 65% Jadi Hambatan Investasi PLTS." *CNBC Indonesia*, June 24t, 2021. https://www.cnbcindonesia.com/news/20210624102240-8-255547/aesi-sebut-aturan-tkdn-65-jadi-hambatan-investasi-plts.
[85] ITB, Webmaster Team Direktorat Teknologi Informasi. 2011. "Seminar Nasional IUGC 2011: Memberdayakan Geothermal Sebagai Sumber Energi Di Indonesia -." Institut Teknologi Bandung. https://itb.ac.id/berita/seminar-nasional-iugc-2011-memberdayakan-geothermal-sebagai-sumber-energi-di-indonesia/3115.
[86] "Pembangunan PLT Panas Bumi di Bengkulu Terkendala Aturan TKDN." 2023. Https://Www.Rri.Co.Id/. September 3, 2023. https://www.rri.co.id/bengkulu/daerah/344961/pembangunan-plt-panas-bumi-di-bengkulu-terkendala-aturan-tkdn?utm_source=news_main&utm_medium=internal_link&utm_campaign=General%20Campaign.
[87] Kencana, Maulandy Rizky Bayu. 2023. "Proyek PLTA Kayan Serap 80% TKDN Material Besi Dan Pasir." *liputan6.com*, December 10, 2023. https://www.liputan6.com/bisnis/read/5477378/proyek-plta-kayan-serap-80-tkdn-material-besi-dan-pasir?page=2.
[88] "Dua Pembangkit Listrik Berbasis Air Resmi Beroperasi, Listrik PLN Makin Andal Dan Hijau - PT PLN (Persero)." 2022. PT PLN (Persero). September 26, 2022. https://web.pln.co.id/media/siaran-pers/2022/09/dua-pembangkit-listrik-berbasis-air-resmi-beroperasi-listrik-pln-makin-andal-dan-hijau.
[89] "Sejumlah Proyek PLN Terganjal TKDN, Nilainya Capai Rp 51,5 Triliun." 2024. Industri.Kontan.Co.Id. January 25, 2024. https://industri.kontan.co.id/news/sejumlah-proyek-pln-terganjal-tkdn-nilainya-capai-rp-515-triliun.
[90] "Permen ESDM No. 9 Tahun 2023." 2023. Database Peraturan | JDIH BPK. https://peraturan.bpk.go.id/Details/265976/permen-esdm-no-9-tahun-2023.
[91] Hund, Kirsten, Daniele La Porta, Thao P Fabregas, Tim Laing, and John Drexhage. 2023. *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition*. https://doi.org/10.1596/40002.
[92] "Shaping the future: Indonesia's proposal for critical minerals in IPEF trade." 2023. Indonesia Bussiness Post. 2023. Accessed May 26, 2024. https://indonesiabusinesspost.com/lobby/shaping-the-future-indonesias-proposal-for-critical-minerals-in-ipef-trade/.
[93] Li, Ling Zhi, and Xiaosheng Yang. 2015. "China's Rare Earth Resources, Mineralogy, and Beneficiation." In Elsevier eBooks, 139–50. https://doi.org/10.1016/b978-0-12-802328-0.00009-7.
[94] "Japan: Priority examination of rare earths by the Foreign Exchange Law: 34 kinds of minerals." 2021. Tokyo Xpress. 2021. Accessed May 26, 2024. http://tokiox.com/wp/japan-priority-examination-of-rare-earths-by-the-law-34-of-minerals/?lang=en.
[95] "Climate Bonds Initiative." 2020. Climate Bonds Initiative. June 15, 2020. Accessed May 26, 2024. https://www.climatebonds.net/certification/geysers%20power.
[96] "Kini Indonesia Menjadi Produsen Listrik Panas Bumi Terbesar Kedua Dunia." 2018. Kementerian Energi Dan Sumber Daya Mineral. April 28, 2018. https://www.esdm.go.id/id/media-center/arsip-berita/kini-indonesia-menjadi-produsen-listrik-panas-bumi-terbesar-kedua-dunia.
[97] Andi, D. 2020. "Begini upaya pemerintah meningkatkan pemanfaatan panas bumi di Indonesia." Kontan.Co.Id. September 10, 2020. https://industri.kontan.co.id/news/begini-upaya-pemerintah-meningkatkan-pemanfaatan-panas-bumi-di-indonesia.

[98] Grahanusa Mediatama. 2023. “Catatan pelaku usaha panas bumi jika PLN mau andalkan PLTP jadi pemikul beban dasar.” Kontan.Co.Id. September 14, 2023. https://industri.kontan.co.id/news/catatan-pelaku-usaha-panas-bumi-jika-pln-mau-andalkan-pltp-jadi-pemikul-beban-dasar.
[99] International Atomic Energy Agency. 2022. “Nuclear Share of Electricity Generation in 2022.” IAEA-PRIS (Power Reaction Information System). 2022. https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.
[100] “ReadWorks | Award-Winning, EdTech nonprofit Organization. In Hydropower Status Report 2022.” 2022. International Hydropower Association. 2022. https://assets-global.website-files.com/5f749e4b9399c80b5e421384/62c402eb2af8db8431332d62_IHA-2022-Hydropower-Status-Report.pdf.
[101] Rosmalia, P. 2023. “Potensi PLTA di Indonesia Belum Berhasil Dioptimalkan.” Media Indonesia. November 23, 2023. https://mediaindonesia.com/nusantara/631931/potensi-plta-di-indonesia-belum-berhasil-dioptimalkan.
[102] “What is Nuclear Energy? The Science of Nuclear Power.” 2022. IAEA. November 15, 2022. https://www.iaea.org/newscenter/news/what-is-nuclear-energy-the-science-of-nuclear-power.
[103] “Which country is currently producing the most nuclear power?” 2024. World Economic Forum. February 29, 2024. https://www.weforum.org/agenda/2022/01/energy-nuclear-power-production-electricity-sustainable/.
[104] Posts, V.M. 2020. “Energi baru: nuklir (Nuclear).” LITA GEO’s. June 22, 2020. https://luciafebriarlita17.wordpress.com/2020/07/11/energi-baru-nuklir-nuclear/.
[105] Setiawan, V. N. 2023. “Genjot energi bersih, PLN Terbuka Garap pembangkit nuklir.” CNBC Indonesia. May 22, 2023. https://www.cnbcindonesia.com/news/20230522171134-4-439554/genjot-energi-bersih-pln-terbuka-garap-pembangkit-nuklir.
[106] “Bioenergy.” 2020. Internatioanal Energy Association. https://www.iea.org/energy-system/renewables/bioenergy.
[107] “Bioenergy Basics.” 2020. Bioenergy Technologies Office. https://www.energy.gov/eere/bioenergy/bioenergy-basics.
[108] “Strategi Pemerintah Wujudkan Pemanfaatan Biofuel Yang Berkelanjutan.” 2022. Direktorat Jenderal Energi Baru Terbarukan Dan Konservasi Energi (EBTKE). February 14, 2022. https://ebtke.esdm.go.id/post/2022/02/15/3085/strategi.pemerintah.wujudkan.pemanfaatan.biofuel.yang.berkelanjutan.
[109] “What countries have the greatest bioenergy power capacity? Visualizing Energy.” 2024. Visualizingenergy. February 15, 2024. https://visualizingenergy.org/what-countries-have-the-greatest-bioenergy-power-capacity/.
[110] MINISTRY OF ENERGY AND MINERAL RESOURCES, Directorate General of New, Renewable Energy and Energy Conservation. *Bioenergy Power Plant in Indonesia: Rules and Implementation.* Slide show presented at the German–Indonesia Business Forum, April 9, 2019.
[111] “Berikut Strategi Pemerintah Dalam Pengembangan EBT, Menuju Kemandirian Energi Nasional.” 2019. Direktorat Jenderal EBTKE - Kementerian ESDM. October 17, 2019. https://ebtke.esdm.go.id/post/2019/10/17/2369/berikut.strategi.pemerintah.dalam.pengembangan.ebt.menuju.kemandirian.energi.nasional.
[112] “Electricity Production Data.” 2023. World Electricity Statistics | EnerData. https://yearbook.enerdata.net/electricity/world-electricity-production-statistics.html.
[113] “Indonesia - Countries & Regions - IEA.” 2022. International Energy Association. https://www.iea.org/countries/indonesia/electricity.
[114] “Strategi Bioenergi Dukung Target Net Zero Emission Indonesia.” 2021. Direktorat Jenderal EBTKE - Kementerian ESDM. December 15, 2021. https://ebtke.esdm.go.id/post/2021/12/15/3037/strategi.bioenergi.dukung.target.net.zero.emission.indonesia.

[115] "World's largest hydrogen fuel cell power plant." 2021. Fuel Cells Bulletin 2021 (11): 5–6. https://doi.org/10.1016/s1464-2859(21)00602-7.
[116] "Fuel Cell Energi Masa Depan." 2014. Direktorat Jenderal EBTKE - Kementerian ESDM. October 20, 2014. https://ebtke.esdm.go.id/post/2014/10/20/693/fuel.cell.energi.masa.depan.
[117] "What are hydrogen fuel cells?" 2024. NS Energy Business. 2024. Accessed May 9, 2024. https://www.nsenergybusiness.com/features/what-are-hydrogen-fuel-cells/.
[118] "Cleaning the Air and Improving Health with Hydrogen Fuel-Cell Vehicles." 2022. Science 308 (5730): 1901–5. https://science.sciencemag.org/content/308/5730/1901.
[119] "Global Hydrogen Review 2022." 2022. IEA. 2022. Accessed May 26, 2024. https://www.iea.org/reports/global-hydrogen-review-2022.
[120] "Green Hydrogen Plant Pertama di Indonesia resmi beroperasi." 2024. ESDM. Accessed May 26, 2024. https://www.esdm.go.id/id/media-center/arsip-berita/green-hydrogen-plant-pertama-di-indonesia-resmi-beroperasi.
[121] "Stasiun Pengisian Hidrogen Pertama Resmi Beroperasi." 2024. ESDM. Accessed May 26, 2024. https://www.esdm.go.id/id/media-center/arsip-berita/stasiun-pengisian-hidrogen-pertama-resmi-beroperasi-.
[122] "Fundamentals of wind energy." 2010. Wind Power Generation and Wind Turbine Design, 3–48. http://dx.doi.org/10.2495/978-1-84564-205-1/01.
[123] "Gwec.net." 2024. Accessed May 26, 2024. https://gwec.net/wp-content/uploads/2024/04/GWR-2024_digital-version_final-1.pdf.
[124] Green, Martin A. 2022. "General temperature dependence of solar cell performance and implications for device modelling." Progress in Photovoltaics Research and Applications 11 (5): 333–40. https://doi.org/10.1002/pip.496.
[125] Goldenstein, T. 2015. "Huge solar farm opens in California: Enough energy for 160,000 homes." Los Angeles Times. 2015.
[126] "Renewable power generation costs in 2022." 2022. Irena.Org. 2022. Accessed May 26, 2024. https://www.irena.org/Publications/2023/Aug/Renewable-power-generation-costs-in-2022.
[127] Pourasl, Hamed H., Reza Vatankhah Barenji, and Vahid M. Khojastehnezhad. 2023. "Solar energy status in the world: A comprehensive review." Energy Reports. https://doi.org/10.1016/j.egyr.2023.10.022.
[128] "Direktorat Jenderal EBTKE - Kementerian ESDM." 2024. Esdm.Go.Id. Accessed May 26, 2024. https://ebtke.esdm.go.id/.
[129] "How do all-electric cars work?" 2022. Energy.Gov. Accessed May 26, 2024. https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work.
[130] "Briefing a. Indonesia Market for Electric Vehicles: Sales and Production Investments." 2022. ASEAN Business News. 2022. Accessed May 26, 2024. https://www.aseanbriefing.com/news/indonesia-market-prospects-for-electric-vehicles-sales-manufacturing-investments/.
[131] "Kolokium Hasil Kegiatan Pusat Sumber Daya Mineral Batubara Dan Panas Bumi, Ungkap Peran Badan Geologi Dalam Penyediaan Energi Masa Depan." 2022. Kementerian ESDM. 2022. Accessed May 26, 2024. https://www.esdm.go.id/id/media-center/arsip-berita/kolokium-hasil-kegiatan-pusat-sumber-daya-mineral-batubara-dan-panas-bumi-ungkap-peran-badan-geologi-dalam-penyediaan-energi-masa-depan.
[132] "Kementerian ESDM Ungkap Strategi Pemanfaatan Kendaraan Listrik di Tanah Air." 2024. Kompas.Com. Accessed May 26, 2024. https://money.kompas.com/read/2024/05/24/235940026/kementerian-esdm-ungkap-strategi-pemanfaatan-kendaraan-listrik-di-tanah-air.
[133] "Kobalt CMOC Salip Glencore, China Kian Kuasai Logam Baterai Dunia." 2024. Bloombergtechnoz. 2024. Accessed May 28, 2024. https://www.bloombergtechnoz.com/detail-news/25786/kobalt-cmoc-salip-glencore-china-kian-kuasai-logam-baterai-dunia.

[134] "Intensifkan Survei Potensi Cadangan Timah di Perairan, PT Timah Teken Kerja Sama dengan P3GL." 2019. Kementerian ESDM. 2019. Accessed May 26, 2024. https://www.esdm.go.id/id/media-center/arsip-berita/intensifkan-survei-potensi-cadangan-timah-di-perairan-pt-timah-teken-kerja-sama-dengan-p3gl.
[135] "Produksi Indonesia dan Malaysia Melimpah Dorong Harga Timah Melemah." 2022. Babel.Com. 2022. Accessed May 26, 2024. https://www.wowbabel.com/ekonomi/pr-5985710673/produksi-indonesia-dan-malaysia-melimpah-dorong-harga-timah-melemah.