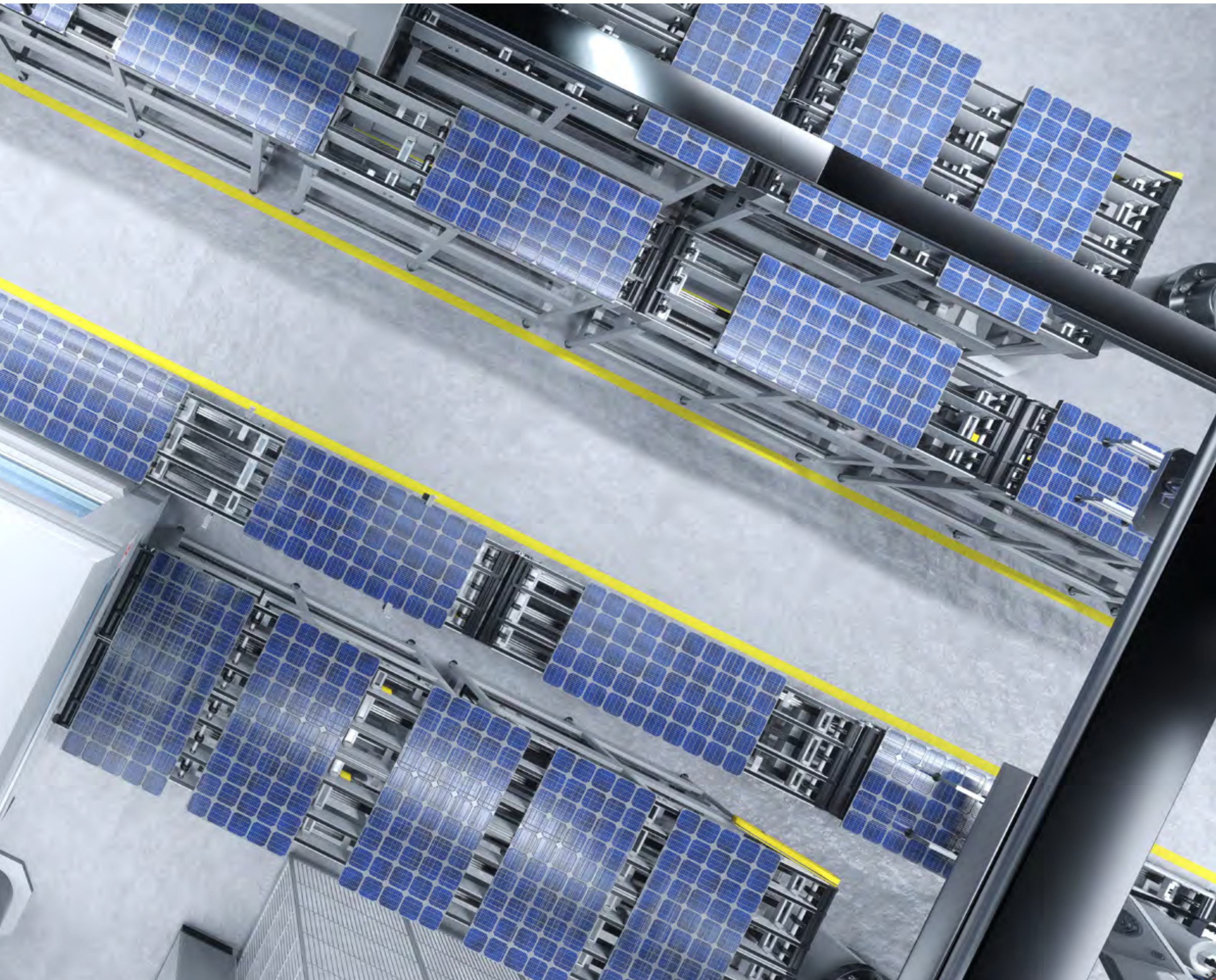
Market Assessment for Indonesia's Manufacturing Industry for Renewable Energy



Market Assessment for Indonesia's Manufacturing Industry for Renewable Energy

Authors

Dr. Farid Wijaya

Abyan Hilmy Yafi

Reviewers

Deon Arinaldo

Dr. Raditya Wiranegara

Dr. Farid Wijaya

Foreword

Tripling the installed capacity of renewable energy by 2030 represents a crucial commitment toward limiting global temperature rise to 1.5°C. Over the past decade, the dramatic decline in the renewable energy investment costs has created genuine optimism that this ambitious target—particularly for solar and wind power—is achievable with serious policy commitment. Moreover, rapid advancements in energy storage technologies, especially batteries, have offered effective solutions to the intermittency challenges of variable renewable energy sources, with lithium battery prices reaching historic lows since 2017.

As cornerstone technologies in the global energy transition, demand for solar PV, wind turbines, and battery systems will continue to surge until 2060. Like many nations, Indonesia has identified solar and wind energy as fundamental pillars in its path toward breaking fossil fuel dependency and achieving decarbonization. The Government of Indonesia (GoI) has recognized the country's extraordinary renewable energy potential in its 2024-2060 National Electricity General Plan, committing to an impressive 109 GW of solar and 73.5 GW of wind power capacity by 2060 as part of its strategy to achieve Net Zero Emissions in the energy sector by 2060 or sooner.

Indonesia's success in its energy transition relies not only on deployment targets but also on building strong, resilient domestic supply chains. Without a strategic development of local manufacturing capabilities, Indonesia risks becoming constantly dependent on imported technologies, making it vulnerable to global supply disruptions and unable to fully reap the economic benefits of the energy transition. The practical implementation of Indonesia's ambitious climate goals hinges on the local manufacturing of renewable energy technologies.

The advancement of Indonesia's renewable energy manufacturing sector presents numerous strategic benefits that extend beyond merely enhancing energy security. With this plan, thousands of decent jobs could be created, advanced technology will grow, foreign exchange will be kept from leaving the country, and Indonesia will become a major exporter in the rapidly growing Asia Pacific renewable energy market. This industrial transformation perfectly aligns with Indonesia's broader economic development objectives, which include reducing unemployment, diversifying the economy beyond natural resource exports, and ascending the global value chain.

To help the GoI establish effective policies and strategies for developing this crucial manufacturing sector, IESR has conducted this comprehensive study: "Market Assessment for Indonesia's Domestic Manufacturing Industry for Renewable Energy." Our analysis examines the current state of Indonesia's renewable energy manufacturing capabilities—specifically for solar PV, wind turbines, and batteries—and identifies concrete opportunities for future growth. Most importantly, this study provides actionable recommendations for policymakers on specific measures to enable Indonesia's clean technology manufacturing industries to develop rapidly and become an integral part of the global renewable energy supply chain.

With this study, we aim to equip policymakers and stakeholders with the insights needed to develop comprehensive industrial policies that strengthen domestic manufacturing capabilities. The energy transition represents an environmental imperative and a historic economic opportunity for Indonesia to transform its economy away from natural resource dependency. By strategically developing its renewable energy manufacturing sector, Indonesia can simultaneously advance its climate goals, strengthen energy security, create quality employment, and enhance economic resilience.

The benefits of a well-executed energy transition must extend beyond environmental improvements to deliver tangible economic and social advantages for all Indonesians. We hope that this study will serve as a roadmap for Indonesia to harness the full potential of the renewable energy revolution, ensuring that the transition to Net Zero Emissions contributes to global climate action and drives sustainable prosperity across the archipelago.

Jakarta, March 2025

Fabby Tumiwa

Executive Director

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Executive Summary

The need for renewable energy is becoming more critical, bolstered by the Paris Agreement, the Methane Pledge, and other global initiatives in mitigating global warming and the threat of climate change. This urgency is realized in the need to augment renewable energy capacity via the Triple Renewable Energy Capacity Pledge at COP28 in 2023 and its financing at COP29 in 2024, with a goal to hold global temperature rise to 1.5℃ through achieving NZE by 2050 or sooner. To encourage the realization of renewable energy adoption targets, three key technologies will need to be developed massively: wind energy, solar energy, and battery energy storage systems.

According to the IEA, renewable energy is expected to account for 80% of global energy consumption by 2050. More than half of this renewable energy is projected to come from solar and wind energy. The energy storage system will become a supporting system and one of the decarbonization technologies for the use of electricity as clean energy, with demand reaching 3900 GW. In fulfilling global commitments, as stated in the draft 2024 KEN, Indonesia aims to reach 70-72% renewable energy by 2060. Referring to the Official 2024 RUKN, renewable energy will reach 73.6% of the total energy mix in 2060 of 443 GW. Solar energy accounts for 24.7%, wind energy accounts for 16.6%, and energy storage systems contribute 7.67% of the total installed capacity projected in 2060. If associated with the expansion of green hydrogen production requirements, there will be an increased demand for energy storage systems and renewable energy.

The large domestic target for renewable energy adoption reflects the large minimum market potential to be utilized in developing the related domestic manufacturing industry and its supply chain. This market potential can be even greater when considering the ever-growing export market. The expansion of the manufacturing sector and its supply chain may foster the industrial ecosystem in the energy sector, enhance national energy security, and have the potential to lower the costs of renewable energy adoption with appropriate policy controls.

Considering the solar energy ecosystem as a whole, solar energy has the greatest potential to become the world's most widely adopted renewable energy source. In 2023, the world's total solar power hit 1.6 TW, and up to 1500 TWh of energy was produced each year, equal to almost 78% of all renewable energy capacity. Fifty-seven percent of the total global installations of solar energy come from China, bolstered by its biggest global solar PV manufacturing industry and supply chain, up to 90% of the global market share. However, the world's installed capacity is still far from the IEA scenario estimate of 21 TW by 2050. Far behind China as the country with the largest adoption of solar energy, Indonesia's installed solar capacity was around 0.32 GW in 2023, which is just under 0.01% of the total solar potential of 3,294 GW. Indonesia faces a challenging journey to achieve the target of at least 109.4 GW. This target can be up to 267 GW with green hydrogen production by 2060, as stipulated by the official target of 2024 RUKN.

Among the several types of solar PV technologies created worldwide, crystalline polysilicon remains the predominant technology, with over 97% of the market share in 2023. It is estimated that by 2034, N-Type TopCon will control more than 50% of the global solar PV market, followed by SHJ at 23%. The global solar PV market value is estimated at USD 171.08-253.69 billion in 2023 and will keep growing to USD 436.36 billion by 2032 at a 6% CAGR, although solar PV prices have decreased almost 90% in the last decade. This data indicates the growth of

solar energy industry trends and values, which can be used as a foundation to strengthen Indonesia's solar PV manufacturing sector and supply chain.

In addition to solar energy, wind energy is the next renewable energy with the biggest adoption potential in the world. By June 2024, wind power had about 1.1 TW of installed capacity worldwide, generating up to 2,300 TWh of electricity annually or equal to 7.8% of world electricity production. China leads global wind energy generation at 39%, followed by the USA at 18.5%. China's preeminence in wind energy is propelled by its dominance in the main wind turbine component industry, with a share of 50-80%. Current installed wind energy capacity is still far from demand, with global demand estimated to reach 7.9-25 TW in 2050. Far behind its potential and targets of wind energy, Indonesia only had a wind energy installed capacity of 154.3 MW by 2023 from a potential of 155 GW or a utilization rate of less than 0.1%. Like solar energy, it is a long road for Indonesia to realize the installed wind energy capacity target of 73.2 GW in 2050, referring to the official target of 2024 RUKN.

Looking at the technology trends of wind energy, onshore wind accounts for over 90% of wind energy generation. However, offshore wind is expected to expand to 25% by 2050 due to advancements in wind energy technologies and utilization. The adoption of larger-scale wind turbines is possible and would be preferred to increase the energy generated. The estimated market for wind turbines is projected to reach USD 318.02 billion by 2034, with a CAGR of 7.81%, increased from USD 139 billion in 2023. This information provides a glimpse into the trends and value of the wind energy markets that will continue to grow until 2050 or beyond. Further, Indonesia can consider it as a potential for wind turbine domestic manufacturing industry development and its supply chain.

Solar and wind energy are examples of intermittent renewable energy, which means it needs support to maintain its electricity output. Energy storage based on batteries can play a role in maintaining the electricity grid and contributing to meeting grid stability, helping to meet peak load and improving the integration of rising shares of variable renewable energy. Battery can also be a solution in the transportation sector since it becomes the alternative to internal combustion engines in the form of EVs. Li-ion batteries are the market leaders for the application in the transport and power sectors due to their high energy density and long lifespans.

Indonesia has the potential in the battery supply chain due to its abundant nickel reserves. Indonesia accounts for 52% of global nickel production, positioning it as a key player in the mining and refining stages, particularly in NMC batteries. Currently, Indonesia has 44 nickel smelters, but most of them focus on material for stainless steel, not EV batteries.

To be globally competitive, a battery cell production capacity of at least 10 GWh is needed. Compared to the global battery capacity that has reached 3,000 GWh, Indonesia is currently still in the early stages of large-scale manufacturing since there is only one facility with a capacity of 10 GWh.

To support the development of renewable energy technologies supply chain, an ideal policy needs to be applied. Indonesia needs a consistent target of renewable energy adoption to drive the development of the renewable energy technology supply chain. Indonesia should also adopt a comprehensive approach addressing all stages of the supply chain, with integrated planning and collaboration among stakeholders.

Indonesia's economy will be strengthened by domestic-centered economic activities brought about by the presence and growth of the manufacturing sector of solar PV, wind turbines, battery energy systems, and their supply chains in alignment with natural resource and mineral downstream programs. Furthermore, these strategies will yield advantages, such as job creation, human resource development, industry growth resilience, supply and demand stability, economic vitality with a circular economy, and community welfare. Ultimately, they will bolster initiatives to improve national energy security and the nation's economic resiliency.

The potential value of the circulated economy and job creation opportunities from the manufacturing industry for renewable energy and its supply chain for solar PV is up to USD 236.3 billion and 5.7 million jobs-yrs, wind turbines up to USD 75.2 billion and 1.8 million jobs-yrs, and battery for EV and energy storage up to USD 240 billion and 2.2 million jobs-yrs by 2060 for domestic demand fulfillment only. Consequently, the potential value of the circulated economy and job creation opportunities can have a significant increase by utilizing export market potential. This is influenced by a variety of factors that are analyzed in this study through SWOT analysis. It is crucial to implement key enablers and conduct additional research to ensure the best practices are implemented to promote the domestic manufacturing sector for renewable energy, with a particular emphasis on solar PV, wind turbines, and battery energy systems as the center of the sustainable industrial ecosystem in the energy sector for economic and transition energy alignment to achieve 8% economic growth and 2045 Golden Indonesia.

Ringkasan Eksekutif

Kebutuhan akan energi terbarukan menjadi semakin penting. Hal ini didorong oleh Perjanjian Paris, Janji untuk Memangkas Metana (Methane Pledge), dan inisiatif global lainnya untuk memitigasi pemanasan global dan ancaman perubahan iklim. Urgensi ini diwujudkan dengan adanya kebutuhan untuk meningkatkan kapasitas energi terbarukan hingga tiga kali lipat melalui Triple Renewable Energy Capacity Pledge pada COP28 di tahun 2023 dan pembiayaannya pada COP29 di tahun 2024, dengan tujuan untuk menahan kenaikan suhu global di angka 1,5°C melalui pencapaian NZE pada tahun 2050 atau lebih cepat. Untuk mendorong realisasi target adopsi energi terbarukan, tiga teknologi utama perlu dikembangkan secara masif: energi angin, energi surya, dan sistem penyimpanan energi baterai.

Menurut IEA, energi terbarukan diperkirakan akan mencapai 80% dari konsumsi energi global pada tahun 2050. Lebih dari separuh energi terbarukan ini diproyeksikan berasal dari energi surya dan angin. Sistem penyimpanan energi akan menjadi sistem pendukung dan salah satu teknologi dekarbonisasi untuk penggunaan listrik dari energi bersih, dengan permintaan mencapai 3900 GW. Dalam memenuhi komitmen global, seperti yang tertuang dalam draf KEN 2024, Indonesia menargetkan untuk mencapai 70-72% energi terbarukan pada tahun 2060. Mengacu pada RUKN 2024, energi terbarukan akan mencapai 73,6% dari total bauran energi pada tahun 2060 sebesar 443 GW. Energi surya menyumbang 24,7%, energi angin menyumbang 16,6%, dan sistem penyimpanan energi menyumbang 7,67% dari total kapasitas terpasang yang diproyeksikan pada tahun 2060. Jika dikaitkan dengan perluasan kebutuhan produksi hidrogen hijau, maka akan terjadi peningkatan permintaan sistem penyimpanan energi dan energi terbarukan.

Target domestik yang besar untuk adopsi energi terbarukan mencerminkan potensi pasar minimum yang besar untuk dimanfaatkan dalam mengembangkan industri manufaktur dalam negeri dan rantai pasokannya. Potensi pasar ini dapat menjadi lebih besar lagi jika mempertimbangkan pasar ekspor yang terus berkembang. Perluasan sektor manufaktur dan rantai pasokannya dapat menumbuhkan ekosistem industri di sektor energi, meningkatkan ketahanan energi nasional, dan berpotensi menurunkan biaya adopsi energi terbarukan dengan kontrol kebijakan yang tepat.

Dengan mempertimbangkan ekosistem energi surya secara keseluruhan, energi surya memiliki potensi terbesar untuk menjadi sumber energi terbarukan yang paling banyak digunakan di dunia. Pada tahun 2023, total kapasitas energi surya dunia mencapai 1,6 TW dan hingga 1500 TWh energi diproduksi setiap tahun, setara dengan hampir 78% dari seluruh kapasitas energi terbarukan. Lima puluh tujuh persen dari total instalasi energi surya global berasal dari Cina, didukung oleh industri manufaktur dan rantai pasokan photovoltaic (PV) surya terbesar di dunia, dengan pangsa pasar global hingga 90%. Namun, kapasitas terpasang dunia masih jauh dari perkiraan skenario IEA sebesar 21 TW pada tahun 2050. Jauh di belakang Cina sebagai negara dengan adopsi energi surya terbesar, kapasitas terpasang energi surya di Indonesia adalah sekitar 0,32 GW pada tahun 2023, atau kurang dari 0,01% dari total potensi energi surya yang mencapai 3.294 GW. Indonesia menghadapi perjalanan yang menantang untuk mencapai target setidaknya 109,4 GW. Target ini dapat meningkat hingga 267 GW dengan produksi hidrogen hijau pada tahun 2060, seperti yang ditetapkan oleh target resmi RUKN 2024.

Di antara beberapa jenis teknologi PV surya yang diciptakan di seluruh dunia, polisilikon kristalin tetap menjadi teknologi yang dominan, dengan lebih dari 97% pangsa pasar pada tahun 2023. Diperkirakan pada tahun 2034, N-Type TopCon akan

menguasai lebih dari 50% pasar PV surya global, diikuti oleh SHJ sebesar 23%. Nilai pasar PV surya global diperkirakan mencapai USD 171,08-253,69 miliar pada tahun 2023 dan akan terus tumbuh hingga USD 436,36 miliar pada tahun 2032 dengan CAGR 6%, meskipun harga PV surya telah menurun hampir 90% dalam satu dekade terakhir. Data ini menunjukkan pertumbuhan tren dan nilai industri energi surya, yang dapat digunakan sebagai dasar untuk memperkuat sektor manufaktur dan rantai pasokan PV surya di Indonesia.

Selain energi surya, energi angin adalah energi terbarukan berikutnya dengan potensi adopsi terbesar di dunia. Pada Juni 2024, kapasitas terpasang energi angin sekitar 1,1 TW di seluruh dunia, menghasilkan hingga 2.300 TWh listrik per tahun atau setara dengan 7,8% produksi listrik dunia. Cina memimpin pembangkit energi angin global dengan 39%, diikuti oleh Amerika Serikat dengan 18,5%. Keunggulan Cina dalam energi angin didorong oleh dominasinya dalam industri komponen utama turbin angin, dengan pangsa 50-80%. Kapasitas energi angin yang terpasang saat ini masih jauh dari permintaan, dengan permintaan global diperkirakan mencapai 7,9-25 TW pada tahun 2050. Jauh tertinggal dari potensi dan target energi angin, Indonesia hanya memiliki kapasitas terpasang energi angin sebesar 154,3 MW pada tahun 2023 dari potensi 155 GW atau tingkat pemanfaatan kurang dari 0,1%. Seperti halnya energi surya, jalan panjang masih harus ditempuh Indonesia untuk merealisasikan target kapasitas terpasang energi angin sebesar 73,2 GW pada tahun 2050, mengacu pada target resmi RUKN 2024.

Melihat tren teknologi energi angin, angin darat (onshore) menyumbang lebih dari 90% pembangkit energi angin. Namun, angin lepas pantai (offshore) diperkirakan akan meningkat menjadi 25% pada tahun 2050 karena kemajuan teknologi dan pemanfaatan energi angin. Penggunaan turbin angin berskala lebih besar dimungkinkan dan akan lebih disukai untuk meningkatkan energi yang dihasilkan. Perkiraan pasar untuk turbin angin diproyeksikan mencapai USD 318,02 miliar pada tahun 2034, dengan CAGR 7,81%, meningkat dari USD 139 miliar pada tahun 2023. Informasi ini memberikan gambaran sekilas tentang tren dan nilai pasar energi angin yang akan terus berkembang hingga tahun 2050 atau lebih. Lebih lanjut, Indonesia dapat mempertimbangkan pasar energi angin sebagai potensi untuk pengembangan industri manufaktur turbin angin dalam negeri dan rantai pasokannya.

Energi surya dan angin merupakan contoh energi terbarukan yang bersifat intermiten, yang berarti membutuhkan dukungan untuk mempertahankan produksi listriknya. Penyimpanan energi berbasis baterai dapat berperan dalam menjaga jaringan listrik dan berkontribusi dalam memenuhi stabilitas jaringan, membantu memenuhi beban puncak dan meningkatkan integrasi peningkatan pangsa energi terbarukan yang bervariasi. Baterai juga dapat menjadi solusi di sektor transportasi karena menjadi alternatif dari mesin pembakaran internal dalam bentuk kendaraan listrik. Baterai Li-ion adalah pemimpin pasar untuk penggunaan di sektor transportasi dan listrik karena kepadatan energinya yang tinggi dan masa pakainya yang panjang.

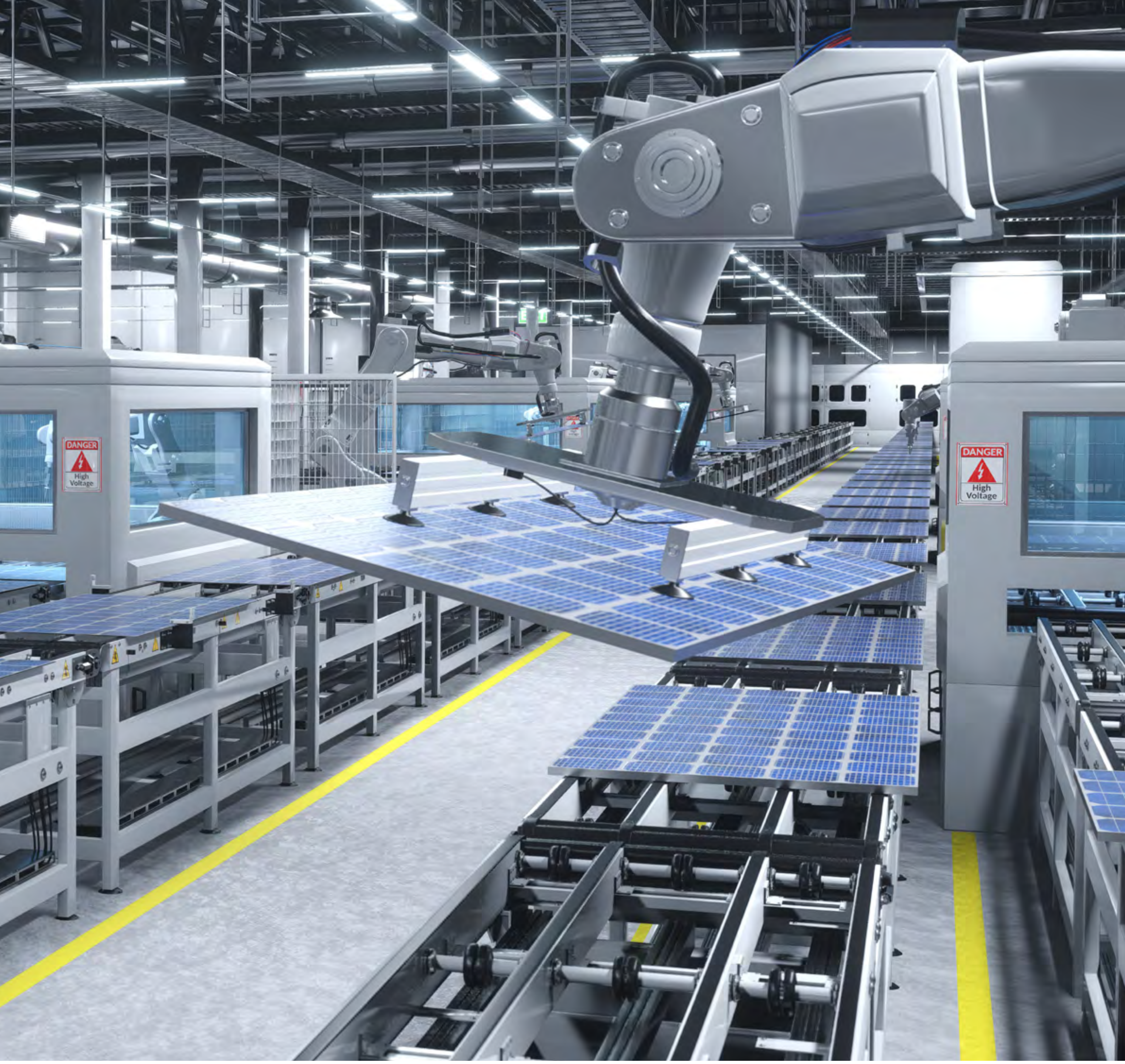
Indonesia memiliki potensi dalam rantai pasokan baterai karena cadangan nikelnya yang melimpah. Indonesia menyumbang 52% dari produksi nikel global, memposisikannya sebagai pemain kunci dalam tahap penambangan dan pemurnian, terutama untuk baterai NMC. Saat ini, Indonesia memiliki 44 pabrik peleburan (smelter) nikel, tetapi sebagian besar dari pabrik-pabrik tersebut berfokus pada bahan untuk baja tahan karat, bukan baterai mobil listrik.

Agar dapat bersaing secara global, diperlukan kapasitas produksi sel baterai setidaknya 10 GWh. Dibandingkan dengan kapasitas baterai global yang telah mencapai 3.000 GWh, Indonesia saat ini masih berada di tahap awal manufaktur skala besar karena hanya ada satu fasilitas dengan kapasitas 10 GWh.

Untuk mendukung pengembangan rantai pasok teknologi energi terbarukan, kebijakan yang ideal perlu diterapkan. Indonesia membutuhkan target adopsi energi terbarukan yang konsisten untuk mendorong pengembangan rantai pasok teknologi energi terbarukan. Indonesia juga harus mengadopsi pendekatan yang komprehensif dalam menangani semua tahapan rantai pasokan, dengan perencanaan yang terintegrasi dan kolaborasi di antara para pemangku kepentingan.

Perekonomian Indonesia akan diperkuat oleh kegiatan ekonomi yang berpusat di dalam negeri yang disebabkan oleh kehadiran dan pertumbuhan sektor manufaktur PV surya, turbin angin, sistem energi baterai, dan rantai pasokannya yang selaras dengan program hilirisasi sumber daya alam dan mineral. Lebih lanjut, strategi ini akan menghasilkan keuntungan, seperti penciptaan lapangan kerja, pengembangan sumber daya manusia, ketahanan pertumbuhan industri, stabilitas pasokan dan permintaan, vitalitas ekonomi dengan ekonomi sirkular, dan kesejahteraan masyarakat. Pada akhirnya, strategi ini akan mendukung inisiatif untuk meningkatkan ketahanan energi nasional dan ketahanan ekonomi bangsa.

Potensi nilai perputaran ekonomi dan peluang penciptaan lapangan kerja dari industri manufaktur energi terbarukan dan rantai pasoknya untuk PV surya mencapai USD 236,3 miliar dan 5,7 juta lapangan kerja per tahun, turbin angin mencapai USD 75,2 miliar dan 1,8 juta lapangan kerja per tahun, serta baterai untuk EV dan penyimpanan energi mencapai USD 240 miliar dan 2,2 juta lapangan kerja per tahun pada tahun 2060 hanya untuk memenuhi kebutuhan dalam negeri. Akibatnya, potensi nilai ekonomi yang beredar dan peluang penciptaan lapangan kerja dapat mengalami peningkatan yang signifikan dengan memanfaatkan potensi pasar ekspor. Hal ini dipengaruhi oleh berbagai faktor yang dianalisis dalam penelitian ini melalui analisis SWOT. Sangat penting untuk mengimplementasikan faktor pendukung utama (key enablers) dan melakukan penelitian tambahan untuk memastikan praktik terbaik diterapkan untuk mempromosikan sektor manufaktur dalam negeri untuk energi terbarukan, dengan penekanan khusus pada PV surya, turbin angin, dan sistem energi baterai sebagai pusat ekosistem industri berkelanjutan di sektor energi untuk penyelarasan ekonomi dan energi transisi sehingga dapat mencapai pertumbuhan ekonomi 8% dan Indonesia Emas 2045.



1 Exploring the necessity for the adoption of renewable energy and its manufacturing industries in Indonesia

A. Recognizing the significance of renewable energy adoption to provide clean energy

The threat of climate change can be avoided by reducing greenhouse gases (GHG)-carbon emissions almost half by 2030 and reaching Net Zero Emissions (NZE) by 2050. The urgency to decrease reliance on fossil fuels as a major contributor to carbon emissions makes the adoption of renewable energy crucial. As a part of a global effort, 195 Parties (194 States plus the EU) have joined the Paris Agreement by the end of 2024 and are committed to reducing their GHG emissions (UNFCCC, 2024). Among them, over 140 countries have committed to NZE targets, covering about 88% of global GHG emissions (UN, 2024a). This endeavour is also strengthened by the Methane Pledge. By the end of 2023, more than 150 parties have committed to lowering and regulating methane emissions (WRI, 2023). These global initiatives emphasize the need to switch to renewable energy and minimize GHG emissions.

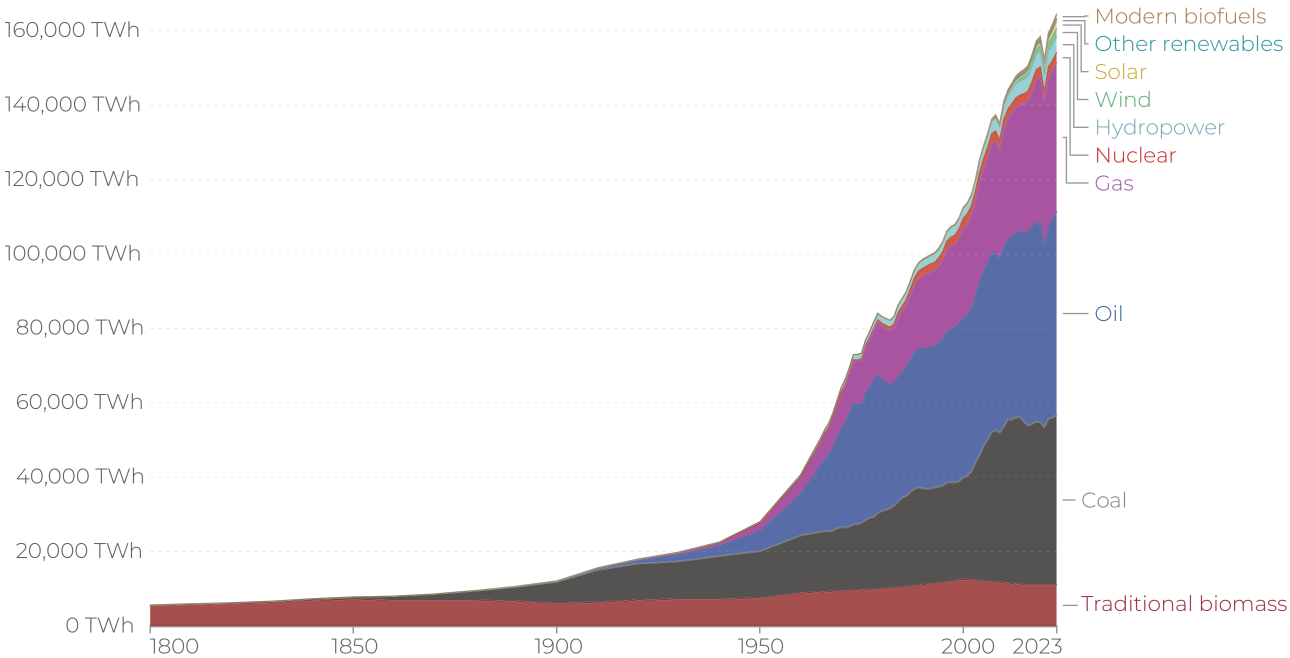
As a follow-up to the urgency of adopting renewable energy, Conference of the Parties (COP) 28 in 2023 has produced a Triple Renewable Energy Capacity Pledge (UNFCCC, 2023). The pledge implies that all countries under the Paris Agreement are required to increase their renewable energy capacity, tripling it to achieve the worldwide target of 11 TW by 2030 and 81.9 TW by 2050. This step is crucial to maintain the global target to reach the 1.5°C target scenario by 2050 (IEA, 2024; IRENA, 2023; WEF, 2023). As a consequence, the investment value must rise and is expected to reach USD 1.5 trillion annually between 2024 and 2030 (IRENA, 2024). This has been adebated topic at COP29 in 2024 and resulted in developed countries providing USD 300 billion annually as climate finance funds to support developing countries minimizing GHG emissions (WMO, 2024).

In 2023, the world's GHG emissions reached 53.0 Gt CO_2eq (without counting land use, land use change, and forestry). This number consists of 73.7% CO_2, 18.9% CH_4, 4.7% N_2O, and 2.7% F-gases, which is the focus of reducing GHG emissions from the Paris agreement (European Commission, 2024). According to the International Energy Agency (IEA), methane (CH_4) emissions from energy usage in 2023 accounted for 31% of total methane emissions. The methane emissions from energy use consist of 49 mt CH_4 from oil, 29 mt CH_4 from natural gas, 40 mt from coal, and 10 mt CH_4 from bioenergy (IEA, 2025a-b). Methane emissions from both energy use and other causes are the focus of methane emission reduction from the methane pledge.

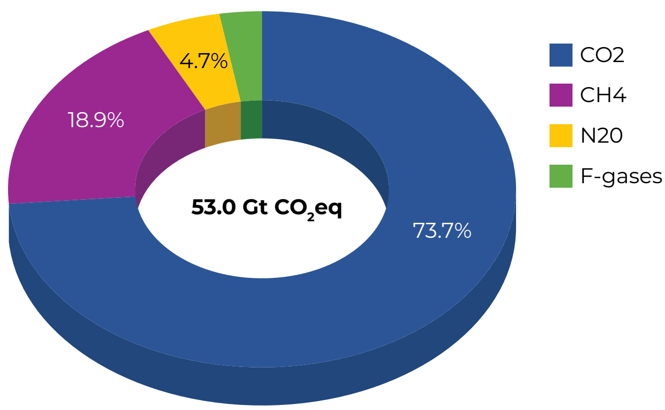
Globally, the combination of China, the USA, India, the EU27, Russia, and Brazil accounted for 64.2% of total fossil fuel consumption and 62.7% of total GHG emissions (European Commission, 2024). Referring to 2023 data (see Fig 1.1.), the global energy transition effort requires almost 140,000 TWh of renewable energy to replace energy generated from fossil fuels into clean energy to achieve NZE (Our World in Data, 2024). Fossil fuels contribute to nearly 86% of the total energy share and are responsible for more than 75% of GHG emissions (IEA, 2023a; UN, 2024b). Therefore, intervention in energy consumption can be directly associated with the effort to mitigate the amount of emissions produced.

Global direct primary energy consumption

Energy consumption is measured in terawatt-hours[1] in terms of direct primary energy.[2] This means that fossil fuels include the energy lost due to inefficiencies in energy production.



Data source: Energy Institute - Statistical Review of World Energy (2024); Smil (2017)
Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.



Source: Our World in Data, 2024

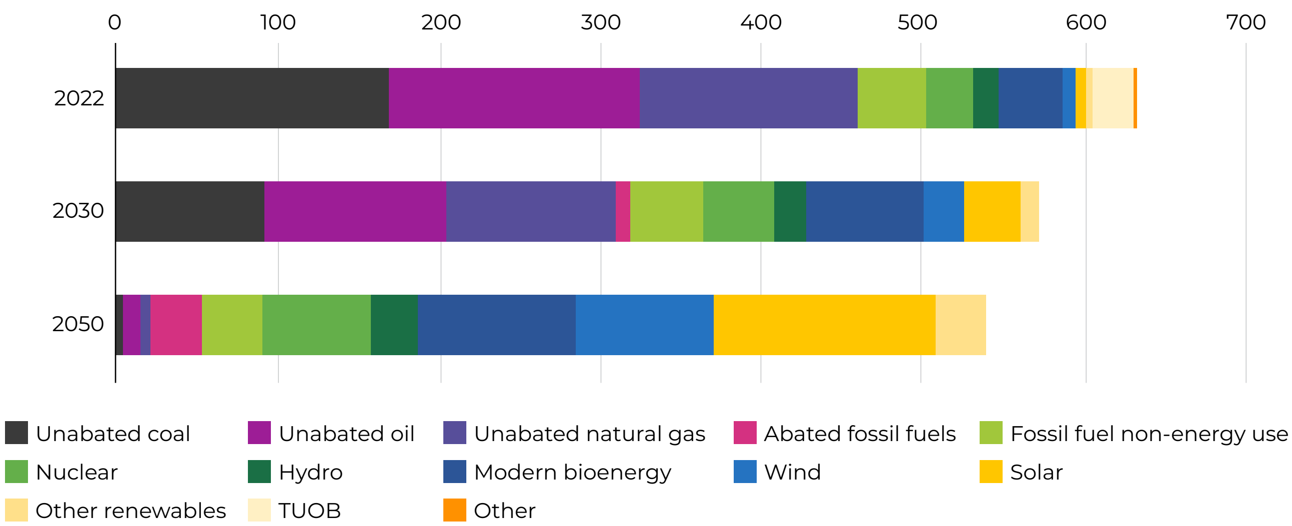
Fig 1.1. Global direct primary energy consumption (above) and global emission share (below)

As part of the world community, Indonesia is obliged to actively participate in the energy transition by utilizing its renewable energy potential to achieve NZE in accordance with the Paris Agreement (UN, 2024c). However, adopting renewable energy is neither easy nor cheap. Renewable energy technology is still classified as an emerging technology due to its low adoption rate as compared to fossil fuels. At the end of 2023, renewable energy contributed almost 15% of global primary energy supply and 14% of Indonesia's primary energy supply (Gini, 2024; MEMR, 2024a). Furthermore, there are still many limitations in performance efficiency, life durability, and end-use management that require significant R&D costs. As a result, adopting renewable energy technology still requires significant capital expenditures (CapEx), leading to high upfront costs (IEF, 2024; IEA, 2023b). Depending on the technology, renewable energy may also have high operation and maintenance (OpEx) costs, while some may be much cheaper than fossil fuel utilization. The lower OpEx cost makes some renewable energy, such as wind and solar energy, produce lower-cost electricity compared to fossil fuels with or without carbon, capture and storage (CCS) even after integration with energy storage systems such as batteries (IRENA, 2021; Lazard, 2023; Wood Mackenzie, 2022; Roser, 2020). A mass adoption and usage of the technology can further reduce CapEx costs even more with the push of the Paris Agreement and other global initiatives, making the renewable technology market, both domestic and international markets, attractive for Indonesia.

What needs to be considered next is the potential for economic activities from the adoption of renewable energy within Indonesia, or Southeast Asia, and further worldwide as potential market for Indonesia. Prioritizing these activities in order to achieve domestic economic development is highly desired for the short and long term. In the short term, the Indonesian government's new leadership is ambitious, aiming for 8% annual economic growth. Meanwhile, in the long term, Indonesia has a dream of becoming a developed country toward Golden Indonesia 2045. To achieve an economic development rate of 8%, it is necessary to establish a sustainable and secure energy infrastructure (PLN, 2024). The domino effect of infrastructure development will have a significant impact on the economy, especially if economic activity is centered on domestic, notably the manufacturing industry for solar PV, wind turbines, batteries, and its supply chain through natural resource and mineral downstream programs (PLN, 2024; MoF, 2024; MEMR, 2025). This is in line with Indonesia's commitment to the Paris Agreement to achieve NZE (MEMR, 2025).

It should be noted that to realize the 2060 primary energy mix compliance with NZE under the Official 2024 National Electricity General Plan (Rencana Umum Ketenagalistrikan Nasional/RUKN), at least USD 1 trillion is needed in investment costs for power plants, along with USD 104 billion for electricity transmission networks (MEMR, 2024b). This makes aligning the energy transition strategy toward NZE and the economic growth goal crucial to Indonesia's aim to become a developed nation under the 2045 Golden Indonesia. The alignment is critical so that the energy transition does not only impose an economic cost but can also generate economic benefits. In order to maximize the economic benefits, Indonesia should establish itself as the technology hub that processes and produces renewable energy technology and its supply chain. This can be achieved by utilizing domestic natural resources under downstream programs, engineering, procurement, construction (EPC), operations and maintenance (O&M), decommissioning, and recycling renewable energy technologies. The primary objective is to provide a significant impact on domestic economic growth, at least in meeting domestic renewable energy needs and maintaining national energy security through the renewable energy manufacturing supply chain. A more ambitious objective is to become the technology hub for Southeast Asia and the global community. Thus, the development of renewable energy technology manufacturing in the country is a priority. It is important to note that opportunities do not consistently arise; rather, they must occasionally be generated and pursued.

B. Renewable energy demand to push the manufacturing adoption technology



Sourcs: IEA, 2023c

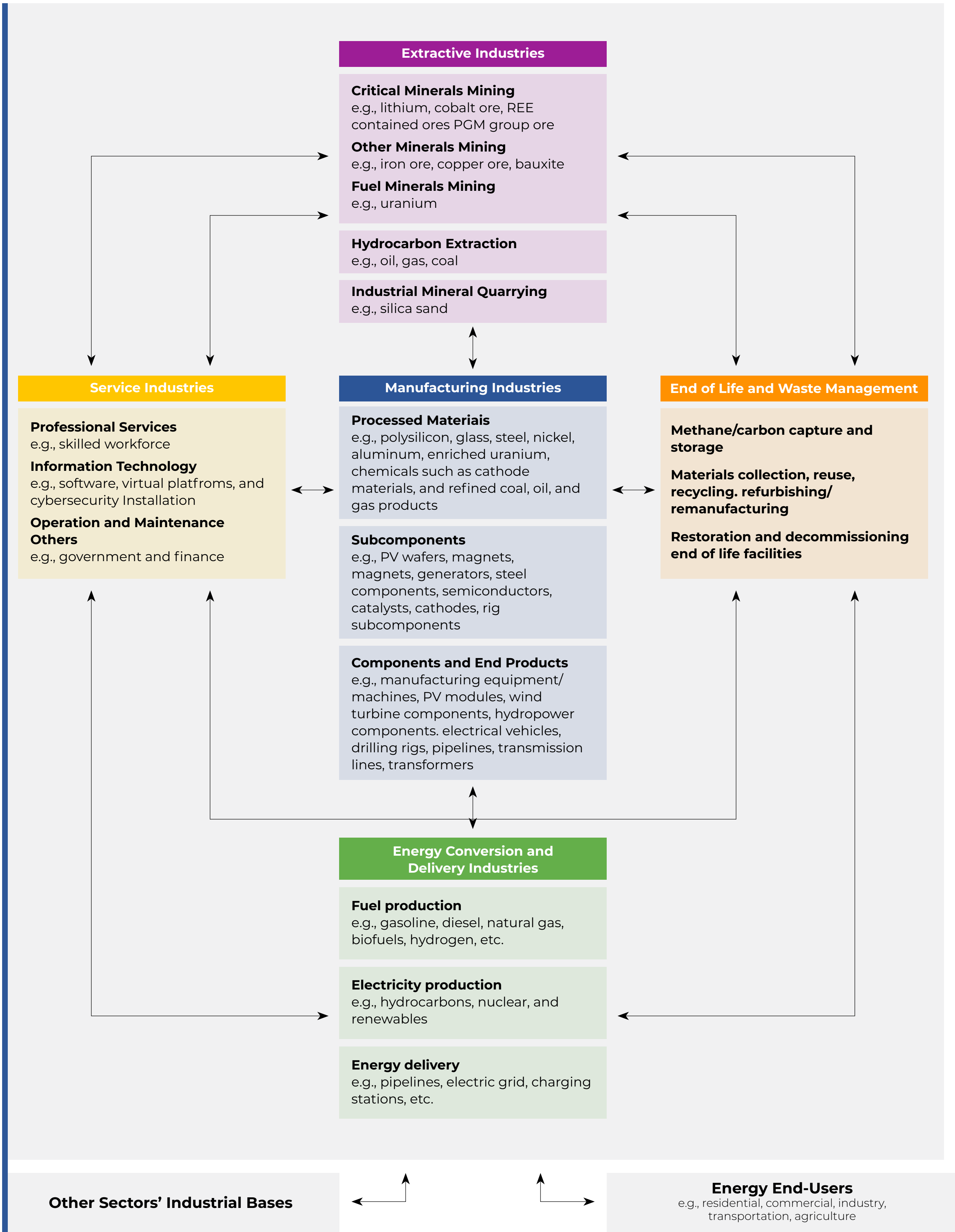
Fig 1.2. The net zero scenario for energy supply by source, 2022-2050

By 2050, global energy demand is anticipated to transition from fossil fuels to renewable energy, comprising 80% of total energy consumption worldwide (IEA, 2021). According to Fig 1.2., a number of renewable energy sources are predicted to be very significant by 2050, with solar energy accounting for about 25.5% and wind energy for approximately 15.6% of the world's energy supply (IEA, 2023c). Meanwhile, the battery energy storage systems demand is estimated to reach 3900 GW by 2050 (IEA, 2022; Schönfisch, et al., 2024). It is important to note that the previously mentioned key figures for solar, wind energy, and batteries represent the projected total demand necessary to achieve NZE with high energy efficiency in mind.

Photovoltaic (PV) solar power and wind turbines play a crucial part in delivering clean energy due to their simplicity and mobility, which can harvest renewable energy from the sun and wind, respectively, in a variety of locations. The advancement of solar PV systems and wind turbines may enhance energy resilience against supply vulnerabilities and price volatility of fossil fuels. This, in turn, can help prevent an energy crisis like the one experienced in the EU due to the war between Russia and Ukraine in 2021-2022, which resulted in the disruption of natural gas supply and led to electricity prices soaring by six times or more (ANS, 2024; Mandys, 2024). By increasing energy diversification and reducing dependence on fossil fuels, solar and wind power significantly lower the risk of such potential crises. Should a nation's energy sources fail—due to fossil resource depletion and its price volatility, prolonged drought affecting hydropower, or nuclear reactor malfunctions—maintaining a diverse energy portfolio, particularly through the integration of solar and wind energy with energy storage, allows the country to operate continuously with a sustainable power supply as sun and wind will mostly be available as it is.

In addition to that, battery energy storage—a kind of electrical energy storage technology—plays a critical part in the electrification of energy consumption and ensuring power grid reliability. Batteries store electricity from unused or oversupplied electricity production from traditional and renewable energy sources and supply their stored electricity as desired. Thus, batteries can bridge the production of variable renewable energy (VRE), such as solar and wind energy, as well as balance the grid from the possibility of unstable energy supply to demand and vice versa. The usage of batteries facilitates the use of electrical energy off-grid, especially in the portable and high-mobility applications such as logistics and transportation sectors. Thus, the utilization of batteries means using electricity directly, relieving reliance on fossil fuels if electricity is generated cleanly, which helps reduce GHG emissions.

As part of the global community, Indonesia is also attempting to decrease GHG emissions via various means, including the use of renewable energy. Referring to the draft of the National Energy Policy (Kebijakan Energi Nasional/KEN) in 2024, the renewable energy mix was aimed at 17-19% in 2025, 19-22% in 2030, and continuing to increase to 70-72% in 2060. The KEN draft aims for solar energy to account for over 31% and wind energy for nearly 10% of the country's electrical energy requirements by 2060 (MEMR, 2024c). According to the latest official RUKN published at the end of 2024, renewable energy will reach 73.6% of the total installed capacity of 443 GW by 2060. Of this 443 GW, solar and wind energy are expected to reach 109.4 GW and 73.2 GW, respectively, equal to 24.7% and 16.6% of the total installed capacity. This effort will be accompanied by the adoption of energy storage, including batteries, which will start in 2025 and reach 34 GW by 2060 (MEMR, 2024b). However, considering additional electricity demand for green hydrogen production, renewable energy is estimated to reach 77.7% of the 660 GW total installed capacity by 2060, with solar energy reaching 267 GW or 42.4% and wind energy reaching 73.2 GW or 11.6% of the total installed capacity complemented with energy storage of 58 GW (MEMR, 2024b). This has essentially shown the government's commitment and may serve as the foundation for the renewable energy manufacturing sector market and supply chain.



Source: DOE, 2022

Fig 1.3. Industry ecosystem in the energy sector

The adoption of renewable energy in Indonesia offers a pathway to sustainable development and presents significant economic potential. In the framework of a domestic renewable energy economy, the growth of the manufacturing industry and its supply chain for renewable energy creates more accessible products, cuts down time-logistics shipping from overseas, and utilizes the domestic potential of human and natural resources for domestic interests. As a result, it may promote the growth, innovation, and cost-effectiveness of renewable energy technology while helping promote the domestic economy, job creation, and environmental sustainability, as well as the potential for lowering CapEx and Opex costs from minimizing dependence on the supply of potentially high-cost foreign technology and labor.

Developing the manufacturing industries for renewable energy and their supply chain is an integral part of efforts to build a sustainable and resilient industrial ecosystem in the energy sector, as shown in Fig 1.3., The manufacturing industry holds a central position within the energy sector's ecosystem. Its growth will indirectly support the growth of this entire ecosystem. Thus, establishing the manufacturing industry for renewable energy can provide a broader economic opportunity impact not only the manufacturing industry itself but the whole industry ecosystem in the energy sector. This significant value underscores the critical role that manufacturing locations play in fostering a nation's independence, sustainability, and resilience. Nevertheless, every industry within the energy sector's ecosystem should be developed along the way. So, the industry's ecosystem in the energy sector could have a strong foundation to provide an ideal and sustainable renewable energy supply and strengthen domestic energy security.

C. Study objective and limitations

This study was designed to identify the potential, challenges, and important factors that must be considered in the development of the manufacturing industry and its value chain for renewable energy in Indonesia, benchmarked with the global situation perspective.

The objectives of this study can be summarized as follows:

1. To provide critical information in developing a sustainable ecosystem of the manufacturing industry and its value chain for renewable energy as part of national energy and industrial security in decarbonization-climate change mitigation efforts toward NZE.
2. To serve as a benchmark for future research on the potential domestic investment in the manufacturing industry and its value chain for renewable energy that is either commercially viable or can be funded. This benchmark is intended for investors and other interested parties in the development of manufacturing industry for renewable energy and its value chain, which is still in its infancy.
3. To contextualize Indonesia in the development of renewable energy, the manufacturing industry, and its value chain for renewable energy, along with its market opportunities, the readiness of existing ecosystems, future suggestions, and the policy framework, SWOT analysis, opportunity, and challenge.
4. To illustrate potential impacts in the creation of the manufacturing industry and its value chain, including job creation, potential value of an investment for domestic economic activity, and other benefits.
5. To describe key risk points, vulnerabilities, and enablers that need to be anticipated and prepared in the development of manufacturing industries and their supply chains for renewable energy.

The context of this study is limited by its focus on manufacturing and construction sectors in general and does not discuss upstream processes, such as the processing industry and mining extraction, and limited technology of solar PV, wind turbines, and battery energy storage. These technologies were chosen as they have a very high strategic role and are projected to have a highly significant utilization share contribution to accommodate renewable energy. Additionally, such technologies require the use of critical minerals in substantial quantities in comparison with other renewable energy technologies, making them essential in decarbonization and climate change mitigation efforts toward NZE.

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2 An overview of solar energy and its future projections

A. Solar energy's overview technology and its supply chain

The solar PV system converts light (photons) into electricity (voltage). The energy required to produce electricity is exclusively supplied by the photons that are absorbed by the semiconductor material in a PV cell. Since solar energy is abundant, it can be harvested as long as it is absorbed and can be predicted more accurately than wind energy (EIA, 2024). It is applicable in stationary and mobile applications, in all orientations (horizontal, diagonally, and vertically), and with low to high loads. This makes solar energy a priority for deployment in many countries due to its ease of installation with or without requiring a dedicated, sacrificing productive area. Moreover, it always works in silent mode with minimum maintenance, which works well in most places.

The solar PV system produces electricity that requires no fuel, requires little maintenance, and emits no GHG emissions (Fthenakis, et al., 2006; Chandrasekharam, et al., 2020), making it one of the cleanest solutions to protect the environment. Solar PV can be installed in various settings but perform best on open, flat surfaces with ample sunlight and proper inclination to optimize sun-ray interaction. Therefore, they can be deployed in various forms, as shown in Figs. 2.1. and 2.2.

Sources: En:former, 2023; Lewis, 2023; Aandslandscape, 2024; David Carroll, 2021; Garca, 2024; Qasim, 2023

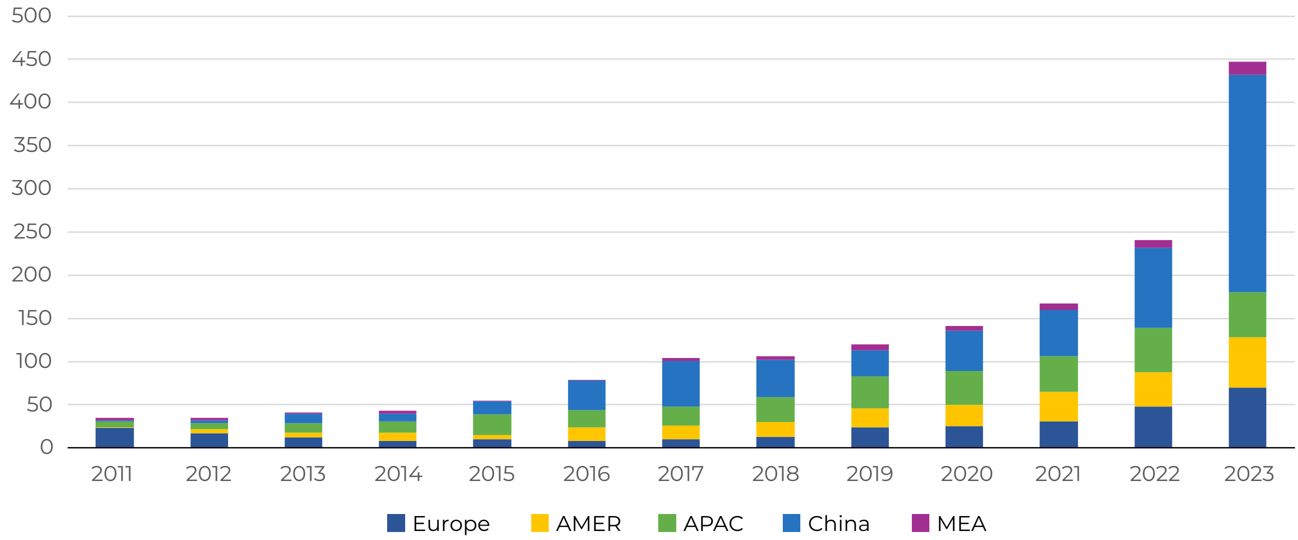
Fig 2.1. Installation of floating solar PV, road walls, building walls, fences, roofs, and canopies.

Sources: Spanne, 2022; BTN, 2024; Brusselstimes, 2022; Hislop, 2024; Maritime-Executive, 2024.

Fig 2.2. Installations of solar PV for light, pavement materials, vehicle materials, open spaces, and logistics vehicles.

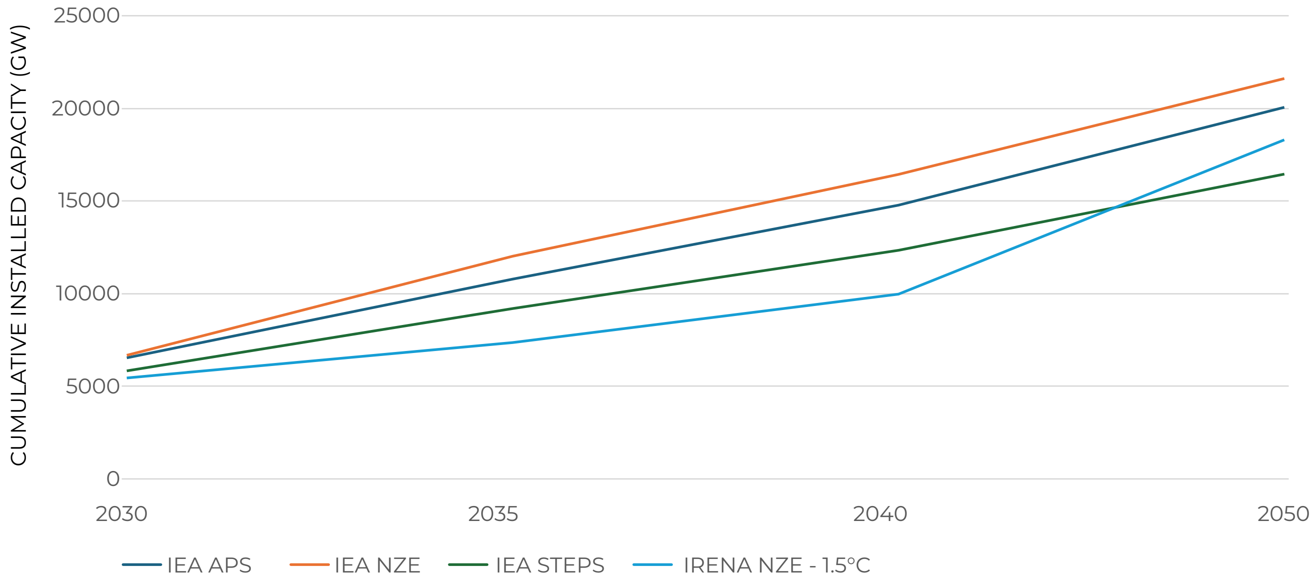
The global installed capacity for solar has reached 1.6 TW in 2023, with annual generated energy up to 1500 TWh (IEA, 2024a; ISES, 2024), with China dominating the growth, accounting for 57% of the total global installations. An additional 447 GW of solar power capacity was recorded globally in 2023, as shown in Fig 2.3., China's installed solar capacity has increased by 256 GW. The USA increased its solar capacity by 32.4 GW, representing a 48% increase compared to 2022. This addition increases the overall capacity to 173 GW, representing 6% of the USA's power consumption. In the EU, Germany added 15 GW of solar power. Japan has reached 90 GW of solar power capacity, which is equal to 12% of domestic power consumption (BGEN, 2024; Rueter, 2024). Solar power now accounts for 78% of all renewable energy capacity, a 12 % increase compared to 2022. This amount will continue to rise due to plans for additional installed capacity worldwide, with goals of 574 GW in 2024, 627 GW in 2025, and 880 GW in 2030 (Bellini, 2024; Solar Power Europe, 2024).

The anticipated demand for renewable energy, particularly through the utilization of solar PV technology, is expected to escalate further following the tripling of the renewable energy targets and associated investments established during COP28 and COP29. Subsequently, the solar PV installed capacity may reach more than 21,000 GW by 2050 worldwide, as the projected scenario of Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS), and NZE by the IEA and IRENA in Fig 2.3.



Source: Adapted from Solar Power Europe, 2024

Fig 2.3. Annual addition of installed solar PV capacity per year from 2011 to 2023



Source: Analysis adapted from IRENA, 2024a-b; IEA, 2024b

Fig 2.4. Projected cumulative installed capacity of solar PV from 2030 to 2050

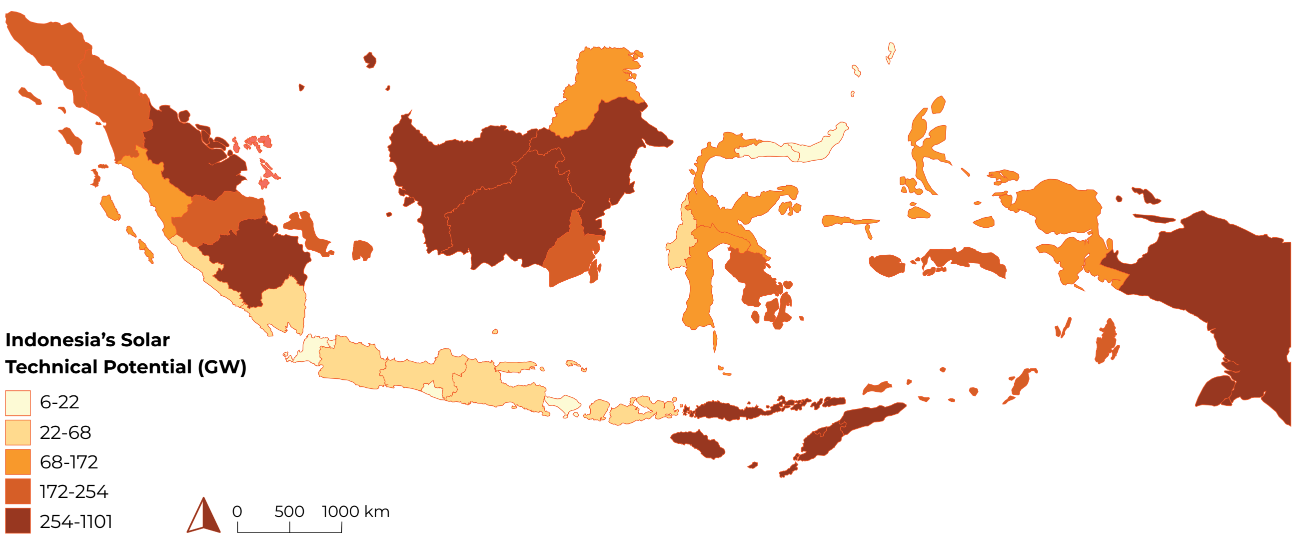
Table 2.1. The solar PV's adoption target by country

Country/Region	2030 target	Annual average solar capacity additions needed to hit 2030 target	Actual capacity additions of solar capacity in 2022
India	40% zero-carbon generation by 2030 (includes nuclear)	16 GW	2 GW
China	28% renewables by 2030	57 GW	55 GW
USA	739 GW of wind and solar by 2030 to reach zero-carbon electricity by 2035	34 GW	11 GW
UK	60% renewables by 2030	4 GW	4 GW
EU	REPowerEU: 42.5% renewables by 2030	38 GW	16 GW

Source:Selin Oğuz, S., 2023

As presented in Table 2.1, several countries have met or almost met their annual solar energy adoption targets. In contrast, some countries are still far from their targets and may experience obstacles in achieving them. This demonstrates that solar energy adoption is not easy, and many factors need to be considered to make it possible, including the domestic development of the solar PV manufacturing industry and its supply chain.

Indonesia participates in the solar energy ecosystem and is committed to steadily increasing its solar power capacity. By 2023, Indonesia had about 0.32 GW of solar power installed capacity, barely less than 0.01% of its entire solar potential of 3,294 GW (MEMR, 2023). Solar energy is predicted to overtake all other energy sources in Indonesia and is projected to reach at least 109.4 GW by 2060, according to the Official 2024 RUKN, as explained in Sub-chapter 1.b. (MEMR, 2024). Referring to the JETP CIPP document, solar power is targeted to reach at least 29 GW by 2030 (JETP Indonesia, 2023). This amount exceeds the long-term Electricity Business Plan (Rencana Usaha Penyediaan Tenaga Listrik/RUPTL) of Indonesia, which projects a cumulative addition of 4.7 GW of installed capacity by 2030 under the Greenest 2021-2030 RUPTL or 16.5 GW by 2040 under Accelerated Renewable Energy Development (ARED) scenario in the Beyond the Greenest 2024-2040 RUPTL (PLN, 2024; Koons, 2024). With an average daily solar irradiation of 4.5 to 5.5 kWh/m² and global horizontal radiation (GHI) of 4.8 kWh/m2 (Sugihartono, 2024; Business Indonesia, 2024), the solar potential is spread evenly across the nation (Fig 2.5.).

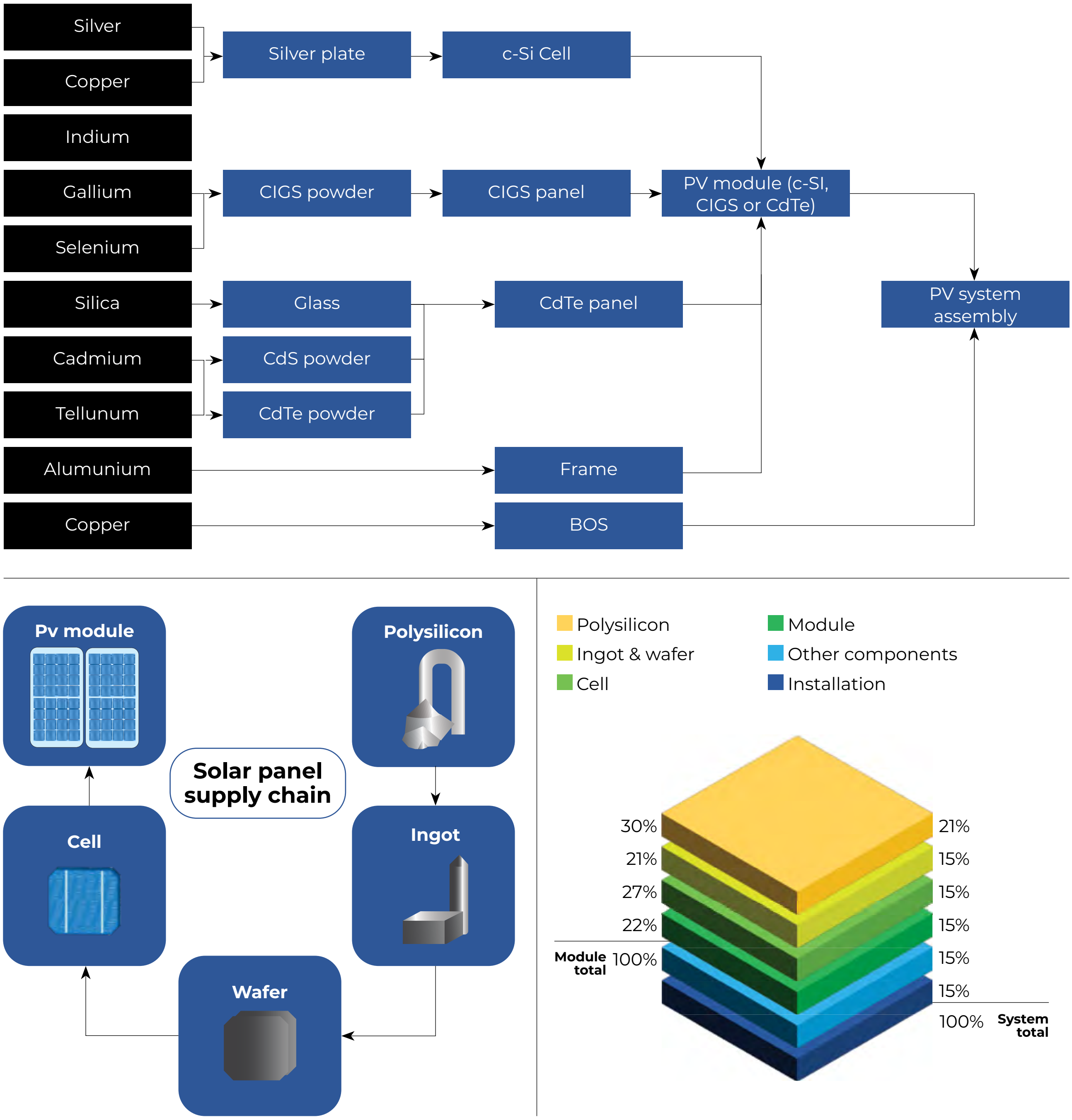


Source: Adapted from Beyond 433 GW IESR, 2021

Fig 2.5. Distribution of solar power potential in Indonesia, Beyond 433 GW IESR

The manufacture of solar PV is a complex process that includes many steps, from the extraction of raw materials to the creation of wafers, cells, and modules, as illustrated in Fig 2.6. Solar cells, which are responsible for transforming the energy of the sun into usable electricity, are the most critical element of a solar panel (Almerini, 2025). Currently, approximately 95–97% of solar cells are made from crystalline silicon (c-Si), the most widely used semiconductor material (DOE, 2025; IEA, 2025). This market is dominated by monocrystalline silicon and polycrystalline silicon technologies. The remaining market share consists of thin-film technologies, such as cadmium telluride (CdTe) and copper indium gallium (di)selenide (CIGS) (Brian, 2023; UTS, 2019).

The solar PV manufacturing process commences with the production of silicon crystals, which are shaped into ingots, sliced into thin wafers, and then modified to generate an electrical field (Cao, 2024). In the following process, metal conductors are added, and the solar cells are assembled into a complete solar panel. The panel is then encased in a durable glass shell for protection (Cao, 2024). Throughout the production process, the materials used to construct the panels are inspected for flaws. Defects have a significant impact on solar PV performance. Hence, product quality must be ensured and quality control is strictly enforced throughout the process to guarantee efficiency and longevity.



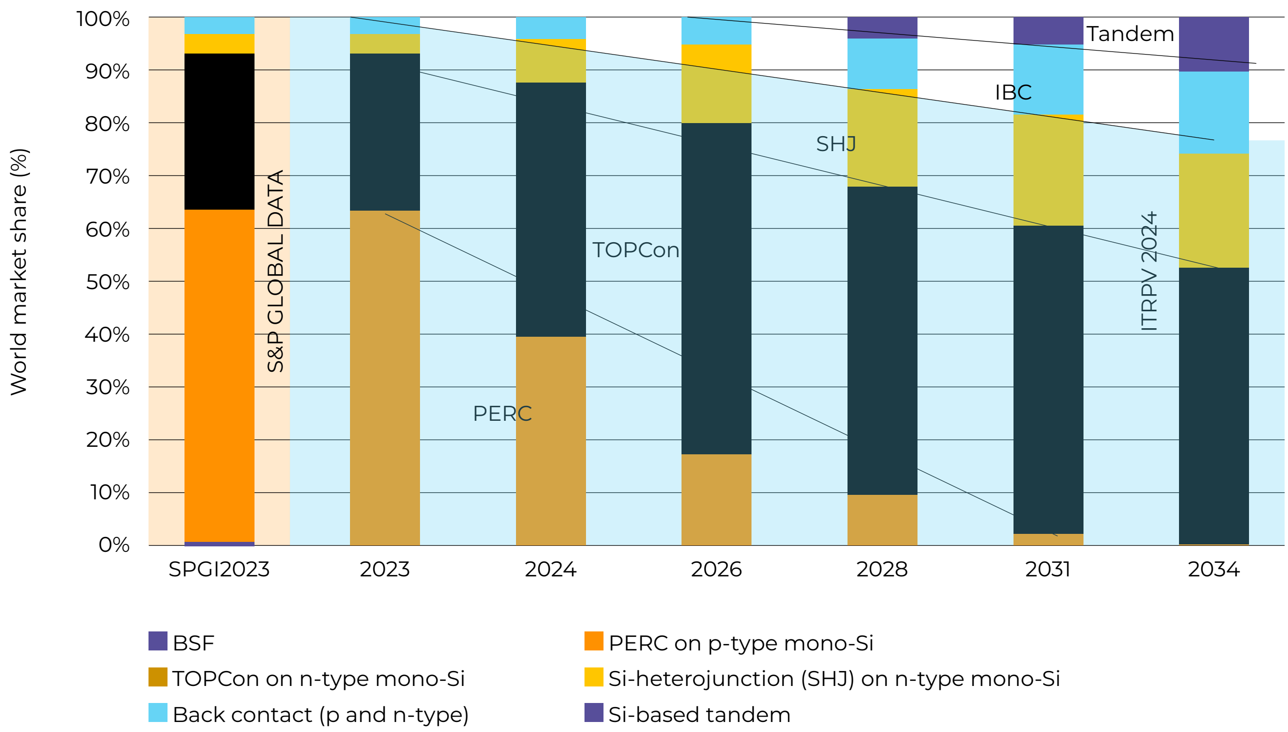
Source: Analysis adapted from Eitrawmaterials, 2020; Giurco et al., 2019; Greenrhin https://www.greenrhinoenergy.com/solar/industry/ind_valuechain.phpoenergy, 2024

Fig 2.6. Typical material compositions (left) and components (right) of solar PV

In terms of efficiency, solar PV has significantly improved, rising from around 15% in 2010 to 19–26% for most modern monocrystalline panels (Smith, 2024; SNP, 2024). Alongside these advancements, the industry is undergoing a transformative shift from P-type to N-type solar PV technology. P-type solar cells approach their efficiency limits with P-type PERC efficiency of up to 23.6%. Meanwhile, N-type innovations are emerging as the next step forward, with N-TYPE Topcon reaching 26.6% (Intersolar, 2023; Trina Solar, 2024; Shaw, 2024). Both N-type TOPCon and P-type PERC solar cells are engineered to have extended operational lifespans up to 25-30-year warranties from manufacturers (SNP, 2024). Other than that, heterojunction (HJT) solar PV or silicon heterojunction (SHJ) have efficiency of up to 24.7%, black contact of up to 25.6%, and Si-tandem of up to 24.5% (VDMA, 2024; Bhambhani, 2024).

In 2022, P-type PERC cells dominated with almost 60% market share, while N-type TopCon captured about 35% (IEA, 2025). According to International Technology Roadmap for Photovoltaic (ITRPV) study, as shown in Fig 2.7., N-type TOPCon is predicted to surpass P-type PERC, reducing P-type PERC's market share from 63% in 2023 to 40% by 2024 and nearly less of 10% by 2028. Meanwhile, N-Type TOPCon is expected to account for 49% of the market in 2024 and may reach 50% market share by 2034. Lastly, by 2034, Si-tandem is expected to achieve a 10% market share, up from 0.1% in 2026.

Trend: share of cell technology



Sources: Nedo, 2024; Estébanez, 2024 adapted from VDMA, 2024

Fig 2.7. Projection of solar PV market share from 2023 to 2034 by technology

Material composition for solar PV may vary depending on the technology. Glass is the main component of every type of solar PV, with a composition range of 55-97%, followed by polymers with a composition of around 3-18%. In addition to these two common materials, the other materials used depend on the type of solar PV technology, as summarized in Table 2.2. Further, there is a global effort to make solar PV last up to 50 years to reduce the required materials consumption (Santos, 2022; Dreves, 2022).

Table 2.2. The typical solar PV's material composition

No	Material	Share in solar PV (w/w%)		
		Crystalline silicon (c-Si) PV	CdTe	CIGS
1	Glass	54.70-80	96-97	88-89
2	Polymer	6.68-18.45	3-4	4
3	Alumunium	8.12-22.01	-	7
4	Silicon	1.82-5.00	-	-
5	Copper	0.56-3.89	-	-
6	Silver	0.006-0.12	-	-
7	CdTe	-	<1	-
8	CIGS	-	-	<1
9	Others	0.03-0.3	-	-
Authors adapted from:		Mulazanni et al., 2022; Giurco et al., 2019; UTS, 2019	Giurco et al., 2019; UTS, 2019	Giurco et al., 2019; UTS, 2019

The solar PV system needs another main component, such as energy storage and an inverter, as explained in its future trend (Fig 2.8.). Energy storage media will be increasingly popular to alleviate the intermittency of solar energy supply in solar rooftop applications. Energy storage usage will increase from 30% in 2023 to almost 65% in 2034. In the meantime, string inverters will become more popular than the central inverter type for systems larger than or equal to 10 MW. It will slowly rise from 60% in 2023 to almost 66% in 2034. Knowing these trends will help in the future adoption rate of solar PV. This information provides insight into the fact that a solar PV system, which supports supply stability, would be highly desirable in minimizing the potential risk of an energy crisis.

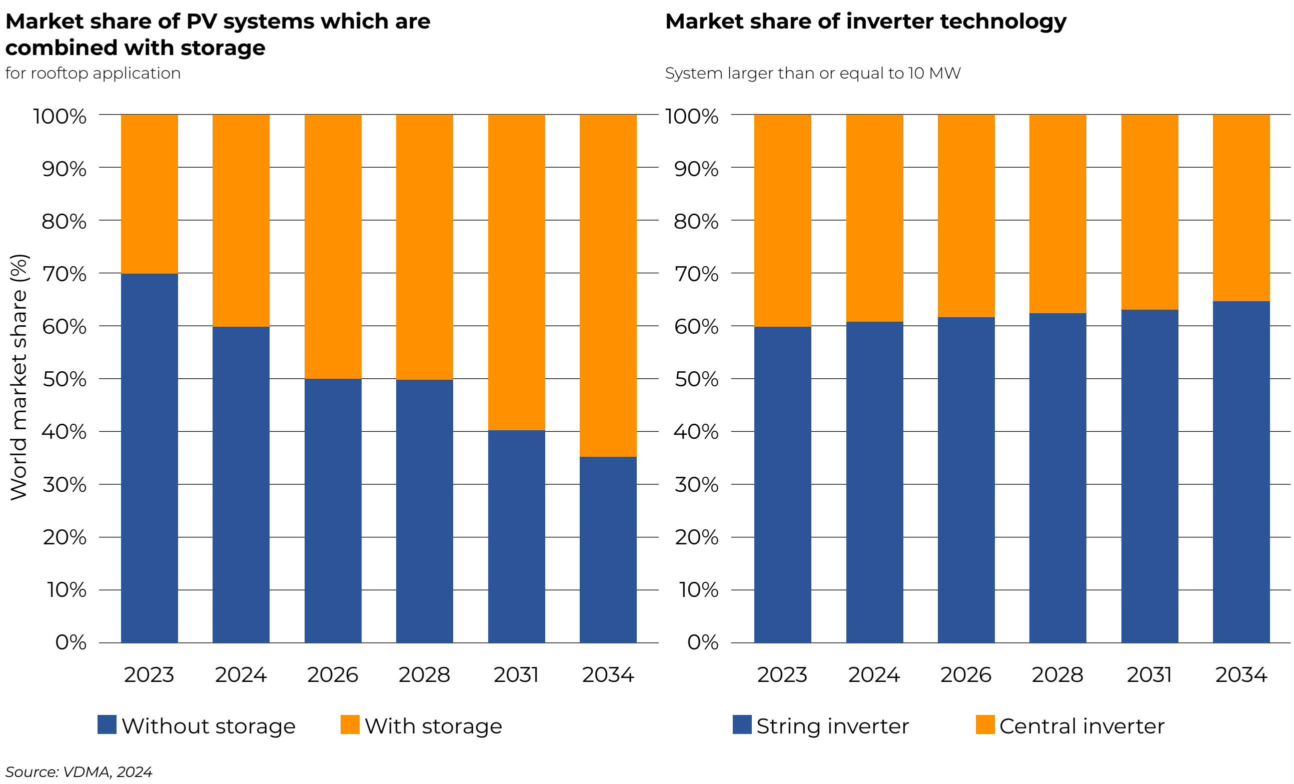


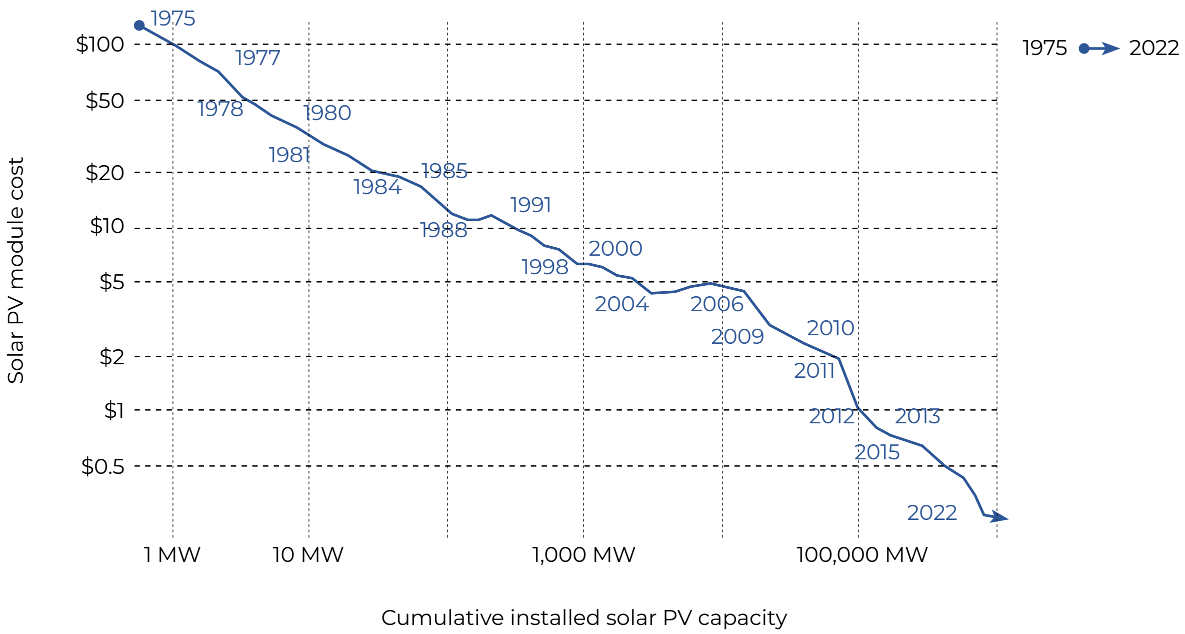
Fig 2.8. Market share of PV system combined with storage for rooftop application (left) and PV system combined with inverter type of string or central for system larger than or equal to 10 MW (right)

B. Investment and projection over the supply chain for solar PV

Solar PV technology is a rapidly expanding industry with the development of the global solar PV market value is estimated to reach USD 171.08-253.69 billion in 2023, and to grow to USD 436.36 billion by 2032 at a 6% CAGR (FBI, 2025; Precedence research, 2025; SNP, 2024). It is estimated that the global market size of important solar PV components in 2023 is as follows: polysilicon (USD 11.5-37.31 billion; Precendence Research, 2025; GVR, 2024); silicon wafer (USD 12.2-17.3 billion; Imarc, 2024; GII, 2023); and solar cell (USD 116-127.5 billion; GVR, 2024; GNW, 2024). It is anticipated that the market value will rise steadily in tandem with the growing demand for the use of solar energy worldwide.

The huge drop in the price of clean energy over the last few decades has been one of the most critical changes in technology, as shown in Fig 2.9. In the past ten years, the price of solar PV has dropped by 90%. Further decline in 2023 is due to global oversupply, which also undermines the manufacturing industry in many countries, including the USA and EU (Kuwait Times, 2024; BNE Intellinews, 2024; Hayley, 2024).

Solar panel costs have fallen by around 20% for every doubling of global cumulative capacity
Costs are measured in US dollars per Watt, adjusted for inflation

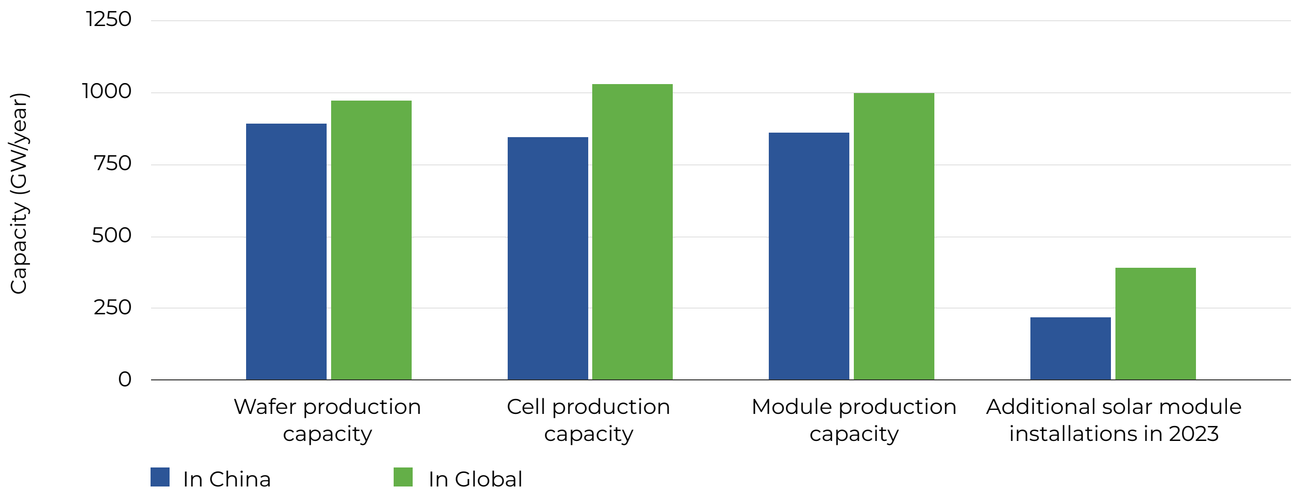


Source: Our World in Data, 2024

Fig 2.9. Solar PV module cost in comparison to cumulative installed solar PV capacity, 1975-2022

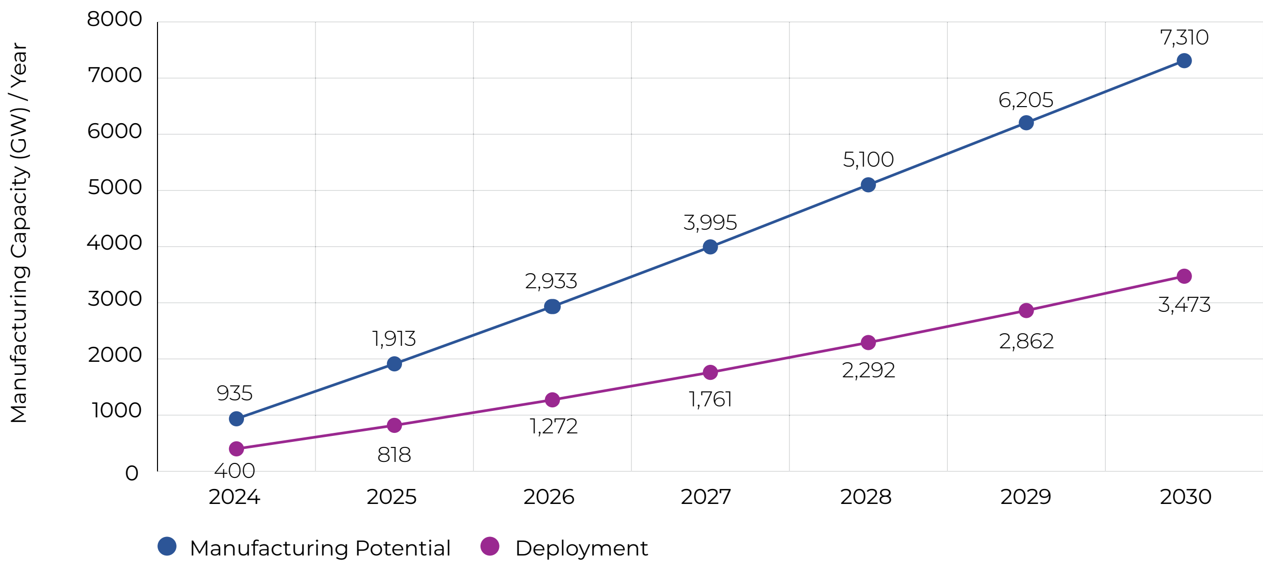
The supply chain for solar PV is heavily reliant on China. Seven of the top ten producers of polysilicon, including the top three, are based in China. China is forecasted to have more than 80% of the global production capacity for polysilicon, wafers, cells, and modules in 2023-2026 (Wood Mackenzie, 2023). In 2021, China produced 79.4% of the polysilicon, 75% of the modules, 85% of the cells, and an astounding 97% of the wafers. Xinjiang Uyghur Autonomous Region (XUAR) is responsible for over 54% of China's polysilicon production.

China's yearly manufacturing capacity for completed solar modules was 861 GW by the end of 2023, more than double the 390 GW of module installations worldwide, as depicted in Fig 2.10. Similarly, China's manufacturing capacity for wafers and cells also follows the same trend as its solar modules. Lastly, by 2026, it is predicted that China's solar PV module manufacturing capacity will reach 1,687 GW, or 80% of global production capacity (Wood Mackenzie, 2023). Additionally, it is projected that the dominance of the Chinese solar PV manufacturing sector will cause the surplus capacity of solar PV production to reach 4TW in 2030, as shown in Fig 2.11. (Casey, 2024; Ember, 2024; Intellinews, 2024).



Source: Analysis adapted from Reuters, 2024; ADB, 2023; Gunawan, 2024; Sinovoltaics, 2024; Energy Trend, 2024; Hayley, 2024; Indrawan, 2024; ISEO-IESR, 2024

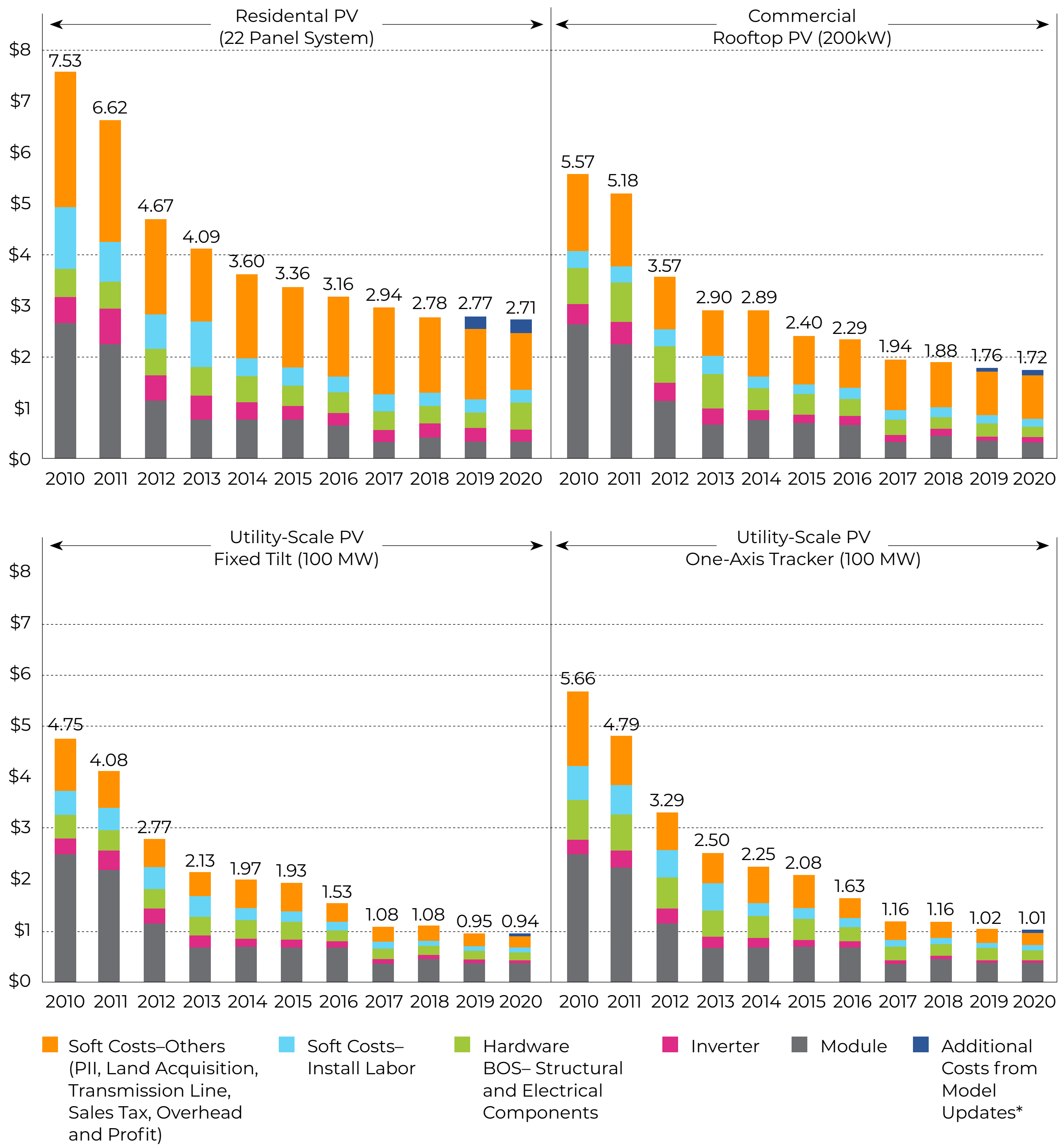
Fig 2.10. Status of the solar PV manufacturing industry in China compared to global solar PV installed capacity at the end of 2023



Source: Analysis adapted from Casey, 2024; Ember 2024; Intellinews, 2024

Fig 2.11. Global cumulative capacity addition manufacturing vs, deployment of solar PV

To address the demand for solar energy, five categories of market elements are essential: the solar PV module, the inverters, the installation labor, the soft costs, and the balance of system (BoS). The solar PV module compositions and components are already depicted in Fig 2.6. while soft costs include engineering, construction, and logistics. On the other hand, BoS comprises of financing, contingency, and warranty. Although each component's cost may vary, the solar PV module accounts for 34-45% of the total cost, with inverter for 7-14%, installation labor for 10-20%, the BoS for 8-29%, and soft costs for 17-44% (ISEO-IESR, 2024; E-greenelectrical, 2024; Holler, et al., 2019). Fig 6.9. shows the specific share value for this study. These five categories of market elements (solar PV module, the inverters, the installation labor, the soft costs, and the BoS) must be taken into account, as they may have been generated domestically to bolster the Indonesian economy and energy security. Moreover, Indonesia is projecting itself to use solar energy as one of the largest renewable energy domestically. Regardless, the costs arising from the value of global solar PV installation projects are decreasing, as presented in Fig 2.12.

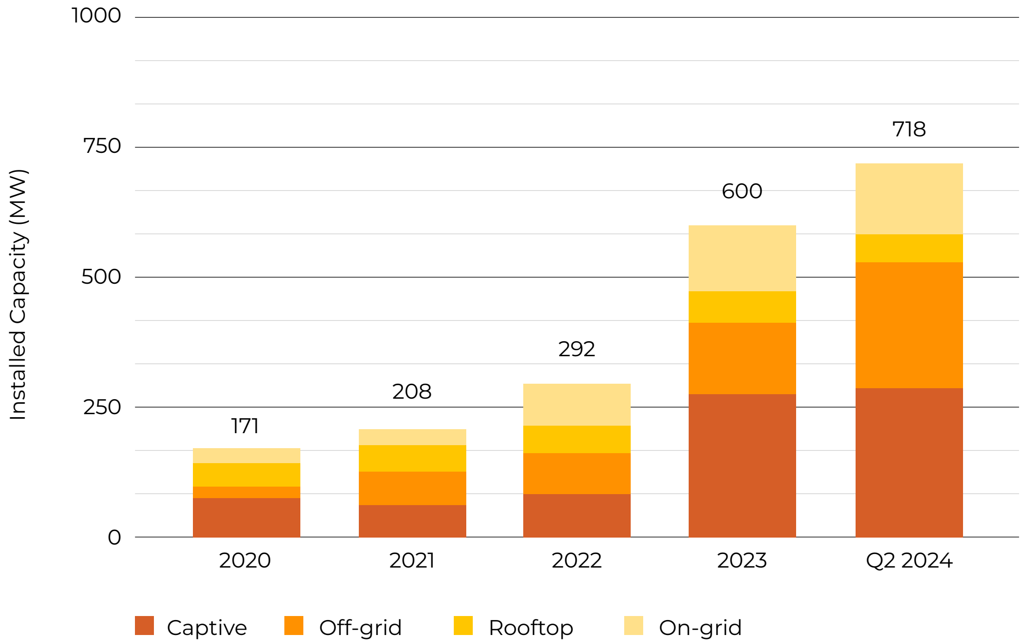


Source: NREL, 2021

Fig 2.12. The expense of global solar technology is consistently decreasing in residential (top left), commercial (top right), and utility-scale PV systems (bottom left and right), mostly due to enhanced module efficiency and reduced hardware and inverter costs

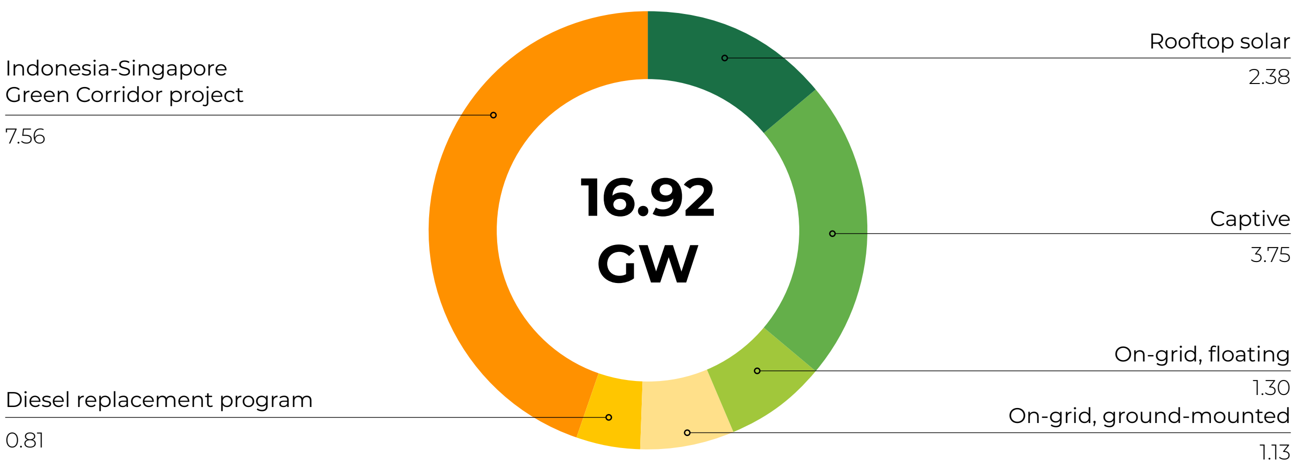
C. Domestic manufacturing status and development of solar PV

Indonesia's solar PV manufacturing industry has begun to develop and has tremendous potential for further development in the acceleration of solar energy adoption. The Indonesia's installed solar energy capacity by August 2024 barely reaches 718 MW, as shown in Fig 2.13., with the most significant contribution, 285 MW, caming from on-grid (PLN) installations, which include the recently implemented 145 MW Cirata floating solar (ISEO-IESR, 2024). This number is still not in line with the target of the RUPTL 2021-2030, where cumulative solar energy should reach 1.7 GW by 2023 and 4.7 GW by 2030 (PLN, 2021). Moreover, this shows extensive work to achieve the new target of installed solar energy capacity of reaching at least 109.4 GW by 2060 according to the Official 2024 RUKN, as explained in Sub-chapter 1.b., even when compared to the initial draft of the RUKN target before it was officially published, which had a bigger target of 451 GW (MEMR, 2024).



Source: ISEO-IESR, 2024

Fig 2.13. Solar power capacity in Indonesia, 2020-Q2 2024



Source: ISEO-IESR, 2024

Fig 2.14. Projects of announced solar power capacity in Indonesia

Efforts to increase the adoption of solar PV can be seen by the announcement of 16.92 GW of solar power projects by August 2024 (Fig 2.14.). The presence of domestic sector demand, backed by the existence of domestic manufacturing industry, would allow for major adoption and notable reciprocal expansion of the domestic manufacturing industry for national energy security.

The solar PV manufacturing ecosystem has developed quite rapidly in Indonesia and several Southeast Asian countries. This occurred due to the fact that the tropical climate of Southeast Asian countries is particularly conducive to power generation from solar energy. In the adoption of solar energy, Vietnam has the highest installed capacity, reaching 13 GW by 2023, followed by the Philippines with 2.34 GW, Malaysia with 1.58 GW, and Thailand with 1 GW (GEM, 2024).

Table 2.3. Operating and prospective of solar energy in Indonesia and Southeast Asia in 2023

No	Country	Operating installed capacity of solar energy (GW)	Prospective (in planning) of solar energy (GW)	Total technical potential (GW)
1	Vietnam	13.04	10.20	1,646
2	Thailand	1.04	2.70	300
3	Philippines	2.34	36.59	122
4	Malaysia	1.58	2.37	269
5	Cambodia	0.43	2.47	8.1
6	Myanmar	0.19	0.34	35
7	Singapore	0.19	0.62	8
8	Indonesia	0.72	16.92	3,286
9	Brunei Darussalam	0.00	0.30	-
10	Laos	0.00	0.30	-
11	Timor-Leste	0.00	0.00	-

The solar PV supply chain manufacturing industry in Southeast Asia is well developed, as presented in Table 2.4. Several countries that have a substantial installed solar energy capacity are generally supported by a more robust manufacturing sector. For instance, Vietnam has a solar PV module manufacturing industry exceeding 48 GW, although cell manufacturing and wafers are still at lower capacity. Malaysia and Thailand, on the other hand, have solar PV module capacities of 15 GW and 10 GW, respectively. The Philippines is an example of a nation that has adopted solar energy more widely than Indonesia despite having a less established industrial sector.

In cases where a well-established manufacturing industry is lacking, there is often greater potential to promote renewable energy deployment through supportive policies along with a supportive ecosystem. However, due to regulatory inconsistencies, Indonesia faces significant challenges in developing its solar PV manufacturing ecosystem, as the regulation itself hinders the ecosystem.

Despite both countries having similar developing infrastructure, the Philippines' higher solar PV installed capacity than Indonesia is largely attributed to the country's supportive regulatory environment and strong near-term renewable energy targets. Similarly, Vietnam stands out in the region as the only country to achieve a 'high' score on the World Bank's Regulatory Indicators for Sustainable Energy (RISE) for renewable energy (ADB, 2023). These examples highlight how consistent and encouraging regulations, along with a supportive ecosystem, can drive increased renewable energy adoption. In the region, there are at least three main archetypes of producing countries (Searemi, 2023):

a. Established producers: capable of meeting both domestic and international demand. The examples are Vietnam, with global supply share of 5%, Malaysia of 4%, and Thailand of 2%.
b. Export-oriented: specialize in international markets (e.g., Cambodia). Cambodia's majority of production is exported to the USA market.
c. Focused on the domestic market. Indonesia is an example of a country that is meeting national objectives by fulfilling local demand for local content requirement (LCR) products.

Table 2.4. Solar PV component manufacturing capacity of Southeast Asia, China, and global in 2023

Location	Manufacturing capacity	Manufacturing capacity (GW/year)		
	Polysilicone production (mt)	Wafer production	Cell manufacturing	Module assembly
Indonesia		-	6.50	4.70
Malaysia	0.14	6.60	20.00	15.00
Singapore	-	-	1.00	2.00
Thailand	-	5.00	14.00	11.00
Vietnam	-	10.00	32.45	48.33
Philippines	-	1.00	-	-
China	2,100.00	892.00	844.00	861.00
Gobal	**2,256.00**	**974.20**	**1,032.00**	**~ 1,000**

Source: Analysis adapted from Sareami, 2023; Gunawan, 2024; Sinovoltaics, 2024; Energy Trend, 2024; Hayley, 2024; Indrawan, 2024; ISEO-IESR, 2024

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3 An overview of wind energy and its future projections

A. Wind energy's technology overview and its supply chain

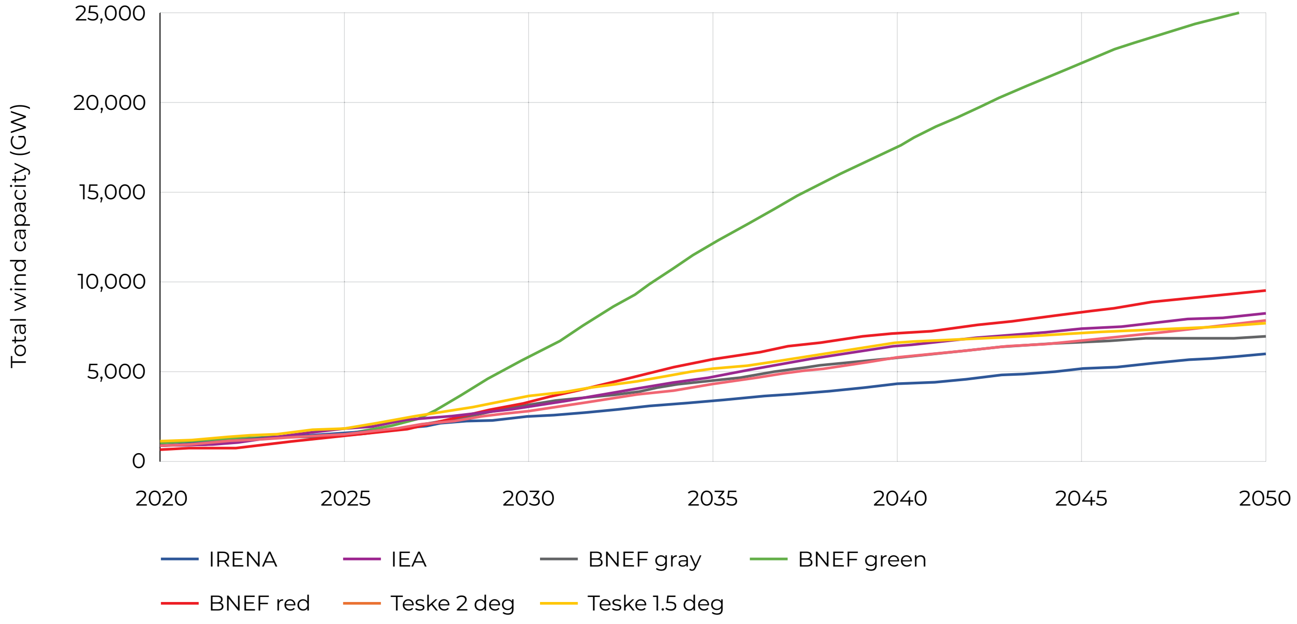
Similar to solar energy, wind power can be harnessed at dimensions ranging from micro to gigascale. Wind turbines employ mechanical power from wind energy to operate a generator, which produces clean electricity without burning any fuel or contaminating the air. Wind turbines may be found on hills, mountains, deserts, buildings, parks, vacant ground, coastal areas, water areas, and offshore, as seen in exemplary Fig 3.1. Utilization of wind turbines can be applied in both sparsely populated and densely populated areas by considering the scale of electricity generation capacity and the level of noise produced. Wind power still has a wide area of coverage and the potential to be used anywhere to produce electricity from renewable energy.

Sources: Koreatechdesk, 2018, Altenergymag, 2019; World record academy, 2023; Forbes, 2017; The Eco Experts, 2024
Note: Some forms of wind turbine applications are used in harvesting wind energy which also can provide functions of aesthetics, fences, security, and direct use with battery for lightning.

Fig 3.1. The use of wind turbines in various applications ranging from open spaces, highways, and building roofs

The total installed capacity of global wind power generation by June 2024 has reached almost 1.1 TW, with annual generated energy of up to 2300 TWh (WWEA, 2024; Our World in Data, 2024; Ember, 2024). Thus, approximately 7.8% of the world's electricity was generated by wind power in 2023, nearly double that of 2015 (Ember, 2024). By 2023, the leading three nations in wind energy generation are China, producing 885.9 TWh (39%), the USA with 425 TWh (18.5%), and Germany with 137 TWh (6%)—together accounting for almost half of the worldwide power output from wind energy (Our World in Data, 2024).

According to the IEA, wind power must be prioritized in the development of low-carbon emission energy and become a cornerstone of national and global electricity (IEA, 2024) due to its ease of installation with or without requiring a special area that sacrifices productive land. For limiting global warming below 1.5°C, it is estimated that wind energy will have to contribute between 7,900-25,000 GW by 2050 or equal to at least 3.4-10.7 times capacity in 2023 (minimum average growth rate of 4.7%/year until 2050).



Source: DOE, 2022a

Fig 3.2. Projection of global wind capacity under multiple scenarios

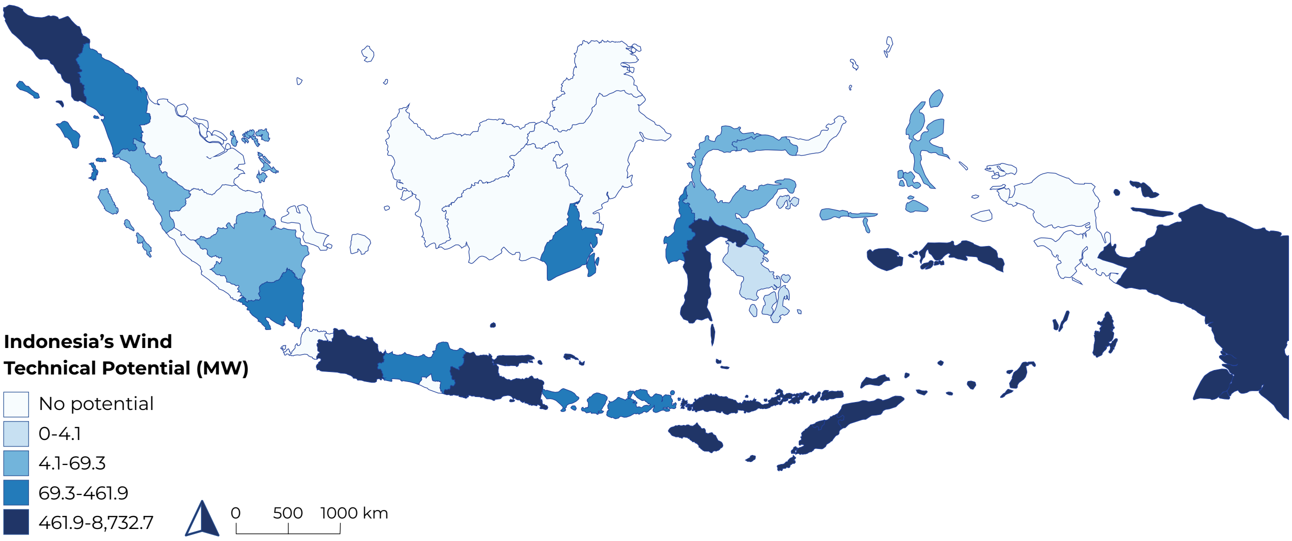
In its realization, several countries have issued 2030 targets for adopting wind energy. Some countries have difficulty in increasing targeted wind energy adoption, as shown in Table 3.1., where the annual increase in wind energy capacity is below what it should be based on the actual realization in 2022. The gap shows the potential increase of wind technology demand towards 2060.

Table. 3.1 Comparison of the target and actual wind energy adoption rates

Country/ Region	2030 target	Annual average solar capacity additions needed to hit 2030 target	Actual capacity additions of solar capacity in 2022
India	40% zero-carbon generation by 2030 (includes nuclear)	16 GW	2 GWchapter
China	28% renewables by 2030	57 GW	55 GW
USA	739 GW of wind and solar by 2030 to reach zero-carbon electricity by 2035	34 GW	11 GW
UK	60% renewables by 2030	4 GW	4 GW
EU	REPowerEU: 42.5% renewables by 2030	38 GW	16 GW

Indonesia's wind energy potential is estimated at 155 GW, consisting of 39% onshore wind and 61% offshore wind. However, less than 0.1% of wind energy potential capacity—only 154.3 MW—is now being used (MEMR, 2024a). The Indonesian government plans to raise the installed capacity of wind power facilities to 73.2 GW by 2060 under the Official 2024 RUKN target with an initial step of incorporating 5-7 GW capacity until 2030, as explained in Sub-chapter 1.b. (MEMR, 2024b).

On average, the wind speeds in Indonesia vary from 1.3 to 6.3 m/s. Around 40% of Indonesia's total wind potential is thought to be found in the country's eastern provinces, which include Maluku, Papua, and Nusa Tenggara, with average wind speeds exceeding 5 m/s (Energy Tracker, 2024; Hartatika, 2024).

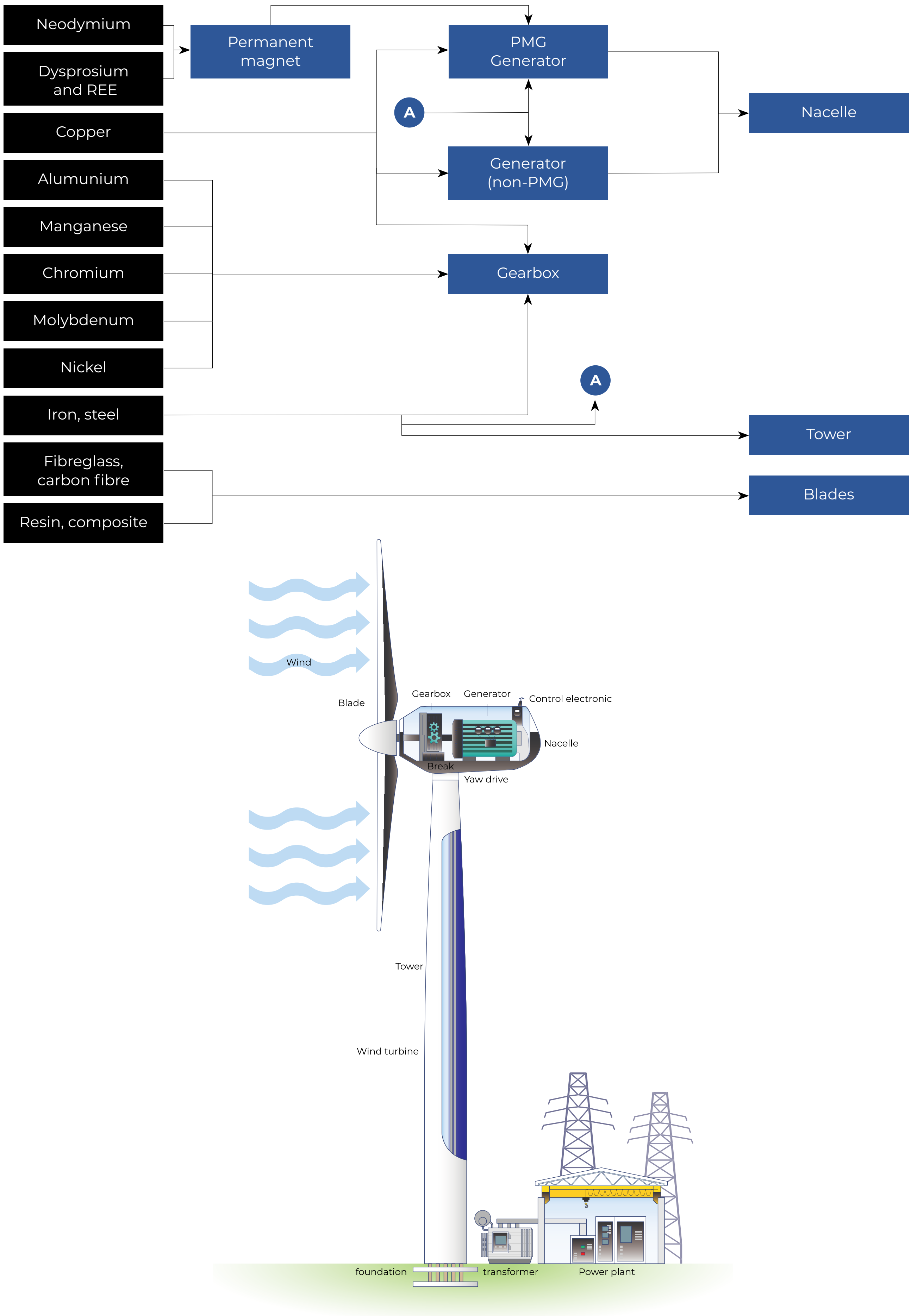


Source: Adapted from Beyond 433 GW IESR, 2021

Fig 3.3. Indonesia's wind energy technical potential

The manufacturing of wind turbines is a critical focal point in ensuring reliable energy supply and maintaining affordable power rates. The wind turbine is a key technology for wind energy harvesting. The wind turbine generates renewable electricity by capturing the kinetic energy of the wind and converting it into rotational energy through its system placed in a nacelle consisting of rotor blades, shafts, and gearboxes, which drive the generator to produce electricity. A typical wind turbine consists of the following major material compositions and components (Fig 3.4.):

- The rotor-blade system: canopy, blades, and hub
- The nacelle system:
    - Nacelle and drive train system: nacelle house, low-speed shaft, high-speed shaft, gearbox, bearing, coupling and brakes, generator, and power electronics (cables, busbars)
    - The gear box-control system: pitch motor and gear, the yaw drive and motor, gear and brake, and sensor (anemometer, wind vane).
    - The generator
- The tower system: the turbine's structure is supported by the tower, which is constructed from tubular steel or another material.
- The foundation and support system: foundation, lightning protection, and other structural systems (platforms, ladders).



Source: Analysis adapted from Eitrawmaterials, 2020; DOE, 2022b; USGS, 2024; De Simone, 2024

Fig 3.4. Typical material compositions (left) and components of wind turbine (right)

Wind turbines go through a complex and multi-material production process that contains more than 8,000 parts and has a lifetime of 20-30 years (DOE, 2024). Replacements and repairs are common when a component has finished its operational lifetime or has severe wear and tear. Consequently, the accessibility of raw resources, including minerals and materials, must be considered in the expansion of the wind turbine manufacturing industries.

The wind turbine's base and tower are the main parts that contribute to its total weight. The remaining components make up another 10%. More than 96% of wind turbines are made of recyclable materials. Their outside shell, shafts, gears, and electrical components are mostly comprise of recyclable polymers and valuable metals like copper, aluminum, and steel (National Grid, 2024). The use of typical materials is summarized in Table 3.2.

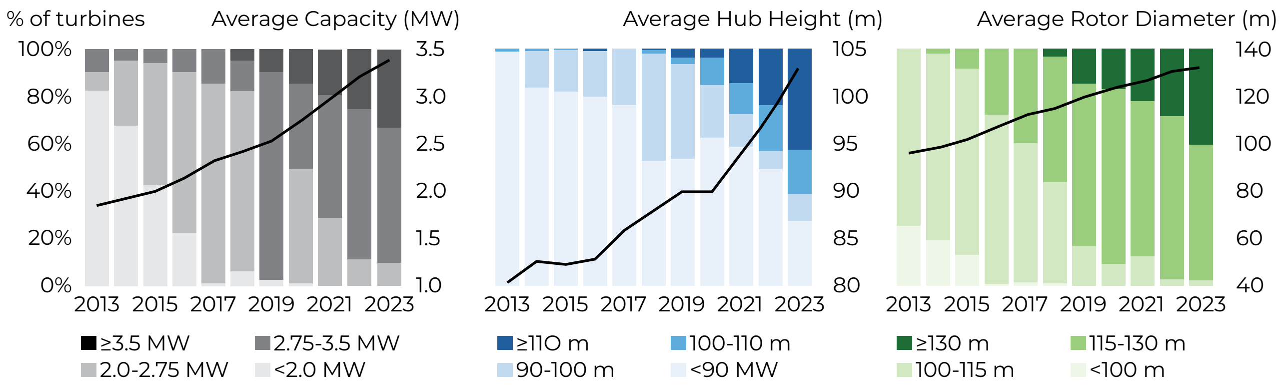
Table 3.2. The typical wind turbine's material composition

No	Material	Share in wind turbine (w/w%)					
		Onshore					Offshore
1	Steel	66-79	66	88	87	83-88	82
2	Iron or cast iron	5-17	16		1.5		
3	Fibreglass, resin, or plastic	11-16	14	0.3	10.6	2.6-4.7	0.9-1.5
4	Glass, carbon fibre, or composite					6-9	7-10
5	Copper	1	1	2.7	0.4	0.6	0.9-1.5
6	Aluminum	0-2	2	0.7	0.5	2	2
7	Others		2	8.3	1.5	-	-
Authors adapted from:		USGS, 2024; Vvcresources, 2024; Power-technology, 2024	University of Gävle, 2015;	Clean Power, 2024; Tota-Mahara, 2020	Nordex Delta4000, 2025	De Simone 2024	De Simone 2024

Out of various wind turbine blade types, horizontal axis wind turbines (HAWT) are the most frequently employed as opposed to vertical axis wind turbines (VAWT). VAWT is susceptible to external factors that affect reliability and lifespan, has a complex structure, and has a reduced efficiency (60%-80% of HAWT). Additionally, it has a higher power generation cost (20%-30% higher than HAWT) (ELGE, 2024; Winslow, 2017). However, VAWT will be touted as a cheap microgrid power source, so its market is predicted to continue to grow, especially in Asia. The continual growth of VAWTS is due to the fact that VAWTs are capable of operating in a variety of conditions, including turbulent wind flow, and can be scaled down to be placed on urban rooftops with minimum noise. Additionally, they require no robust supporting structures, which results in lower production and maintenance costs (Peimani, 2021).

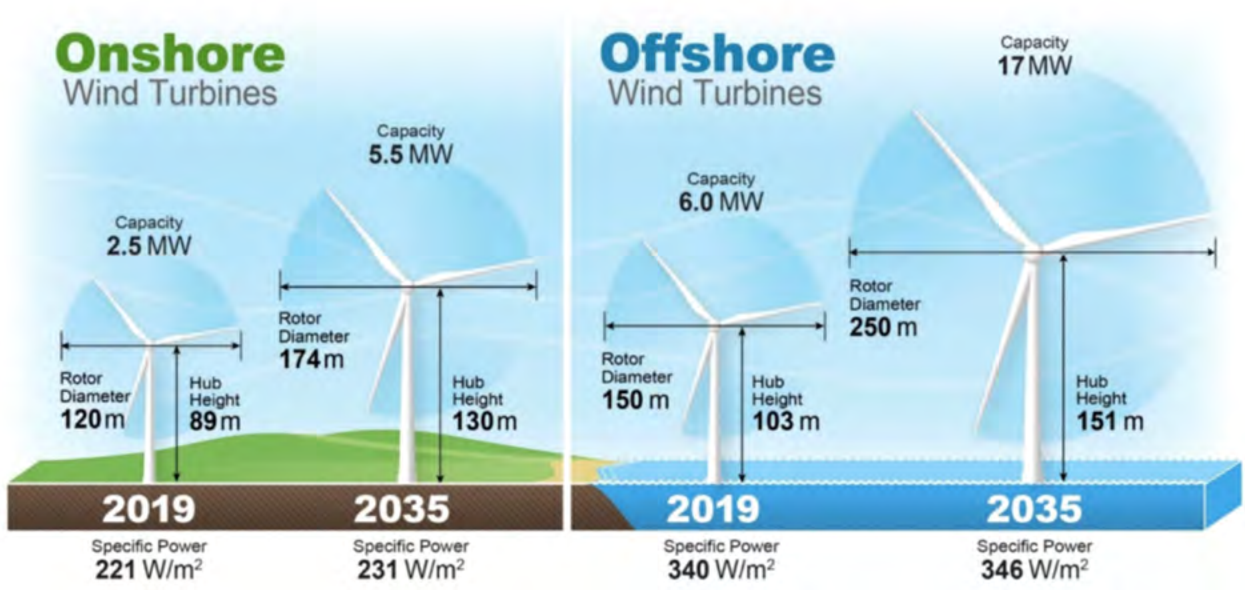
Global wind energy adoption is still dominated by onshore wind energy, despite offshore wind energy gaining popularity recently. Onshore wind energy capacity accounted for 92.9% of global installed wind energy capacity in 2022, down from 98.49% in 2010 (Tumse et al., 2024). Offshore wind capacity has increased year after year as a result of stronger, more consistent winds and simplified large turbine component assembly. By 2050, onshore wind is expected to account for 75% of total wind energy production, fixed offshore wind for 22%, and floating offshore wind for 3% (DNV, 2025).

For onshore wind turbines, an increase in generator ratings is anticipated, increasing from an average of 2.5 MW in 2019 to 5.5 MW by 2035. Similarly, offshore wind turbines are projected to increase in size from an average of 6 MW in 2019 to 17 MW by 2035 (LBL, 2021). This increase is shown by the fact that there were more onshore turbines with a hub height of 110 meters or higher, from 4% in 2020 to 42% in 2023 (LBL, 2024). In the end, progress is still being made toward bigger rotors, which also increase their capacity. This includes increasing the sizes of the blades, the hub, the tower, and the materials used to build the supports for them. Additionally, floating offshore wind is expected to increase its market share, growing from its current pre-commercial phase to representing up to 25% of new offshore wind projects by 2035 (LBL, 2021a).



Source: LBL, 2021a

Fig 3.5. Trends in the development of turbine capacity, hub height, and rotor diameter from 2013 to 2023



Source: LBL, 2021

Fig 3.6. Future technology trends of onshore (left) and offshore (right) wind turbines in capacity growth

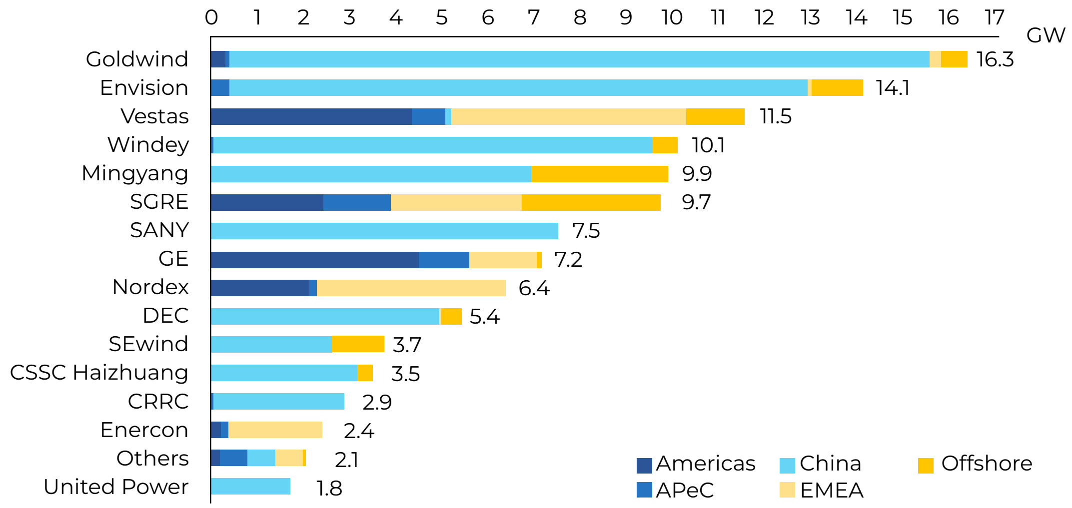
B. Investment and projection over the supply chain of wind turbine

As one of the popular key renewable energy technologies, wind turbine technology continues to grow. The global wind turbine market size is estimated at USD 139 billion in 2023, with Asia Pacific holding the highest market share of 59%. The global market is expected to grow to USD 149.98 billion in 2024 and USD 318.02 billion by 2034, growing at a CAGR of 7.81% (PR, 2024b). The biggest record annual global order intake in 2023 was 100 GW of wind turbines by the Chinese market, while Western markets ordered 55 GW (WoodMac, 2024).

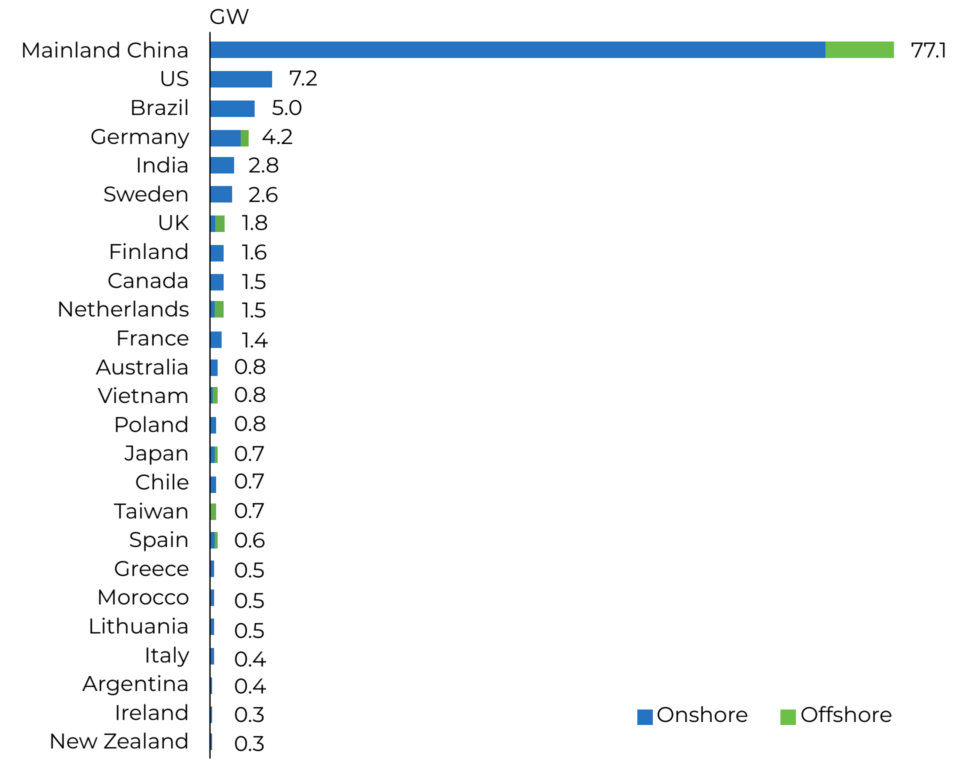
It is estimated that global market size of important wind turbine components in 2023 are as follows: nacelle (USD 22.3 billion; PRnewswire, 2024); gearbox (USD 22.27 billion; FBI, 2024a); control system (USD 9.1 billion; SR, 2023); tower (USD 27.78 billion; GVR, 2024); rotor blade (USD 21.48 billion; PR, 2024b); foundation (USD 9.32 billion; FBI, 2024b). The market value is expected to continuously grow along with the increasing demand for global wind energy adoption.

In 2023, 23,833 wind turbines of 120.7 GW installed capacity were installed worldwide by 30 companies from Asia Pacific (19), EU (8), USA (2), and the Middle East (1). The majority of orders came from manufacturers' home markets, namely China, the USA, and the EU (GWEC, 2024). The Chinese wind sector accounted for 65% of global wind capacity in 2023, allowing four Chinese wind turbine manufacturers to make it into the top five worldwide, as presented in Fig 3.7. It is estimated that China exported turbines and components to the EU for USD 1.42 billion in 2023 (Hayley, 2024). Chinese wind turbines are highly competitive in terms of cost. Chinese motors cost about a third as much as motors made by other countries at the end of 2023 (Asia Nikkei, 2024). A combination of rising raw material prices, higher interest rates, and disruptions in supply chains due to Russia's invasion of Ukraine has slowed wind power generation development projects in recent years.

Global top 15 OEMs: Market share 2023 (GW)



Top 25 global onshore + offshore wind markets in 2023



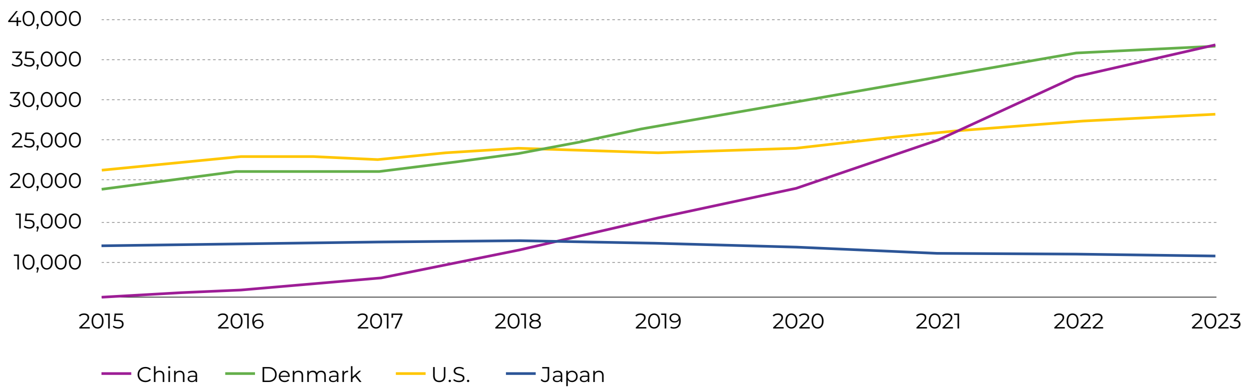
Sources: WoodMac, 2024; BNEF, 2024

Fig 3.7. Wind turbine market share in 2023 by manufacturer (left) and country (right)

Furthermore, Chinese turbine manufacturers also lead in product design and innovation. Four hundred twenty-six new Chinese turbine types have been introduced in the last four years, but only 29 are outside China (Hayley, 2024). This is also shown by the large number of patents produced by China, which took over the first position in the number of wind turbine patents from Denmark in 2023, as shown in Fig 3.8. (Asia NIkkei, 2024). This gives China more freedom to manufacture wind turbine technology and its components without worrying about copyright issues.

China Tops wind power patent ranking

(Points)



Source: Asia NIkkei, 2024

Fig 3.8. Wind power technology patent

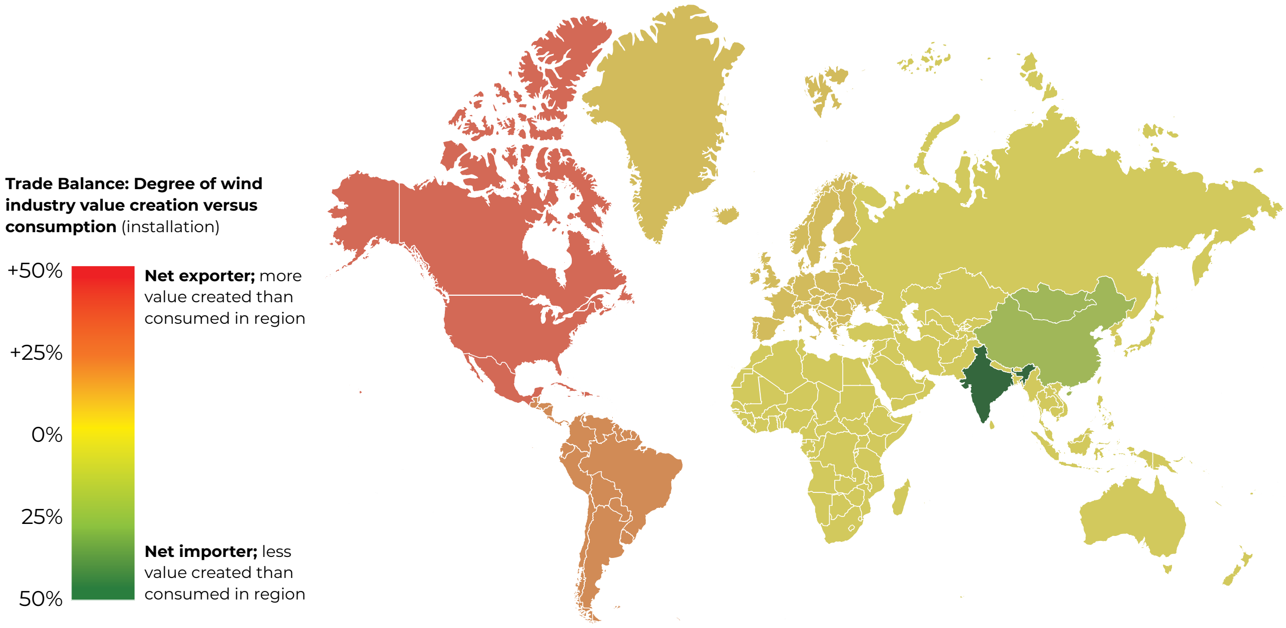
Examining wind turbine supply networks further reveals that regional concentration differs within supply chain components. Similar to the solar PV supply chain, China dominates the market share of wind turbine components (50-80% of worldwide capacity for most individual components), as presented in Table 3.3. Mastery of mining and mineral processing for key raw minerals for wind turbine component manufacturing makes a sense of security in the value chain (see Chapter 7). According to global trends, numerous American nations have become net importers of the wind turbine manufacturing supply chain, while Asian countries, such as China and India, have emerged as significant exporters, as shown in Fig 3.9.

Table. 3.3 Global wind component manufacturing capacity in 2023

Wind turbine		Rotor blades		Nacelle		Tower		Foundation (offshore)	
Market share	Country/ region	Market share	Country/ region	Market share	Country/ region	Market share	Country/ region	Market share	Country/ region
60%	China	61%	China	60%	China	53%	China	76%	China
19%	Europe	13%	Europe	19%	Europe	18%	Europe	16%	Europe
9%	USA	9%	South America	9%	USA	11%	North America	5%	Asia Pacific
7%	India	8%	India	7%	India	7%	India	2%	India

Sources: European Bank, 2023 adapted from Global Wind Energy Council and Boston Consulting Group (2023).

Supply chain has major trade imbalance* with greater exports from Asia



Represents local mining, refining, manufacturing, assembly and services compared to local consumption. Calculation at regional level for North America, South America, Europe, India, China and Rest of World. Value based on location of activity.

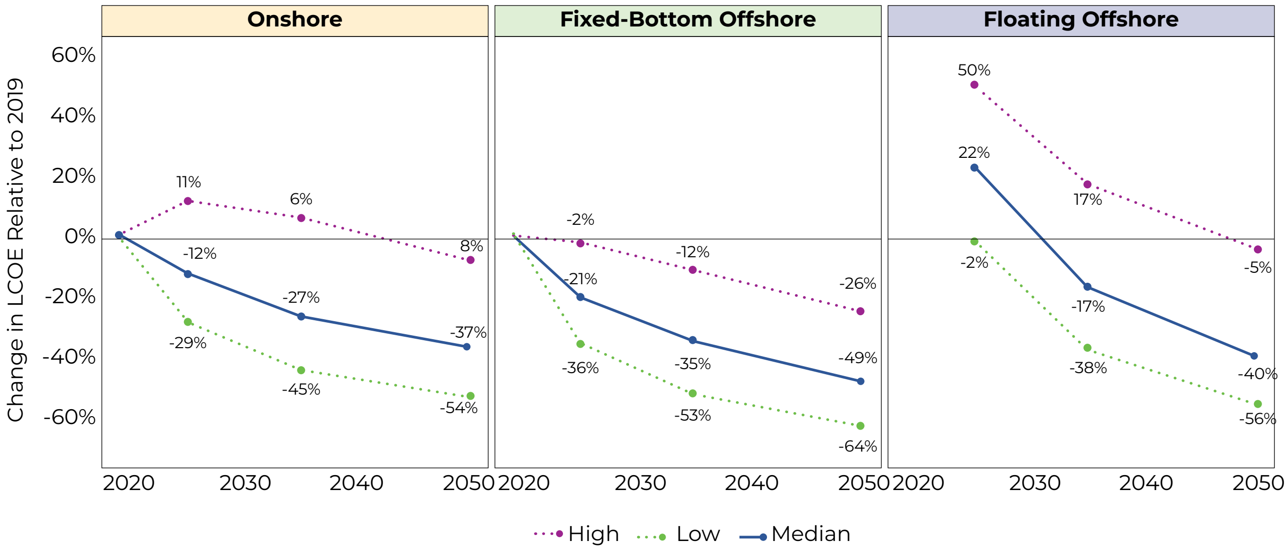
Source: GWEC, 2023a

Fig 3.9. Global wind energy trade balance supply chain from mining, manufacturing, assembly and service

China has developed a robust supply chain and is also the market with the most yearly wind turbine installations. It enables the wind turbine industry size and expertise to develop while lowering prices. Today, the majority of manufacturing assembly and supply chain operations are based in China and, increasingly, in India. To satisfy the demands for commodities and natural resources within the supply chain of wind energy manufacturing, China has cultivated its own resources mining—or guaranteed access to mines abroad. The process of extraction and processing into raw material commodities or even intermediate products either takes place in China or is funded by Chinese funds in areas such as South America, Asia-Pacific, Africa, or even Indonesia, where deposits are concentrated (GWEC, 2023a). Learning from China, building supply chain independence starting from the mining sector is something that Indonesia needs to emulate as part of the downstream program.

In meeting the need for wind power plants, there are 3 categories of market elements required: the turbines, the soft costs, and the BoS. The wind turbine and its components are already represented in Fig 3.4., while the soft cost consists of engineering, construction, and logistics processes. On the other hand, BoS consists of finance, contingency, and warranty. The cost allocation for each element may fluctuate; it is estimated that the wind turbine accounts for 24.3%-69% of the overall expenditure, with the (BoS comprising 23%-61% and soft cost representing 8-16% (NREL, 2019; NREL, 2022; Svoboda, 2021). Meanwhile, for this study, the specific share value is presented in Fig 6.10. Certainly, these three elements must be taken into account, as they have potentially been developed domestically to promote the sovereignty of Indonesia. Furthermore, Indonesia plans to employ wind energy, both onshore and offshore.

Following the levelized cost of electricity (LCOE) of wind turbines, the decrease in LCOE of wind turbines can bring a breath of fresh air to Indonesia and the world, where increasingly affordable prices can encourage greater adoption of wind energy and produce more affordable renewable energy. Fig 3.10. illustrates that the LCOE associated with wind turbine installation projects will continue to decrease. To maximize the value of economic activities, Indonesia also needs to develop the wind turbine industry and its supply chain and encourage more affordable LCOE for wind energy adoption in Indonesia.



Source: LBL, 2021a

Fig 3.10. Estimated change in LCOEs for onshore and offshore wind turbine

C. Domestic manufacturing status and development of wind turbine

Indonesia's wind turbine manufacturing industry is still in the infancy stage but has tremendous potential for further development. In light of the growing global demand for renewable energy sources like wind power, Indonesia has become increasingly involved in manufacturing wind turbines and their components. Companies have already begun investing in wind turbine production facilities in the country in an effort to meet the growing domestic and global demand for clean energy solutions. The primary focus of these companies is manufacturing blades, towers, and gears, which can reduce the cost of importing these parts.

Indonesia has a rich source of minerals and materials necessary for wind turbine production. Copper, aluminum, steel, and rare earth elements are abundant in the country. Mineral resources abound in Indonesia, making it a great location for a manufacturing industry that supports wind turbines. Thus, it gives Indonesia an opportunity to establish itself as a major manufacturer of wind turbines.

The absence of a demand sector for wind energy adoption has been driving the slow pace of development of the wind turbine manufacturing industry. There are currently only three wind turbine-based power plants in Indonesia (Wuri, 2024).

1. Sidrap wind power plant in Sidenreng Rappang district, South Sulawesi. It has a capacity of 75 MW generated by 30 wind turbines with a capacity of 2.5 MW each.

2. Tolo wind power plant in Jeneponto Regency, South Sulawesi. It has a capacity of 72 MW generated by 20 wind turbines with a capacity of 3.6 MW each.

3. Tanah Laut wind power plant in South Kalimantan. It is still under phase 3 development, with a maximum capacity estimated to reach 60 MW.

With only 154.3 MW of built power or contributing around 0.04% of Indonesia's primary energy, Indonesia still has a long way to go before it can fully utilize its highlighted 155 GW of wind energy potential (MEMR, 2024, OurWorldInData, 2024). However, Indonesia plans to harness more wind power potential and has set the goal of developing 73.2 GW by 2060, as explained in Sub-chapter 1.b. (MEMR, 2023; MEMR, 2024b). The JETP Comprehensive Investment and Policy Plan's has aimed for 8.5 GW onshore by 2030, higher than the MEMR's plan, which is 5 GW (MEMR, 2024c). Regardless of the issue, Indonesian manufacturers have exported the towers and monopiles of wind turbines to various regions, including the Asian, EU, USA, African, and Australian markets (KN, 2024a).

Only several Southeast Asia countries have adopted wind energy, including Thailand at 2.1 GW, Vietnam at 6.5 GW, the Philippines at 0.7 GW, and Indonesia at 154 MW by 2023. Other Southeast Asian countries have not been documented to use wind power, as shown in Table 3.4. (GEM, 2024). On average, each nation uses less than 10% of its potential wind energy. However, the Southeast Asian countries plan to expand their wind power in the coming year with close to 140 GW in prospective capacity, showcasing a large potential of the market in the region.

Table 2.3. Operating and prospective of solar energy in Indonesia and Southeast Asia in 2023

No	Country	Operating installed capacity of wind energy (GW)	Prospective (in planning) of wind energy (GW)	Total potential (GW)
1	Vietnam	6.47	76.02	377
2	Thailand	2.09	0.44	17
3	Philippines	0.68	62.81	254
4	Malaysia	0.00	0.00	1.4
5	Cambodia	0.00	0.00	10
6	Myanmar	0.00	4.73	153
7	Singapore	0.00	0.05	-
8	Indonesia	0.16	2.49	155
9	Brunei Darussalam	0.00	0.00	-
10	Laos	0.00	3.68	-
11	Timor-Leste	0.00	0.00	-

The manufacturing of wind turbines in Southeast Asia has not experienced significant growth. Table 3.5. shows that the manufacturing sector supporting wind turbine technology has yet to grow in some surrounding countries of Indonesia, such as Malaysia, Singapore, Thailand, and Vietnam. Simultaneously, it demonstrates the enormous potential of the Southeast Asian market in terms of present wind energy capacity.

Table 2.4. Solar PV component manufacturing capacity of Southeast Asia, China, and global in 2023

Location	Manufacturing capacity (GW /Year)					Manufacturing capacity (Unit/ Year)	Manufacturing capacity (mt/Year)
	Gear box	Nacelle	Genera-tor	Blade	Powerc-Converter	Towers	Wind castings
Indonesia	-	-	-	-	-	500	
Malaysia	-	-	-	-	-	-	
Singapore	-	-	-	-	-	-	
Thailand	-	-	-	-	-	-	
Vletnam	-	-	-	-	-	-	
China	133	98 (18% offshore)	114.5	100.9	185.02	23,910	**2.21**
Gobal	**166.5**	**177.85 (24% offshore)**	**155.6**	**158.8**	**222.77**	**37,940**	**2.69**

Source: Analysis adapted from Hayley, 2024; GWEC, 2023a; GWEC 2023b. KN, 2024b

In order to meet Indonesia's domestic demands, given the existing state of the manufacturing sector, wind turbine technology and its components will need to be imported. The situation can render Indonesia highly reliant on foreign technologies, especially China, which currently dominates wind turbine technology manufacturing. However, Indonesia does have chances to improve its wind turbine manufacturing business, banking on leveraging domestic wind turbine deployment.

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4 An Overview of battery technology and its future projections

A. Battery's technology overview and its supply chain

Batteries could play an important role in energy transition, helping countries meet the commitments on tripling renewable energy made at COP28. They are one of the important components to promoting domestic energy independence, as well as securing affordable clean energy. The development of battery energy, especially Li-ion batteries, become the main catalyst in the global energy transition. Batteries also play a critical role in enhancing energy security. Batteries can increase the level of domestic energy independence by helping reduce fossil fuel demand in multiple sectors. In Indonesia, battery technology has become an opportunity to be developed since the country has rich potential for critical minerals like nickel and cobalt, which are the main composition of batteries.

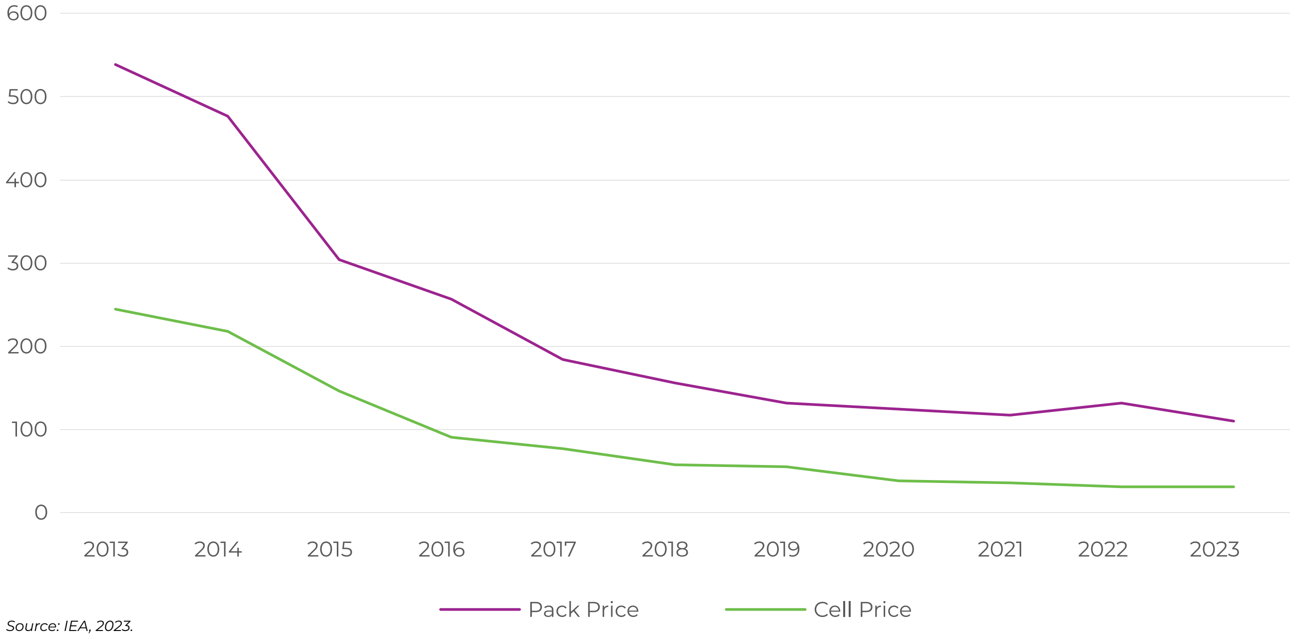
In the transport sector, demand for electric vehicles (EVs) accelerates globally, making battery technology to be more critical and efficient. Batteries are a major component in the effort to shift from internal combustion engines (ICEs) to EVs, which are rapidly gaining popularity. This shift is seen by governments and manufacturers as having a vital role in reducing air pollution and GHG emission. Batteries are the heart of the shift to EVs, which directly impacts their performance, range, sustainability, and cost. Battery EVs must be energy-dense, small, and light (Tepe et al., 2023).

The growing focus on renewable energy (solar, wind power, etc.) planning in the power sector planning could spur the development of energy storage systems in the form of battery energy storage systems (BESS), further amplifying the need for advanced battery solutions. The ability of batteries to store electricity in an electrochemical form is vital in this context, allowing surplus renewable energy to be stored and released when demand exceeds production. Energy storage helps to maintain the grid's stability, contributing to meeting peak load and improving the integration of rising shares of variable renewable energy. To ensure the stability and reliability of power supply, electricity demand and electricity generation need to be in equilibrium at all times (Conzen et al., 2023).

A battery itself comprises one or more electrochemical cells, each with an electrolyte, two electrodes (anode and cathode), and other components. The anode is the negative electrode, and the cathode is the positive electrode. There are various types of batteries, and their classification is based on their chemistry, applications, and structure (Table 4.1.).

Table 4.1 Battery types

Battery type	Key components	Lifetime (cycle)	Energy density (Wh/Kg)	Common application
Lithium ion (Li-ion)	Lithium, cobalt, nickel, manganese, graphite	2,000-20,000	127.8	EV, BESS, Consumer electronic
Sodium Ion	Sodium, transition metal oxides (e.g., iron, manganese),	2,000-20,000	160	BESS
Nickel metal hydride	Nickel, rare earth metals	700-1,000	100	HEV battery
Lithium Iron phosphate (LFP)	Lithium, iron, phosphate, graphite	3,000 or more	90-160	EV
Nickel manganese cobalt (NMC)	Lithium, nickel, manganese, cobalt, graphite	1,000-2,000	150-220	BESS

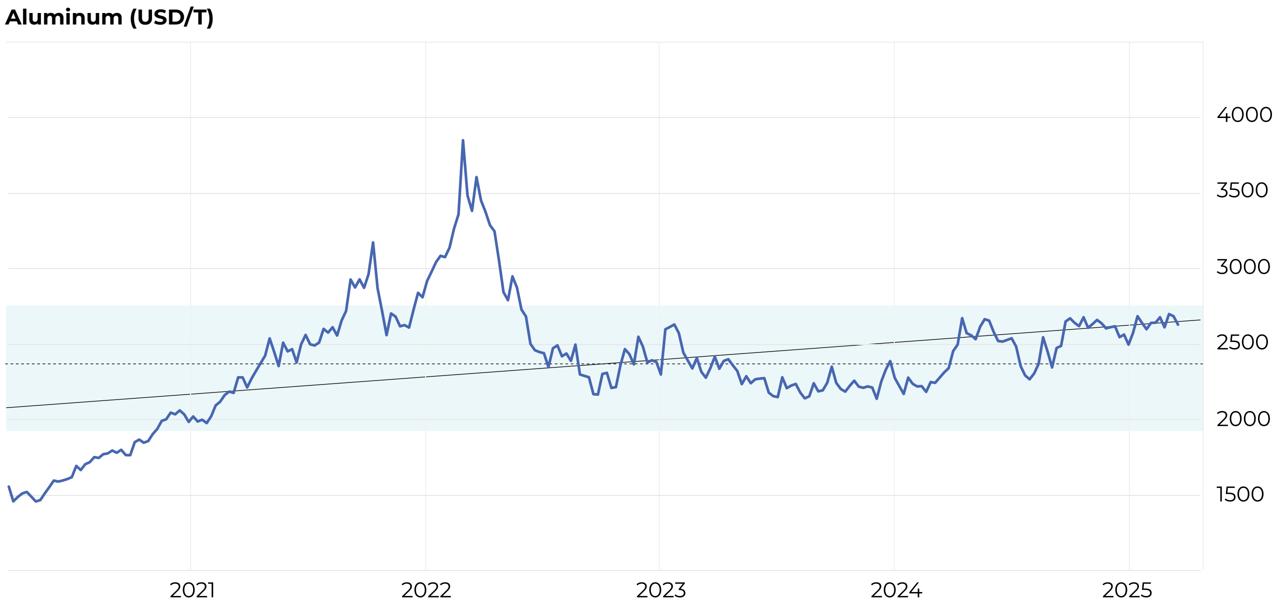


Source: IEA, 2023.

Fig 4.1 Lithium-ion battery prices from 2013 to 2023

Economic scaling of manufacturing and research development has contributed to the declining price of Li-ion batteries. Critical minerals like nickel and lithium affect and contribute a lot to battery prices. The high share of critical minerals in batteries can impact the price of batteries, making it volatile. For example, spikes in battery metal prices in 2022, as illustrated in Fig 4.2., resulted in the first ever year-on-year increase in battery prices.

Fig 4.2. Price fluctuation of critical minerals for Li-ion batteries (1)



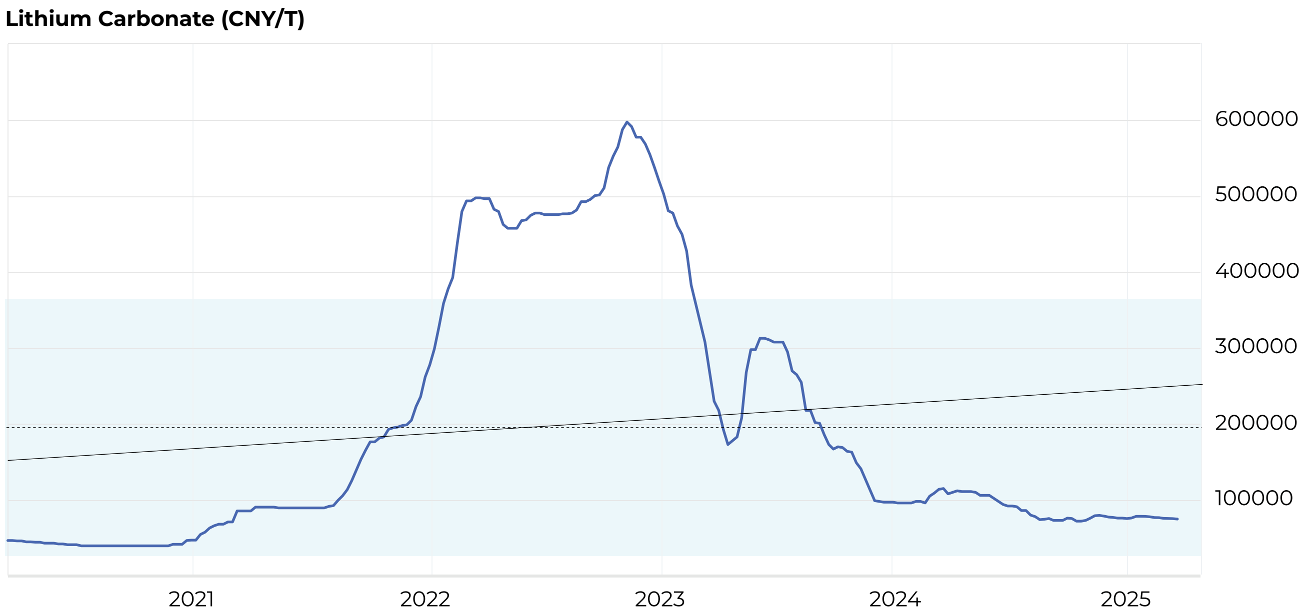
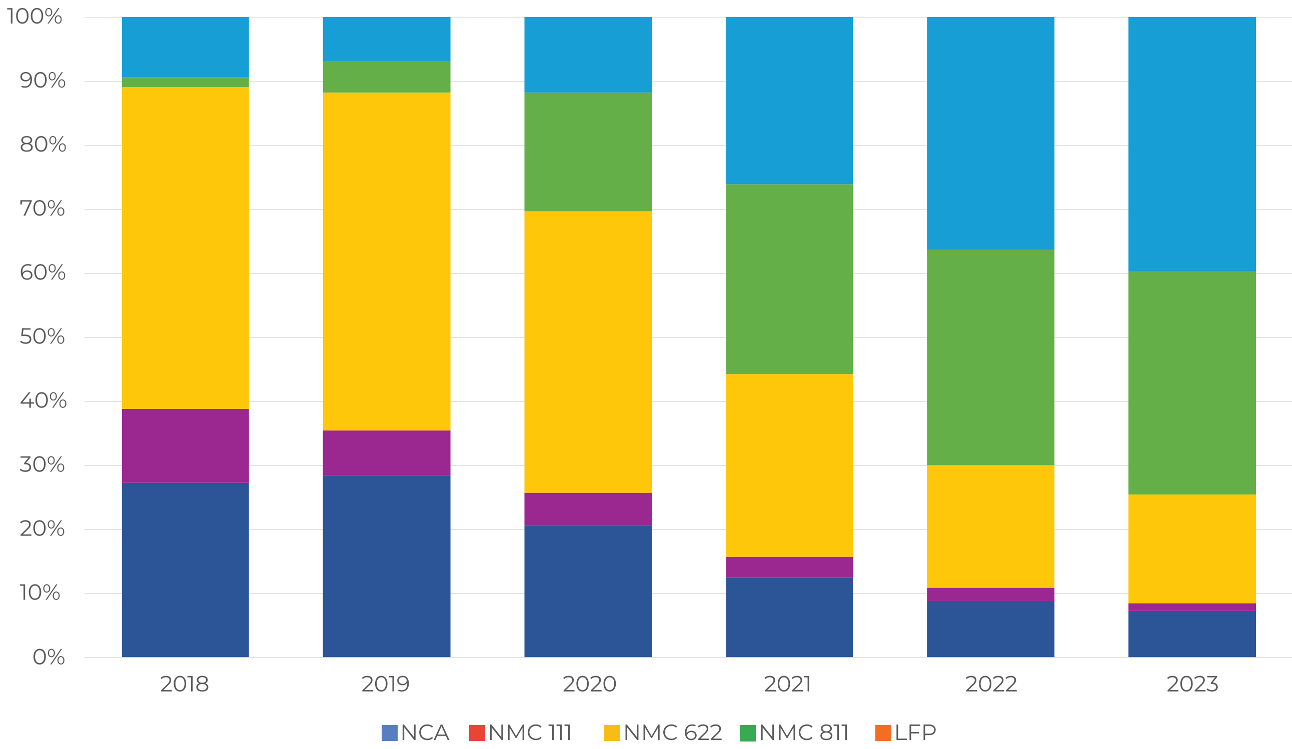


Fig 4.2. Price fluctuation of critical minerals for Li-ion batteries (2)

However, price of Li-ion batteries declined in 2023, impacted by the drop in the price of lithium minerals. This dependency can make the price of batteries volatile. On the other hand, an upsurge in mineral supply and enhanced battery manufacturing capacity, coupled with lower-than-anticipated demand in specific regions, particularly China (IEA, 2023), has contributed to the decline.

Li-ion has become at the forefront of modern battery technology thanks to its high storage capacity and relatively low cost. There are several variants of Li-ion batteries, distinguished by the main materials being used and possessing different electrothermal-chemical properties. NMC batteries are known for their high energy density among Li-ion batteries. Other Li-ion batteries include LFP batteries, which are known for their long cycle life, thermal stability, and safety. Although they have a lower energy density than NMC batteries, their stability makes them ideal for various applications, such as stationary energy storage systems (ESS) and electric buses.

The trend of Li-ion battery variants in global EV sales is presented in Fig 4.3. below.



Source: IEA, 2023

Fig 4.3. Battery cathode chemistry in global electric car sales

As observed from Fig 4.3., in the last 5 years, LFP has gained more popularity than other battery chemistry due to its cheaper cost . LFP's low cost is caused by its use of less expensive material compared to NMC, as it does not contain nickel or cobalt. Although LFP batteries have lower energy density than NMC batteries, LFP's advantages make it an attractive choice for cost-sensitive markets like EV. LFP is a lower-cost battery chemistry and is over 20% cheaper today than NMC. It does not contain nickel or cobalt, and it offers a more stable chemistry than nickel-rich chemistries, with reduced flammability and a longer cycle life. However, it has a significantly lower energy density, which is conventionally 20-30% lower than high nickel chemistries at the battery cell level. Despite its inferior energy density, the use of LFP for EV batteries has increased significantly in recent years. It has been the leading chemistry for new EVs in China since 2021and, more recently, has begun to be used by EU and USA automakers. The new popularity of LFP chemistry is primarily driven by its lower price and longer lifespan relative to the alternatives, energy density improvements such as the cell-to-pack (CTP) configuration, and improved thermal stability. Its cost effectiveness and durability make LFP the preferred battery chemistry for buses and commercial vehicles (Nunes, et al,, 2025). Indonesia does not have lithium or the mineral required to produce LFP batteries, which indicates Indonesia can only produce an NMC battery.

Nickel is a key component of NMC and NCA cathodes. Today, NMC and NCA account for a larger share of EV batteries. Nickel has gained ground at the expense of cobalt in large part because of the pressure for increased EV range. Moreover, the spikes in cobalt material prices and concerns over ethical mining practices in the 2010s gave battery producers additional incentives to reduce the cobalt content in batteries over the past decade. This has led to the development of many variations of NMC chemistry, from the initial NMC 111 to variations with higher nickel content, such as NMC 622 and NMC 811.

Besides LFP and NMC, other types of batteries are gaining prospects for future development. Sodium-ion batteries are seen as an appealing alternative to LFP, as they are less expensive and have more abundant materials and resources. The price of this battery could be 20% cheaper than the equivalent LFP. However, this battery has a lower energy density than LFP. According to IEA, sodium-ion batteries will gain market share in 2030. Solid state batteries (SSBs) have high energy density and higher density since they use solid or quasi-solid electrolytes instead of the conventional liquid electrolytes, which also come up as an alternative. SSBs may be useful for long-range driving applications. However, SSBs still have challenges in integrating them into the battery pack. LCO batteries, on the other hand, are often used in consumer electronics like smartphones and laptops due to their high energy density. However, they are less stable than LFP and have a shorter lifespan (IEA, 2024; IEA, 2023).

The battery supply chain is complex, as shown in Fig 4.4. As a rule of thumb, it starts with mining the raw materials, refining them, making a battery cell, and packing it as one so it can be used in an EV or ESS.

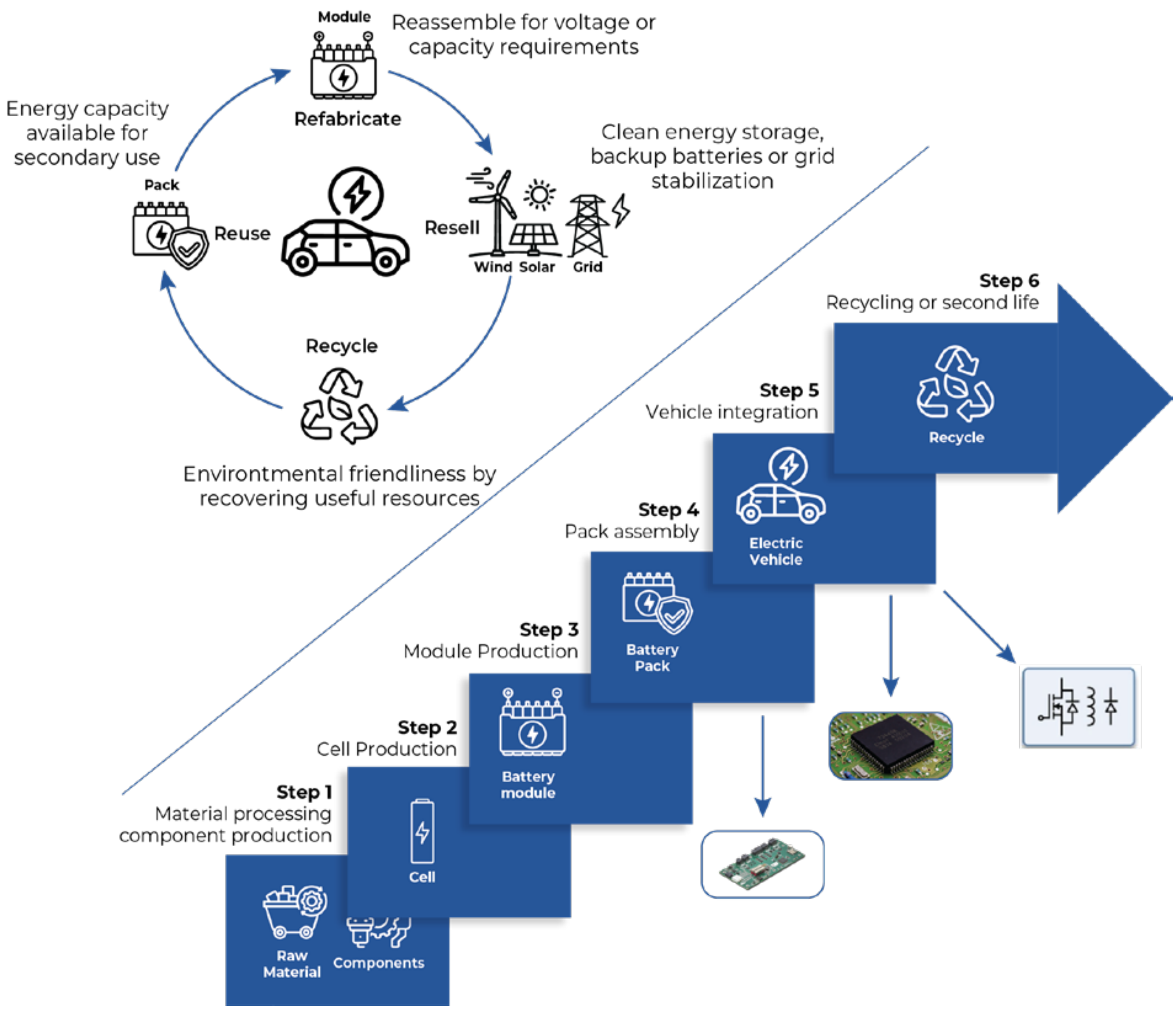


Fig 4.4. The main steps of battery supply chain

These steps have their challenges. The mining and refining steps, which consist of maintaining the extraction, refining facilities, and raw materials production, are not easy since raw materials are often located in remote locations. The raw materials must then be transported far away from the extraction site. For example, the distance between an extraction location and a battery cell factory in the USA is 80,000 km (RMI, 2024). The USA heavily relied on imports of critical minerals required for battery production. This long-distance introduces disruption risks like geopolitical issues, logistic challenges, and price volatility.

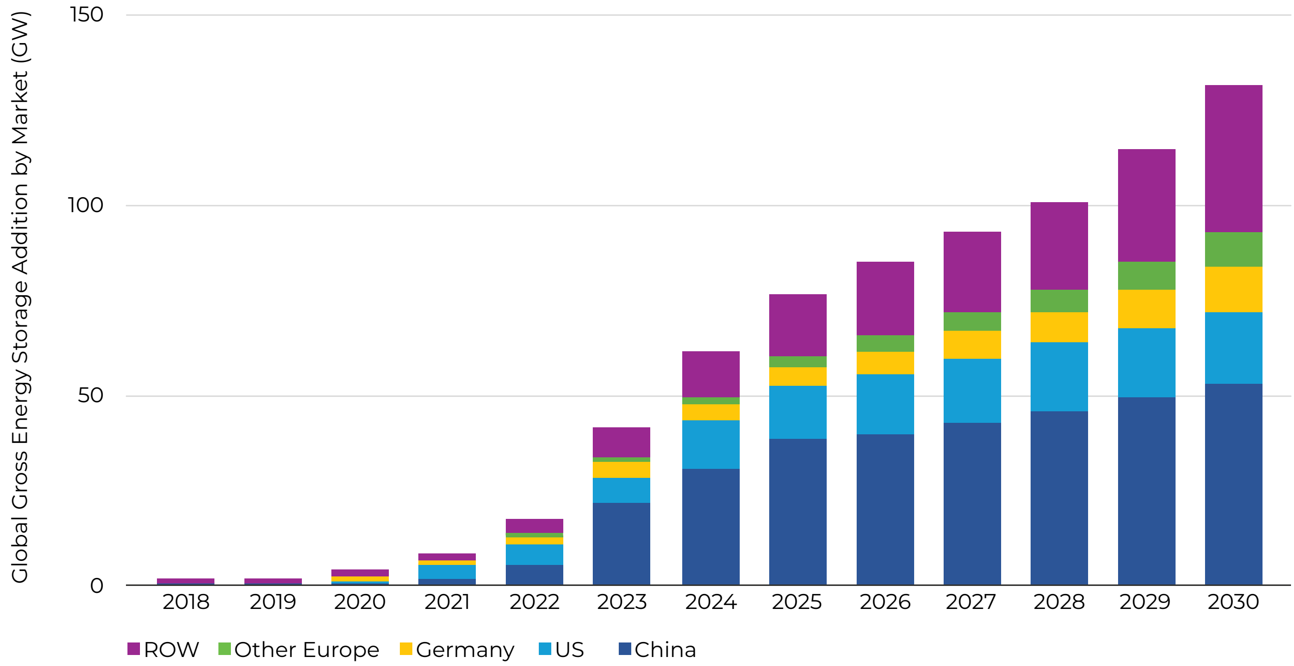
In the manufacturing step, China holds almost 85% of the global manufacturing capacity (IEA, 2024). This can create risk in the potential for supply chain vulnerabilities and economic dependencies that can disrupt the global market. This dominance can lead to supply chain bottlenecks when there is a geopolitical tension or a natural disaster. Any changes in its production level and pricing strategies can have an impact on importer countries like Indonesia. In the final product, standardization of the battery pack can be a challenge since non-standard products make the repurposing process quite difficult. Standardization of the battery pack can make repurposing safer and easier, which can produce financial benefits for both manufacturers and consumers. In the last steps, the challenges lie in limited recycling capacity. Currently, 2 million tonnes of batteries are recycled annually, of which almost 85% of the recycling facilities are in China (IEA, 2024).

On the other hand, these steps also present some opportunities. At the mining and refining steps, diversification of critical mineral supplies by investing in new projects can enhance supply chain resilience. Indonesia has abundant nickel resources and is set to be the market leader in nickel production (US Geological Surveys, 2020). In the manufacturing steps, there is an expansion of battery cell production capacity outside of China, like the EU and North America, which are projected to reach about 15% of the global market share by 2030. Collaboration between China and Indonesia in the form of developing new manufacturing facilities in Indonesia could enhance Indonesia's role in the global supply chain of batteries (Jakarta Globe, 2024). Developing the supply chain in Indonesia could have wider benefits, including boosting EV sales within the country since the cost of EVs can be lowered by manufacturing the battery component instead of importing it. To achieve this, Indonesia needs to build vertical integration of the supply chain and provide easy access to raw materials since the materials account for approximately 40% of the total cell production cost. Manufacturing at sub-scale volumes, i.e., below 10 GWh, can be less competitive due to the high labor and energy costs involved. A larger production scale significantly improves cost competitiveness by around 20% (ADB, 2023).

B. Investment and projection over the supply chain

The global battery supply chain is experiencing a significant increase driven by substantial investment to meet global demand. In 2023, the global battery market was estimated to reach USD 89.61 billion and is projected to reach USD 208.28 billion by 2034, reflecting a compound annual growth rate (CAGR) of 8.8%% (PR, 2024). Several demands from transport and power sectors will drive the rising market value. In the power sector, the worldwide market almost tripled between 2022 and 2024. The growth is driven by the declining price of batteries, especially in China, where turnkey energy storage system costs in February were 43% lower than in 2023. The cost reached a record low of USD 115 per kilowatt-hour for two-hour ESSs (BloombergNEF, 2024). The next large market is the US, where battery energy storage experienced substantial growth in 2024, adding a record 11.9 GW of new capacity across grid-scale as well as distributed applications like homes and businesses (BloombergNEF, 2025). According to the Bloomberg forecast, global energy storage is expected to reach 137 GW by 2030. The annual growth rate is shown in Fig. 4.5. below.

Most energy storage additions are driven by mandates from countries like China, the USA, and Europe (BloomberNEF, 2024). Declining energy prices will support the deployment of energy storage based on batteries worldwide. The main enabler of the falling costs has been LFP batteries, which use no nickel and continue to take market share from Li-ion batteries using nickel manganese cobalt (NMC). The growth in LFP's market share is made possible by a scale-up in manufacturing capacity led by Chinese battery makers.



Source: Bloomberg NEF BNEF,2025

Fig 4.5. Global gross energy storage addition by region

The demand also comes from EVs. There is a clear upward trend in the number of EV units sold, growing from less than 2 million units in 2017 to an estimated nearly 20 million units by 2024 (Rystad Energy, 2024). The growth of EV sales drives the demand for batteries. In 2023, EV battery demand reached almost 800 GWh, up 40% from 2022. The EU shows a steady increase in battery demand, reaching 185 GWh/year in 2023 and contributing more significantly from 2019 onwards. In 2023, the EU became a major E4W market, though still trailing behind China. As illustrated in Fig 4.6., demand for batteries keeps increasing over the years and is expected to grow even more (IEA, 2024).

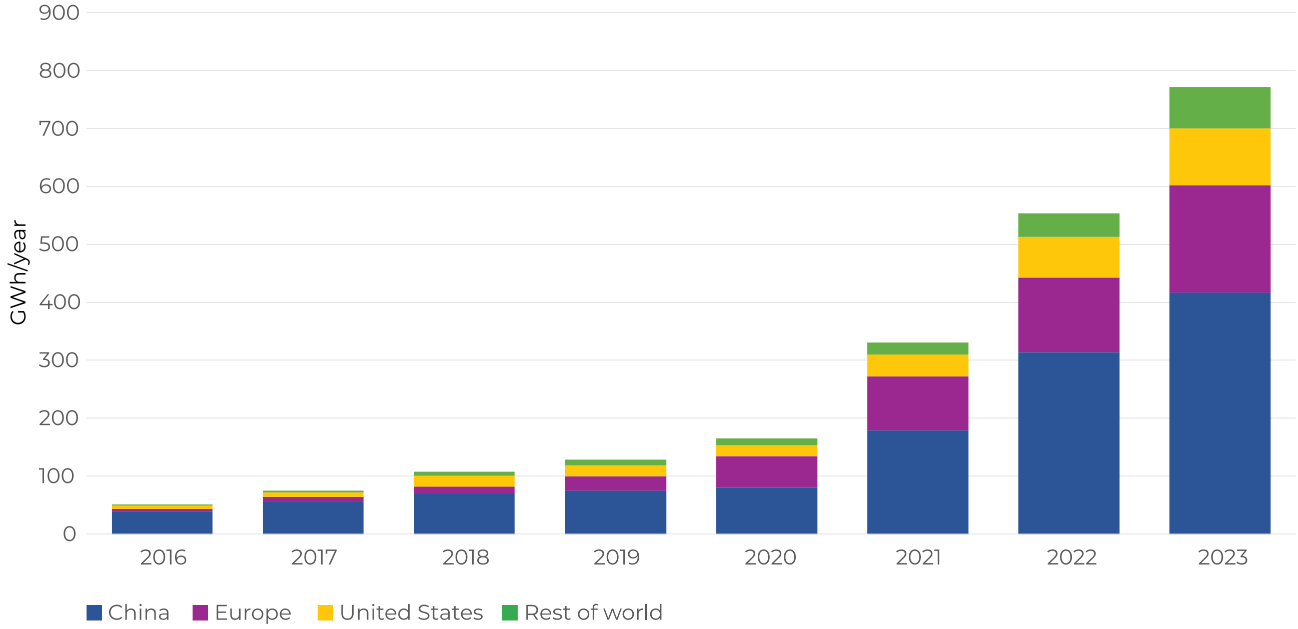


Fig 4.6. Global EV sales in key regions and their market share

The Asian Development Bank also highlights the demand for electric two-wheelers (E2W) and projects the growth until 2030, along with government targets for vehicle electrification. By 2030, Southeast Asia's E2W sales is expected to reach approximately 4.5 million units, with Indonesia emerging as the largest market in Southeast Asia (ADB, 2023). Indonesia's E2W sales are projected to grow from just 17,000 units in 2021 to 2.5 million units by 2030, making up about 29% of the country's total vehicle penetration. To meet the demand for E2W sales in the country, Indonesia will need to develop more battery production. This exponential growth reflects Indonesia's significant commitment to EV adoption and government subsidies driving demand.

Southeast Asia as a whole is seeing a massive transformation toward electric mobility, with total E2W sales expected to grow from around 240,000 units in 2021 to 4.4 million by 2030 (ADB, 2023). This shift is largely driven by government policies, subsidies, and the growing awareness of the environmental benefits of EVs. The region's diverse approaches to electrification, varying by country, demonstrate a collective move toward sustainable transportation supported by ambitious government electrification targets.

As for Indonesia, the demand for energy storage is mentioned in the RUKN document which has been projected until 2060. A projection from the Official 2024 RUKN stated that in 2060, Indonesia will need 50 GW of energy storage (RUKN, 2024). The projection for energy storage over the years is shown in Fig 4.7.

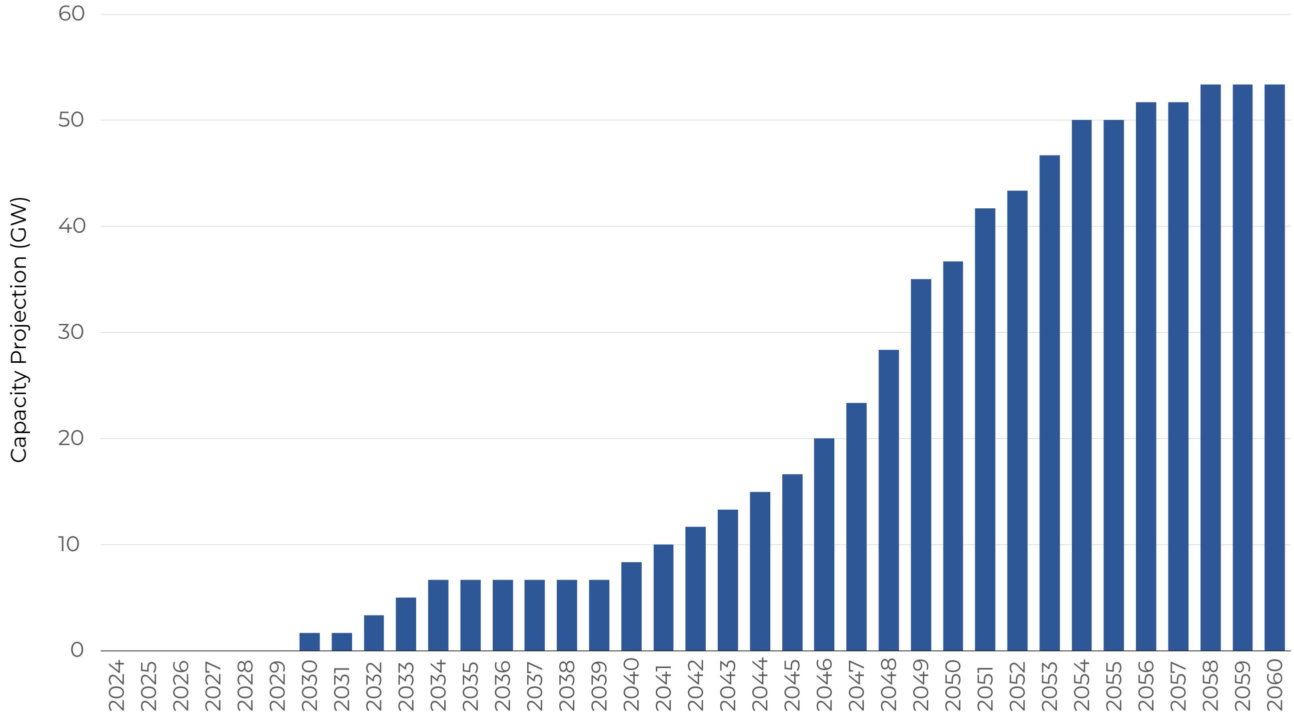


Fig 4.7. The national energy projection demand for energy storage

The same condition also to the transportation sector. There is a growing trend in EV sales. Data from GAIKINDO (The Association of Indonesia Automotive Industry) highlights the growth of electric four-wheelers (E4W) sales in Indonesia. The number of E4Ws in 2023 has tripled that of in 2022. This shows that the demand for E4Ws has kept increasing over the years (Gaikindo, 2025). This growth created a demand for batteries of up to 2.4 GWh, compared to just 0.005 GWh in 2020 (Gaikindo, 2025).

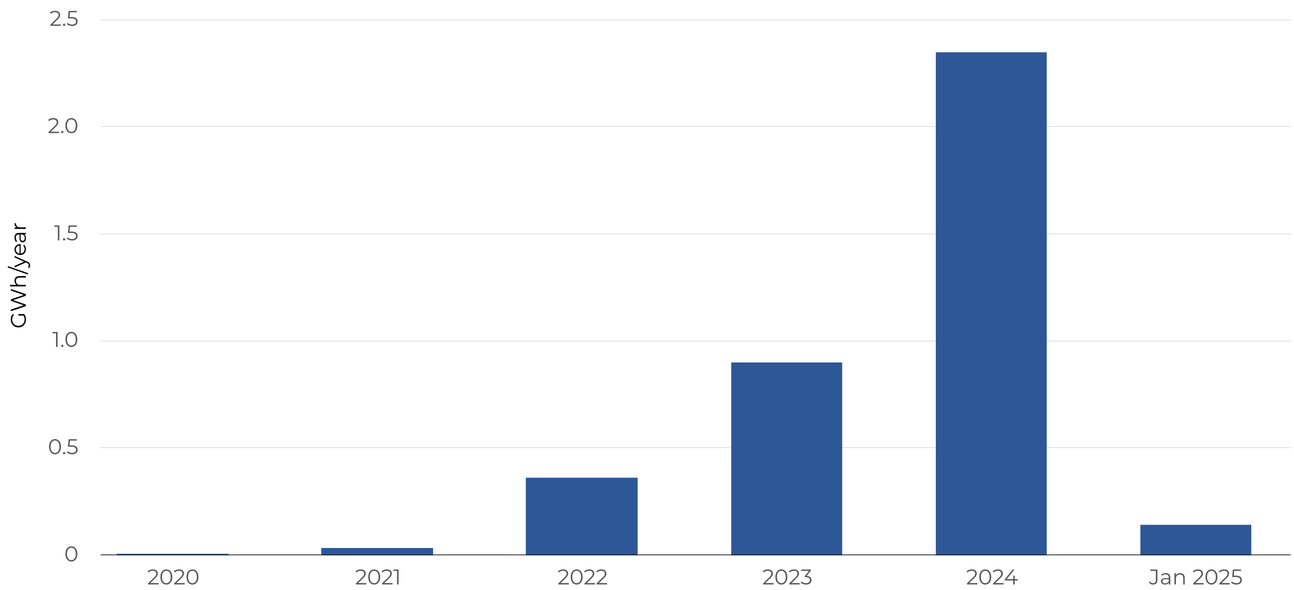


Fig 4.8. Electric vehicle sales in Indonesia, 2020-2024

The growing trend of EV and potentially renewable energy adoption underscores the importance of developing a robust domestic battery supply chain to meet future demands. In 2023, China dominated global battery production, with almost 80% of battery manufacturers in China. China battery manufacturer capacity has reached 1.7 TWh. It is projected that China will maintain the dominance of battery manufacturing capacity until 2030 (Statista, 2024; S&P Global, 2024). In 2030, battery manufacturing capacity will reach 6.5 TWh, led by China, which is projected to have over half the market share. While China leads the market, other regions like Europe and North America start to ramp up their battery production, each boasting over 1 TWh of Li- ion battery capacity (S&P Global, 2024).

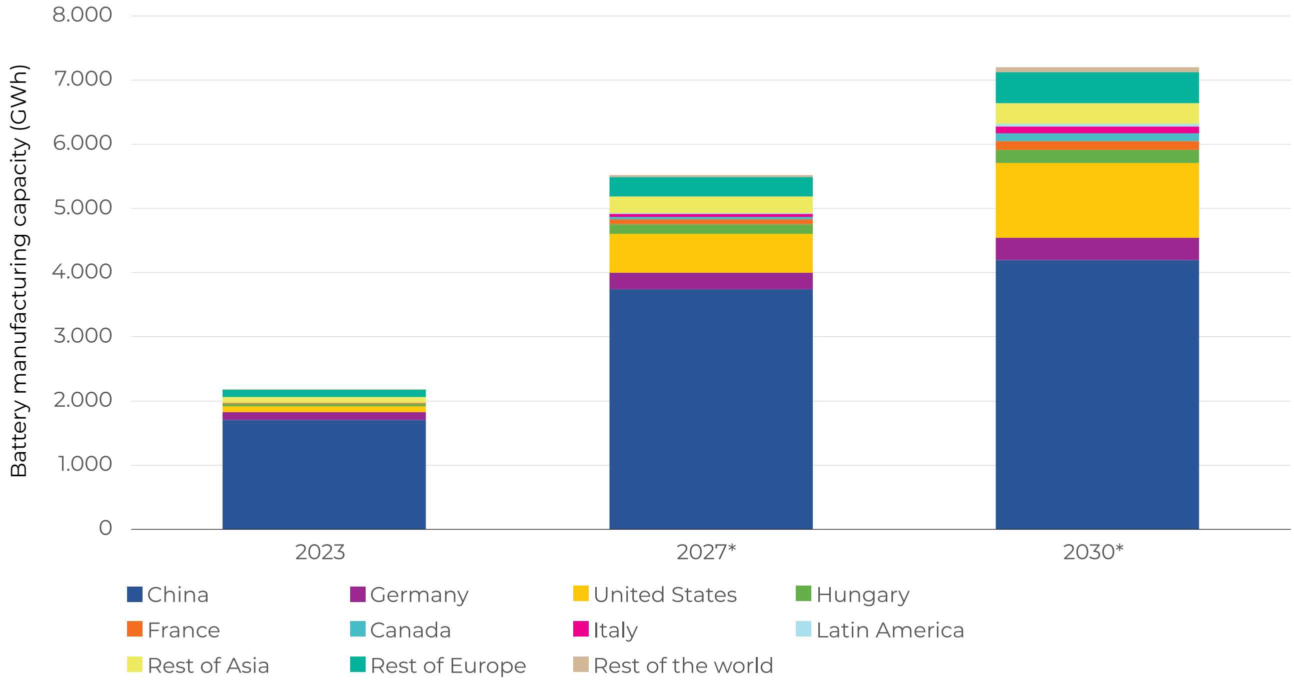


Fig 4.9. Global EV sales in key regions and their market share

Indonesia may benefit from the integrated battery supply chain. The battery supply chain can create job opportunities across various sectors, from mining and manufacturing, to research and development. While Indonesia increases its manufacturing capacity, the demand for labor will increase. The job creation will not only reduce the unemployment rate but also drive local economic development. As Indonesia expands its supply chain, it can attract more investment.

Indonesia's vast amount of nickel reserves could also help the country ensure cost stability within the supply chain. As the world's largest producer, Indonesia has the advantage of stabilizing prices since 60% of the cost of batteries comes from raw materials (ANL, 2024). While the country develops an integrated supply chain, it can establish long-term contracts with manufacturers and foreign investment. Furthermore, the potential for domestic processing of nickel into higher-value products, such as battery-grade nickel sulfate, enhances cost stability and profitability. By investing in refining and processing facilities, Indonesia can capture more value from its natural resources, reducing dependence on foreign suppliers and minimizing the risks associated with global supply chain disruptions. This vertical integration will not only bolster Indonesia's economy but also position the country as a leader in sustainable and cost-effective battery production.

C. Domestic manufacturing status and development

To meet the increasing demand for batteries from EVs and battery storage, Indonesia needs to develop its own supply chain within the country. Domestic supply chains can reduce dependency on imports and reduce cost. Domestic development status includes the current status of domestic manufacturing, including production capacities and key players. It is important to understand Indonesia's positioning as a competitive player in the global supply chain. In recent years, efforts have been made to establish a local supply chain from the mining to the manufacturing steps (MEMR, 2019; CNBC, 2024). These efforts include the banning of nickel export, the production shift of nickel from nickel pig iron (NPI) to mixed hydroxide precipitate (MHP), and also the development of battery factories within the country.

Building a competitive battery industry in Indonesia requires a well-structured supply chain, from upstream to downstream. This action also needs to address the opportunities and challenges in the sector's long-term growth potential. Since Indonesia holds a significant nickel reserve and growing demand for EV batteries and ESSs, realizing the full potential of a fully integrated supply chain will need strategic action.

Fig. 4.10. shows that Indonesia holds the biggest share of nickel production in the world. Indonesia has significant potential to establish the supply chain of Li-ion batteries, especially NMC types, due to its rich supply of critical mineral resources, particularly nickel and cobalt. In the mining sectors, Indonesia accounts for 52% of global nickel production and 8.2% of cobalt production (US Geological Surveys, 2024).

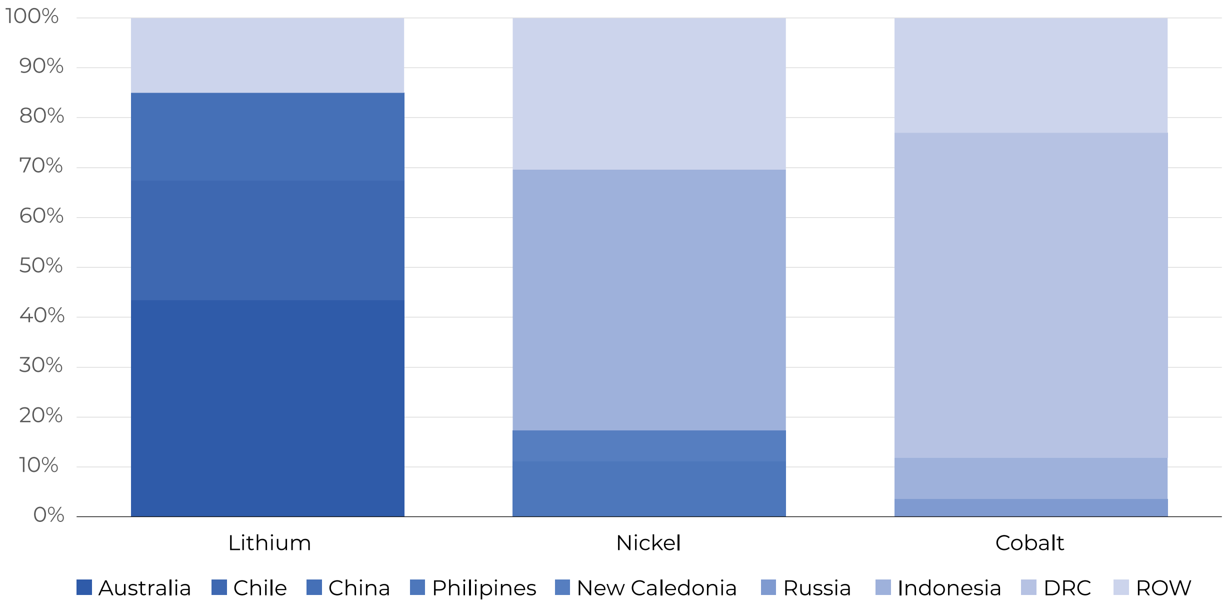


Fig 4.10. Share of mined or raw material production by country in 2023

Currently, Indonesia has a total of 44 nickel smelter facilities with a total capacity of 22,9 million tons per year (MOI, 2024). These smelters are located across the country, including Banten, South Sulawesi, Southeast Sulawesi, and Central Sulawesi. However, most of the current production and processing infrastructure produces more stainless steel than battery cathode materials, as depicted in Fig. 4.11. (VOA, 2024; MOI, 2024). Besides that, the smelter's facility capacity can produce NPI, Ferro Nickel (FeNi), and MHP. NPI and FeNi are semi-finished materials for stainless steel production while MHP is needed to produce EV battery cathodes. Out of the total number of smelters, only 3 smelters with a capacity of 950,000 tons/year produce MHP (MoI, 2024). This shows that nickel refining facilities in Indonesia are more focused on semi-finished material for stainless steel rather than focusing on making EV batteries. Indonesia also has the biggest nickel sulfate processing and refining facility. Nickel sulfate is the key material in the precursor cathode for batteries. This facility has the ability to produce 240,000 tons of nickel sulfate per year (CNBC, 2023), although the product is only intended for export purposes.

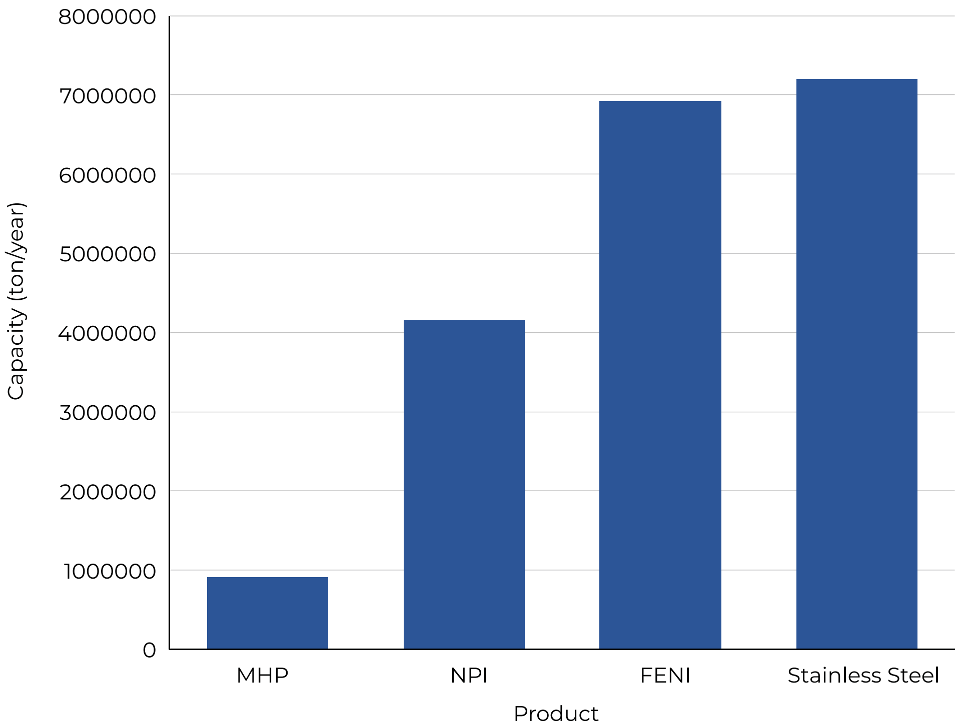


Fig 4.11. Indonesia's smelters product

As of now, Indonesia lacks facilities or manufacturers that produce nickel-based battery cathodes (Bloomberg, 2024), which prevents Indonesia from establishing a fully integrated supply chain for NMC battery production. Over the supply chain, Indonesia can only be a champion in the mining and refining steps. Other steps, such as manufacturing, need to be further developed. To address this challenge, Indonesia is attracting substantial foreign investment (CSIS, 2022). While Indonesia's nickel refining industry is currently geared toward stainless steel production, there are emerging efforts to shift toward battery cathode production. Usually, battery cell manufacturing facilities can produce battery cell materials like cathode, anode, separator, and electrolyte in one place. PT LBM Energi Baru Indonesia, with an investment of about USD 290 million, just opened its facility in Kendal, Central Java, which will produce LFP cathode material with a capacity of 120,000 tons (Kontan, 2024). There is also PT BTR New Energy Material, which invested USUSD 777 million on building anode manufacturing facilities. This facility will produce about 80,000 tons of anode (Industry, 2024).

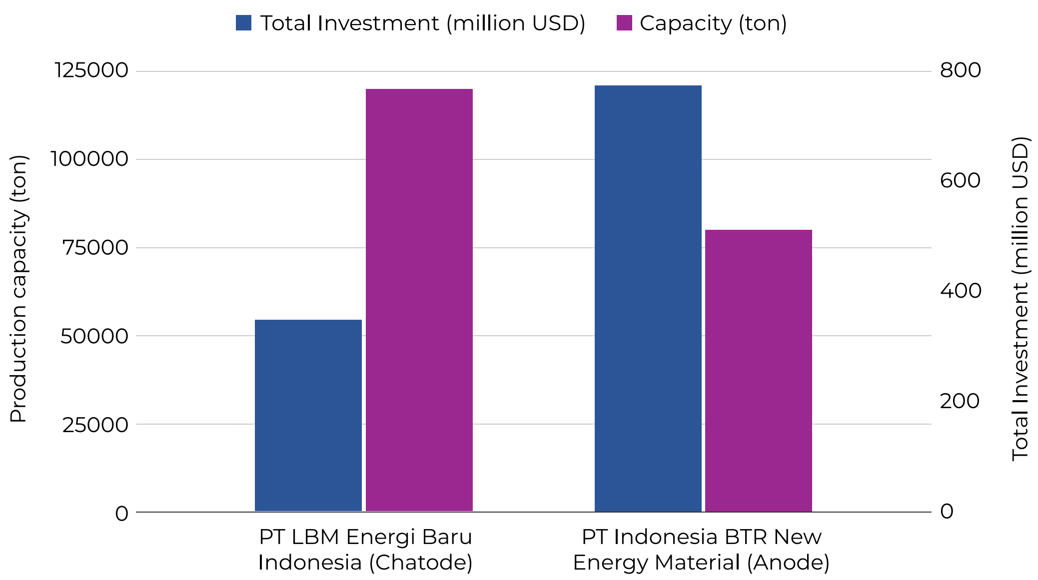


Fig 4.12. Indonesia's battery factory status

While there are ongoing efforts to build battery cell manufacturing facilities in Indonesia, the country still has struggled to reach an economic scale. To reach an economic scale, Indonesia would need a production capacity of at least 10 GWh (ADB, 2023). Without this, the cost of manufacturing batteries will remain high, making Indonesian-made batteries less competitive on the global stage. Besides LBM and BTR, Hyundai, cooperating with LG, has built a battery factory to support Hyundai's EV manufacturing in Indonesia. The purpose of this move is to secure Indonesian nickel to support Hyundai EV. The factory will have 30 GWh production capacity by 2025 (Kontan,2024). Furthermore, other companies like CATL, POSCO, and Lopal have that they will build a battery factory with a total capacity of 30 GWh in 2030 (ADB, 2023). Currently, Indonesia's battery manufacturing capacity lags behind that of countries like China, South Korea, and the USA, which have already achieved large-scale production. For comparison, global battery capacity production has reached 3,000 GWh (IEA , 2023) and is thus able to offer batteries at more competitive prices.

In addition to these challenges, Indonesia also faces significant market uncertainty due to the fluctuation in raw material prices, particularly for nickel. Fig 4.12. illustrates the fluctuating prices of the main materials for Li-ion batteries, such as nickel, aluminum, and lithium. Without addressing these fundamental issues, Indonesia's potential in the global battery supply chain will remain underutilized.

Even though Indonesia has the biggest nickel reserve in the world, selling nickel-based batteries will not be easy. As shown in Figure 4.2, LFP batteries have been dominating the EV market share in Indonesia. In 2024 alone, 90% of EVs sold in Indonesia use LFP batteries, while only 10% use nickel-related batteries.

Despite the aforementioned challenges, Indonesia can leverage its geological position as the biggest nickel producer. Since Indonesia lacks rich lithium deposits, it does not need to build an entire supply chain. Instead, Indonesia can focus on specializing in parts of the EV supply chain, such as nickel precursors. Localizing the EV battery supply chain brings upstream investment opportunities since batteries require a range of critical minerals, processing facilities, and component part manufacturing. Investment opportunities can come with good strategies. For example, the country can strengthen trade relationships with countries that have a lot of demand for batteries. This can create a larger market for Indonesia. The stability of regulation is also important for gaining the investor's trust. The country can leverage natural resources production to attract battery manufacturers that are looking for reliable resources.

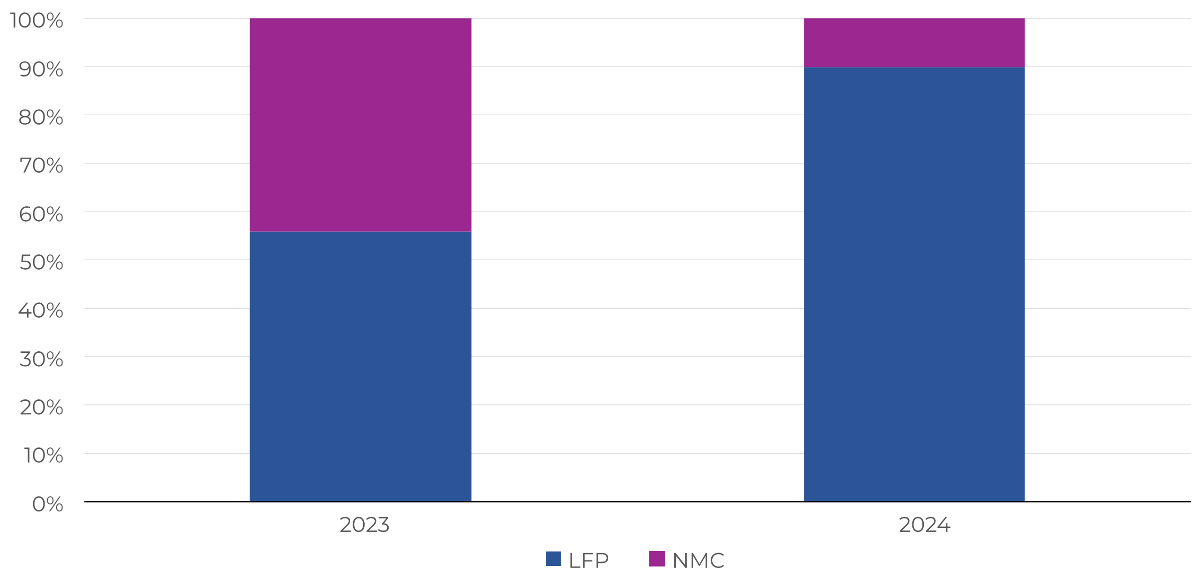


Fig 4.13. The percentage of EV Sold in Indonesia based on batteries chemistry

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5 Readiness Assessment and Impact of Establishing Renewable Energy Manufacturing in Indonesia

A. Evaluating risks of the supply chain

A number of countries, including Indonesia, are at risk of supply and production shortages, trade and distribution disruptions, and unanticipated risks due to underdeveloped local manufacturing capabilities, increasing demand for specialized workers, and the manufacturing industry for renewable energy's dependence on imports. Furthermore, regional concentration, price volatility, government oversight, and public anxiety are a few risks that the renewable energy sector must contend with as it navigates the raw material supply chain.

The development of the renewable energy manufacturing supply and value chain in Indonesia must be connected to natural resource readiness, human resources, and industrial system management. At least four factors constitute risks and vulnerabilities that need to be mitigated and prepared to optimize the development of the supply and value chain in renewable energy manufacturing that consist of: 1) Availability of raw materials; 2) Securing and diversifying foreign and local supply chains; 3) A better management approach to manage the end-of-life waste; and 4) Improved data management for supply chain analytical capabilities (adapted from DOE, 2022).

i. Availability of raw materials

Some of the main raw materials, including silicon for solar PV and rare earth elements, magnesium, tungsten, antimony, gallium, and germanium for wind turbines and batteries, are produced in China. Roughly 90% of the world's rare earth element manufacturing takes place in China (Kearney, 2024). Some countries are also at the forefront of producing certain raw materials, such as the USA (beryllium), Brazil (niobium), Russia, and South Africa (palladium, iridium, platinum, rhodium, and ruthenium) for solar PV, wind turbines, and batteries.

The global mapping of this raw material production is depicted in Fig 5.1. Understanding the raw material mapping is crucial for assessing the future growth of Indonesia's manufacturing sector, which depends on raw material imports, as well as any possible threats from market rivalry. Recognizing the need for raw resources is crucial to meeting domestic demands, particularly when it comes to promoting competitiveness, technology, energy security, and economic stability.

In terms of raw materials commodities, Indonesia is a major producer of nickel, cobalt, tin, gold, and copper. Nickel and cobalt production will reach its peak during the next five years. Indonesia will produce 1.6 million tonnes of nickel (#1 in the world), 8,000 tonnes of cobalt (#2 in the world), 19,800 tonnes of tin (#3 in the world), 125 tonnes of gold (#8 in the world), and 0.9 million tonnes of copper (#7 in the world) in 2022. Additionally, Indonesia produces a wide range of other mining commodities in significant amounts. Across the country, Indonesia has a number of active mines and smelters that produce copper, ferronickel, lead, nickel, tin, gold, graphite, zircon, bauxite, ferromanganese, iron, manganese, and other minerals, as shown in Fig 5.2. However, it is important to take into account other mineral mining commodities in addition to the ones that have been viewed and discussed as the basis of Indonesia's mining riches.

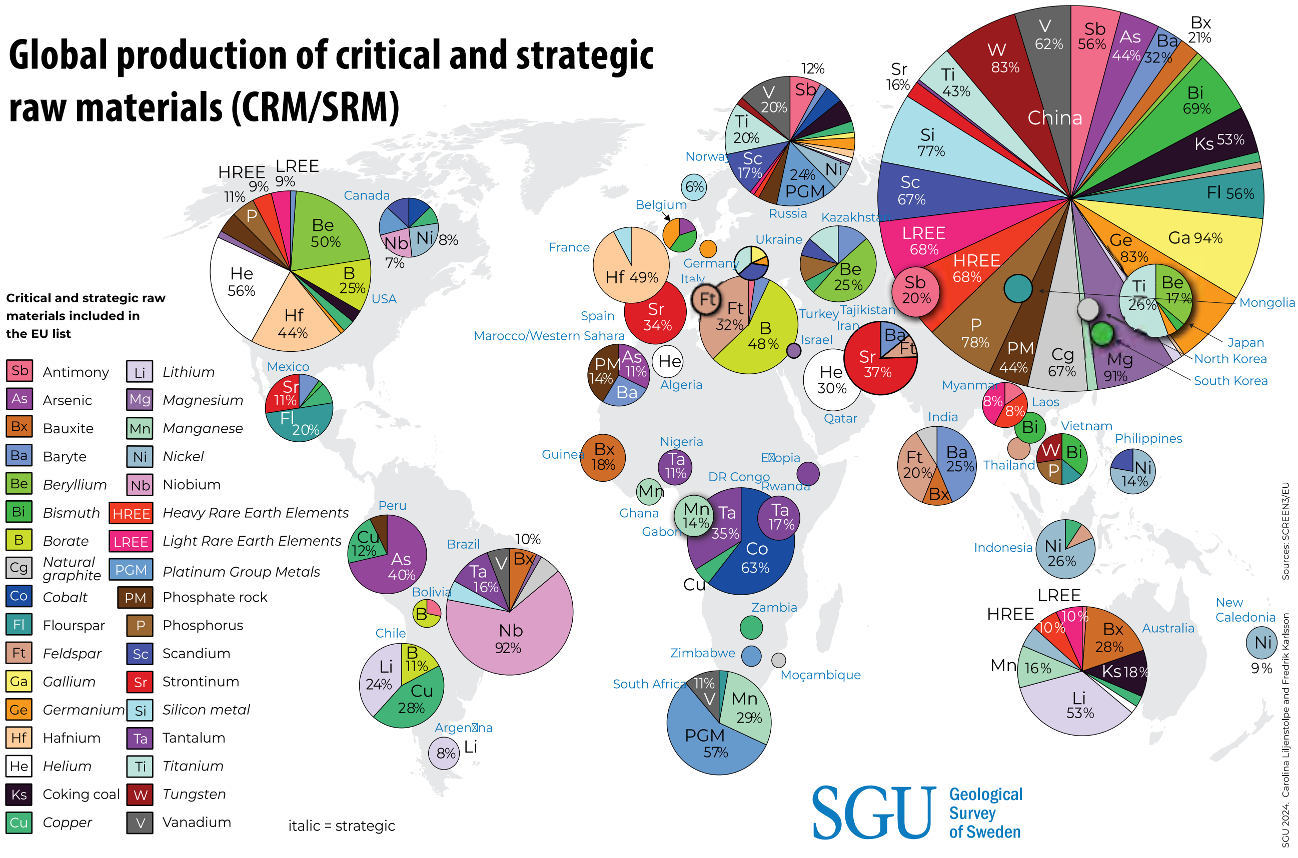

Fig 5.1. Global production of critical and strategic raw materials (CRM/SRM)

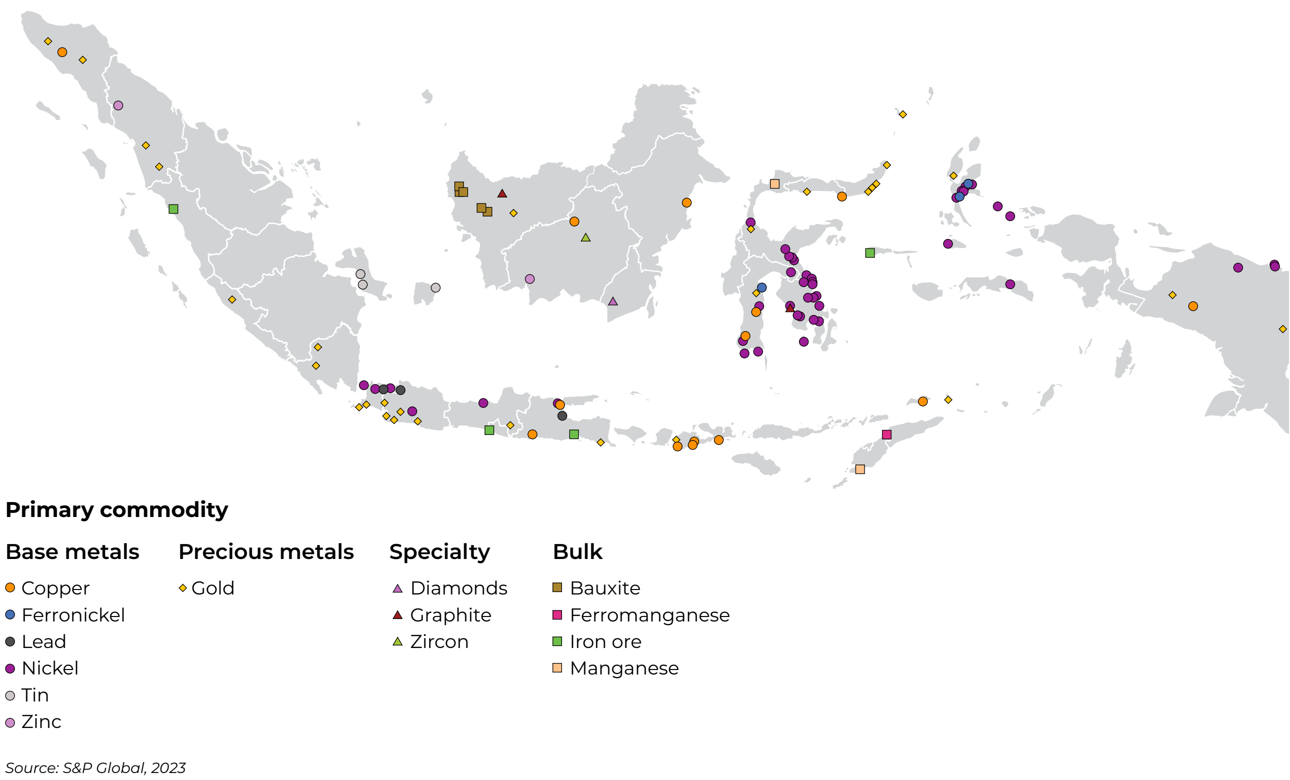

Fig 5.2. Active mines and smelter in Indonesia in 2023

The “downstream” program has a very important role in managing critical minerals. According to MEMR Decree No. 296.K/MB.01/MEM.B/2023, regarding the Determination of Types of Commodities Included in the Critical Mineral Classification, 47 minerals are classified as critical minerals. In addition, unspecified rare earth metals have the potential to add up to 16 minerals. Indonesia has a significant potential to use critical minerals for the manufacturing industry for renewable energy supply chain under the “downstream” program, especially for technology that relies heavily on critical minerals such as solar PV, wind turbines, and batteries. Utilizing domestic raw materials and controlling product markets through “downstream” programs with domestic development and adoption should be a priority.

a. Silica/quartz downstreaming

As the main materials for solar PV, the realization of silica sand mining in 2022 was 3.5 million tons and 330 million tons of total reserves. Meanwhile, total quartzite resources are estimated at 297 million tonnes (Indraputra, 2023; GoI, 2023). Indonesia was the third biggest exporter of silica sand to China in 2021, shipping USD 53.1 million (Indraputra, 2023). The current domestic market potential value from the import of silicon wafers is USD 17.7 million, as well as USD 120 million for semiconductor products, USD 6.2 million for unassembled solar cells, and USD 65.9 million for assembled solar cells (GoI, 2023). This value will rise in tandem with the growing demand for solar energy adoption, which, of course, must be used to drive domestic industrial growth.

Indonesia has total silica reserves amounting to 330 million tonnes, in addition to supplementary quartzite resources totaling 297 million tonnes (IMA, 2024). This positions the country as a significant provider of raw materials for the semiconductor and solar PV manufacturing industries. The Indonesian government is designing an action plan for silica/quartz downstreaming, which is expected to include the development of a downstream silica roadmap into wafers, semiconductors, solar cells, and solar modules. Silica downstreaming investment might reach USD 45.74 billion by 2040, providing USD 12.52 billion to GDP and 202,261 employment (Indraputra, 2023).

b. Copper downstreaming

Copper downstream is part of Indonesia’s national program and is projected to meet the needs of manufacturing components for solar PV, wind turbines, batteries, and other electricity generation components. Five point five million tons of copper per MW solar PV were primarily used for the fabrication of heat exchanger units and electrical cabling. Meanwhile, 4.8 Mt copper were used per MW of onshore wind and 10.54 tons for offshore wind. Copper makes about 53% of a 3 MW PLTB wind turbine’s overall weight. 24% allocated to turbine components, 23% employed in transformers (Virtual Capitalist, 2021; MEMR, 2022; BKPM, 2022). In the case of batteries, the typical 64 kWh battery in a full EV requires 25.4 kg of copper as a component to transport electricity from the cell (Jeffs, 2024).

As of 2023, Indonesia’s total reserves of copper ore amounted to 2.85 billion tonnes, while the total reserves of copper metal were recorded at 21.41 million tonnes (Tanisha et al., 2024). Annual copper concentrate production capacity is expected to reach almost 9.6 million tons, while copper cathode production capacity is expected to reach nearly 2 million tons in 2045, which both are more than four times greater than in 2020 (MEMR, 2022). According to estimates, the added value contribution to GDP would rise by USD 6.8 billion annually if copper commodities could be used for domestic purposes (MEMR, 2022).

c. Nickel and cobalt downstreaming

The downstream nickel and cobalt industry will be essential for the future development of the lithium battery sector and the EV ecosystem. Furthermore, the nickel and cobalt contribution to the stainless steel sector, coating industry, casting industry, and metal alloy (superalloy) sector will also support the renewable energy industry, including solar PV systems, wind turbines, and other renewable energy sources. Indonesia has significant nickel resources of 17 billion tonnes, with reserves of 5 billion tonnes, and projected investment potential of 407 GWh in the EV battery industry (MEMR, 2024).

By 2045, the establishment of nickel-based cathode and battery cell manufacturing facilities is projected to achieve a cumulative capacity of 70 GWh per tonne. The addition of High Pressure Acid Leach (HPAL) and nickel sulfate product facility capacity is up to 620 thousand tonnes of Ni annually, as well as enhanced nickel production for superalloys with a capacity exceeding 107 kt per year (MEMR, 2022). The Indonesian government has prioritized the nickel downstream industry for EV batteries, which are expected to have a market potential of USD 5.91 trillion by 2045. Furthermore, nickel and cobalt downstream may enhance investment value by USD 127.90 billion, GDP contribution by USD 43.20 billion, demand of USD 365 billion, and employment of 357,000 people (Fauzan, 2024; CGSI, 2024).

d. Aluminum downstreaming

Aluminum is an essential element in solar PV, electrical transmission systems, wind turbines, batteries, electric cars, and stand-alone. Aluminum can also be used as an alloy element in many applications owing to its lightweight strength, unparalleled corrosion resistance, and durability. Bauxite reserves are estimated to comprise 1.2 billion metric tonnes, which constitutes approximately 4% of the world's total bauxite reserves (GoI, 2023). By 2035, the aluminum industry is projected to serve as a foundational material for the battery, EV, and renewable energy sectors, with an anticipated total capacity exceeding 165,000 tonnes. Initiatives are also underway to augment aluminum metal manufacturing capacity to 8 million tonnes annually by 2040. Further, the combined amount of aluminum downstream taxes and projected non-tax state revenue (PNBP) is expected to reach USD 3.28 billion by 2045 (MEMR, 2022).

e. Iron and steel downstreaming

The primary advantage of iron and steel commodities is their provision of raw materials for downstream businesses across all sectors, including power generation, manufacturing and construction, processing industry, logistics and transportation, commercial building, residential, and even daily usage applications. Indonesia has iron ore reserves totaling 2.9 billion tonnes, with an annual production of 11 million tonnes. In addition, there are 941 iron sand reserves, with annual production reaching 16.6 million tons (MEMR, 2020). The projected production capacity for 2050 aims to achieve 38 million tonnes of steel, 30 million tonnes of hot-rolled coil (HRC), 10 million tonnes of plate, 25 million tonnes of cold-rolled coil (CRC), 24 million tonnes of coated sheets, 11 million tonnes of pipe, 45 million tonnes of steel billet, 25 million tonnes of bars, 14 million tonnes of wire rod, and 8 million tonnes of sections for diverse applications (MEMR, 2022). By 2045, it is projected that taxes and PNBP from iron and steel downstream will reach USD 2.2 billion (MEMR, 2022).

Ultimately, Indonesia's "downstream" program, which will consist of at least silica/quartz, nickel, aluminum (bauxite), iron and steel, gold, silver, and copper commodities, if appropriately implemented, will bring prosperity to the country in many ways, including the development of the manufacturing industry. It is important to raise the issue where innate commodities can also be processed from previously mentioned commodities of the downstream program, as illustrated in Fig 5.3. For example, as one of the leading state-owned companies, PT Timah has successfully extracted 300 tonnes of rare earth metal monazite, an innate commodity derived from tin minerals (cassiterite). Every 1 tonne of tin ore contains 0.95% monazite, which can be used as a coating for fighter aircrafts, satellites, and electric batteries. This monazite mineral is generally monazite cerium, which molecularly contains 5.5% thorium oxide. Thorium is a radioactive element used in several applications, including nuclear energy, ceramics, and glass. It is predicted that the total potential of the reserve is up to 22,000 tons of Monazite and 1,000 tons of thorium under PT. Timah's strategic planning (Ministry of Defense, 2019; Kata Data, 2022). In addition, PT Timah also plans to monetize innate commodities in the form of zircon, which will amount to 944 tons by 2024 (JPNN, 2024). There are still other rare earth metals—innate commodities potential—that have not yet been utilized under PT Timah, such as lanthanum, cerium, and neodymium. These rare metals have a critical function in the development of renewable energy (Ministry of Defense, 2019).

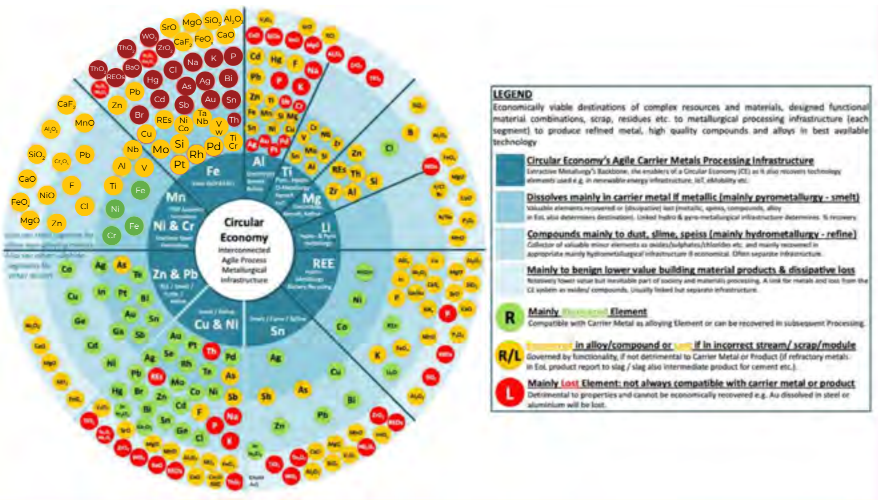

Fig 5.3. The metal wheel displays an interconnected carrier metal cycle, including the main and innate commodities

ii. Securing and diversifying foreign and local supply chains

Certain worldwide sources of materials and components might be deemed "insecure" for the energy industry, even though global supply chains are not always at risk and are often required owing to resource availability or economics. The global energy industry encounters various issues and requires close monitoring, especially due to the highly fluctuating costs of raw materials, components, and final products. In order to produce clean, green, and sustainable energy, companies face challenges from the government, public/private sector, and consumers. It is not possible for them to accelerate the process of producing clean, green, and sustainable energy without a reliable framework. The supply chain issues that Asian companies need to focus on and the supply chain key practices are illustrated in Fig 5.4.

Biggest Disruptions to Asian Corporate Supply Chains

57%

Availability (Supply) of Inputs/ Raw Materials

"Global shortage of several important commodities have not only affected our production but also led to an increase in cost."

44%

Logistics

"Congested ports in addition to labor shortages have greatly increased (2-4 weeks) the time required to ship goods from one location to another."

11%

Fluctuations in Demand

"Demand has declined, our warehouses are full and we would have to cut prices in order to generate additional demand."

7%

Productivity

"Shortage of foreign labor due to policies set in place by the governments. We this has been resolveacity."

Key Practices to Build More Resilient Supply Chains

41%

Diversifying Supply Chain

- Adding sources in addition to primary supplier (mostly China +1/+2)

28%

Agile Supply Chain

- Ability to forecast demand/supply with greater accuracy
- Ability to adapt and react to changes in demand and supply efficiently

22%

Optimizing Risk Management

- Long-term contracts with suppliers/ shipping providers
- Increasing inventory levels
- Utilizing FX/interest-rate contracts

9%

Reshoring Supply Chain

- Adding domestic/regional sources for raw materials

Fig 5.4. Asia's Large Corporate Trade Finance Study is conducted annually to pinpoint supply-chain concerns and its key practices

The excessive dependence on China for essential components, including rare earth elements, polysilicon, and supply chains for solar PV systems, wind turbines, and batteries, has heightened geopolitical and trade tensions that may also affect Indonesia (Kearney, 2024; WTW, 2023; Forbes, 2024; WoodMac, 2024). Moreover, when this is combined with the potential for international price fluctuations, environmental, social, and governance (ESG) issues, resource shortage issues, and logistics delivery process risks, the risks become even more complex and may affect globally, including Indonesia. In the context of the global economy, diversified supply chains that span multiple geographies and produce substantial economic benefits for the countries are essential. Learning from the EU experience, they diversified their imports through the enactment of the European CRM Act to reduce strategic dependencies, enhance the EU's capacity to monitor and mitigate risks of disruptions to the supply of critical raw materials, and enhance circularity and sustainability(EU, 2025). This global increase in stability and prosperity has been facilitated by the intricate networks of supply chains. Supply chain diversification is essential to selecting and prioritizing suppliers that meet needs, standards, regulations, and innovation. Diversification also secures supply, standardizes prices, and minimizes price fluctuations.

The supply chain diversification is very important to secure supplies that are rare or limited domestically, whether in the form of raw materials, semi-finished materials, finished products, or ready-to-use products. In the context of developing the manufacturing industry for renewable energy, supply chains involving critical minerals and certain latest technologies have a critical position to compete and be at the forefront in the domestic and global market.

iii. A better management approach to manage the end-of-life waste and second-life use

It is increasingly important to note that in the next 10 years, the amount of waste from clean energy infrastructure, such as old renewable energy technology, is expected to rise by up to 30 times (EEA, 2023). Approximately 70 million metric tons of solar PV panels, 43.4 million wind turbine blades, and up to 1 million lithium batteries will reach their end of life by 2050, with a significant portion coming from China, the EU, and the USA (Zhdaneev et al., 2024). Meanwhile, in Indonesia, the potential amount of final waste will depend on the government's seriousness in encouraging the adoption of clean energy infrastructure. The importance of waste, especially those generated by batteries, as an energy storage system is increasing. In early Q4 2024, it is estimated that Indonesia will have a collected used battery capacity of 12,676 MWh by 2030, waiting for its end-of-life management (IESR, 2024). In empowering the circular economy value and good management-saving of limited mineral resources, second-life usage should be taken into account as part of the end-life management in dealing with Indonesian and world waste of clean energy infrastructure. The concept of "second life" pertains to the practice of repurposing or reprocessing items that are no longer in active use. Second life in renewable technologies of solar PV, wind turbines, and batteries can also be done to generate profits, consisting of:

- Establishing a secondary marketplace that extends the service life of renewable energy in generating clean energy with solar PV and wind turbines. Meanwhile, batteries can be used as energy storage and supply energy as needed. In this case, repairing the damage and restandardizing becomes desirable to generate maximum benefits.
- Reuse by replacing its original function in producing energy to be physically or aesthetically useful
- Utilization of recycled materials in the production of renewable energy technologies and other items.

Recycling renewable energy technology components has the potential to reduce demand for new materials and their carbon footprint significantly. Some of the materials used in these technologies are poisonous, while others have high value but are difficult and expensive to obtain, process, and recover. Thus, additional skills, incentives, and strategies for managing end-of-life materials are required.

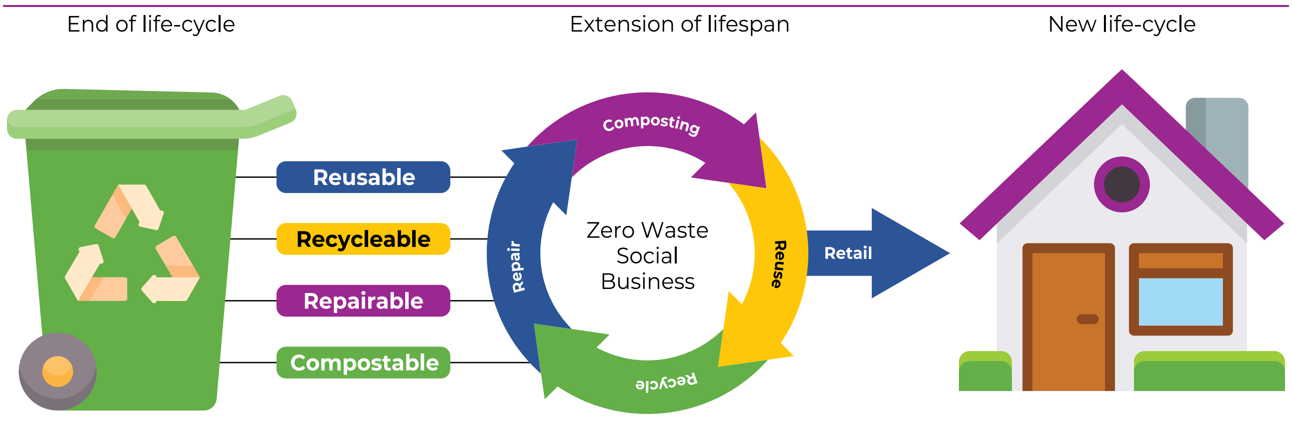

Fig 5.5. Waste management as a social business for product lifetime growth

As shown in Fig 5.5., there are numerous challenges associated with the recovery and reintroduction of materials into the manufacturing cycle, such as the presence of hazardous chemicals, the need to retrieve large quantities of material from remote locations, and the design that fails to consider end-of-life or recyclability (EEA, 2023).

In terms of the three energy product technologies—solar PV, wind turbines, and batteries— almost all material composition is recyclable, as depicted in Fig 5.6. Meanwhile, the challenge and opportunity in recycling of solar PV, wind turbine, and battery is presented in Table 5.1. The establishment and execution of a circular economy are essential components of a sustainable approach to renewable energy waste. For instance, IRENA predicted that global solar PV waste will reach at least 78 million tons by 2050 (IRENA, 2016). Nevertheless, the effective management of renewable energy technology waste necessitates advanced technology and enhanced policies that promote the reuse of these materials.

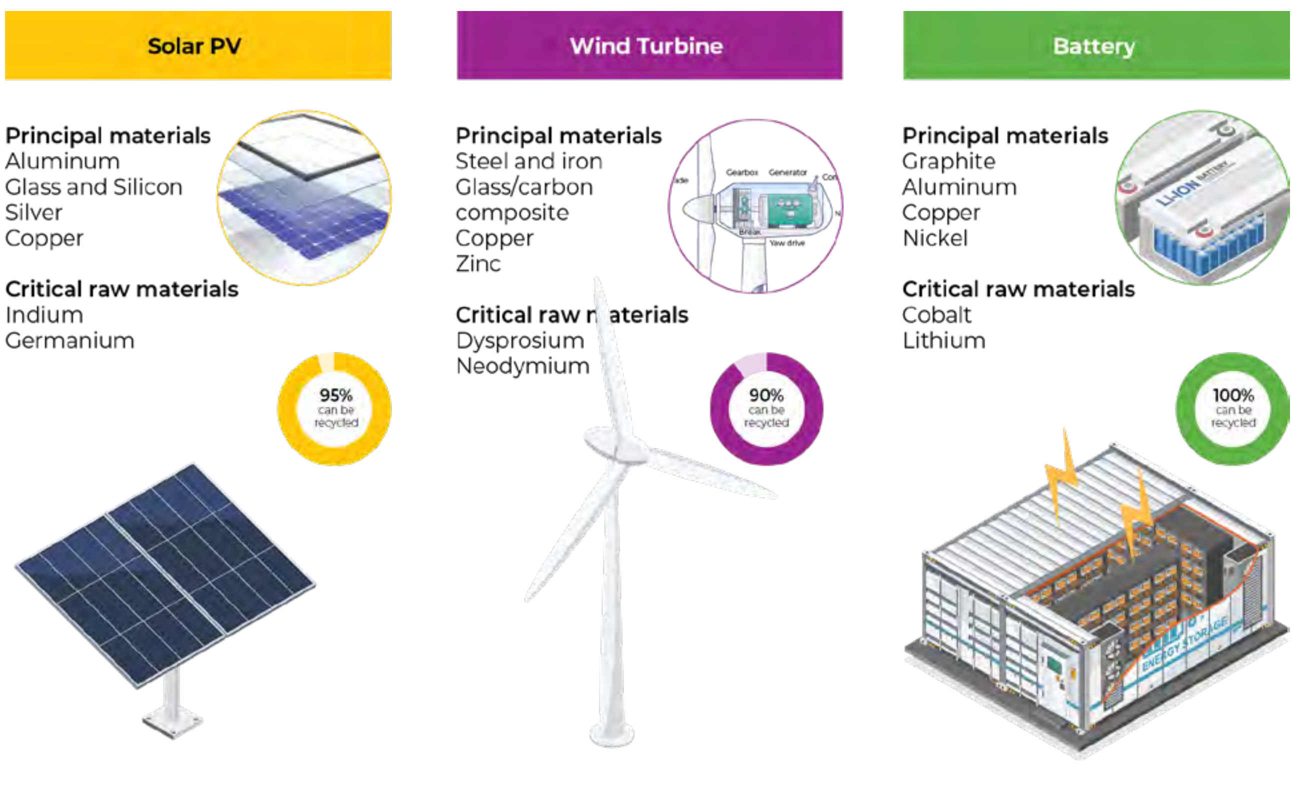

Fig 5.6. Possibilities of material recovery from solar PV, wind turbine, and battery

Table 5.1. Challenge and opportunity in recycling of solar PV, wind turbine, and battery

Solar PV	
Opportunities	Glass, copper, aluminium, and other components can be recovered up to 95%.
Challenges	Breakdown of the solar PV module, including delamination, silicon separation, and purification from glass and semiconductor thin film, provides major technical and economic challenges for PV recycling.
	Separating and extracting dangerous materials, such as cadmium, arsenic, lead, antimony, polyvinyl fluoride, and polyvinylidene fluoride, present additional difficulties for recycling solar PV modules.
	End-of-life issues related to solar PV built at heights present extra hurdles due to access issues and maintenance history, which are often overlooked during the PV system design process.
	Long life with no guarantee when it will be recycled.
	The composition of solar panels varies greatly and is not consistent.
Wind	
Opportunities	Most materials, like steel, aluminum, copper, cast iron, and concrete, can be recovered up to 90%.
	Recycling permanent magnet generators of wind turbines may be profitable depending on future trends and concentrations of critical raw materials (neodymium, praseodymium, boron, dysprosium, and niobium).
Challenges	Recycling infrastructure is still under development for turbine blades made of lightweight materials like carbon fibre, glass fibre and composite materials, are further research and implementation are needed.
	Potential for recycling of carbon fibers into plastic-molded Euro pallets and polymer concrete, noise-proof barriers, and thermal insulation materials.
	Considering the large sizes of the blades, long-distance hauls to recycling facilities may be prohibitively expensive.
	Blades are often constructed from carbon fiber or plastic (polymer), and separating, breaking down, and recycling the polymers from the binding resin is exceedingly difficult.
	Complex structures and mixed materials make them difficult to recover.
Battery	
Opportunities	All metals utilized in batteries are recyclable. Battery recycling might be profitable if the mineral prices are high and sufficient amounts are recoverable. Critical minerals composition in batteries, including non-available minerals in Indonesia, can be generated for the domestic manufacturing industry.
	Modular or uniform design and better knowledge of the makeup of high-impact materials are two ways to increase circularity.
Challenges	Battery designs vary widely, necessitating distinct logistical strategies.
	Waste battery storage and transportation infrastructure must be improved in order to handle the expected future high volumes of battery end life.
	There are not enough battery recovery methods and large-scale recycling facilities in the world.
	Due to changing material prices, it can be hard to make reusing batteries cost-effective and generate profit.
	Taking expensive steps to lower the risk of a "thermal runaway" during transport and handling is needed to keep people safe.
	Battery recycling is challenging due to the variety and complexity of battery designs.

Source: Analysis adapted from EEA, 2023; Tamesol, 2024; Resources, 2023; Ewasa, 2024; Orsted, 2024; Kubiak, 2023; Qurator, 2023

iv. Improved data management for sustainable supply chain analytical capabilities

To construct and sustain reliable energy sector supply networks, it is helpful to have access to data and analytical tools that may assist this process. The data and analytical tools are particularly important for monitoring and controlling the production and supply of the high demand for specific materials and materials that are derived from critical minerals. Further, the data management system can also cover product components, finished products, product sales and consumption, and end-of-life products. This will aid in decision-making for addressing new risks, opportunities, vulnerabilities, and threats that may arise in the supply chain.

All data processing and analysis techniques are intended to be used in order to examine vast amounts of data, uncover hidden data structures (correlations, patterns), and assist in the formulation of public policies and business decisions that impact nearly every link in the value chain (sourcing, manufacturing, distribution, and logistics). Thus, it is easier to manage data governance in order to mitigate supply crises as well as crime action prevention. The goal of supply chain analytics is to use data-driven decision-making to enhance supply chain performance.

In the context of Indonesia, where data transparency and management are still not ideal, the development of this system presents its own challenges, especially in the middle of many conflicts of interest from various key stakeholders. In some instances, the mechanism for gathering data is either not yet operational or has not yet been established, particularly those involving the private sector and data collection from civil society, such as industry, transportation, buildings, and households. It is very important to take a comprehensive view of the entire supply chain and how to improve it as a whole, as depicted in Fig 5.7.

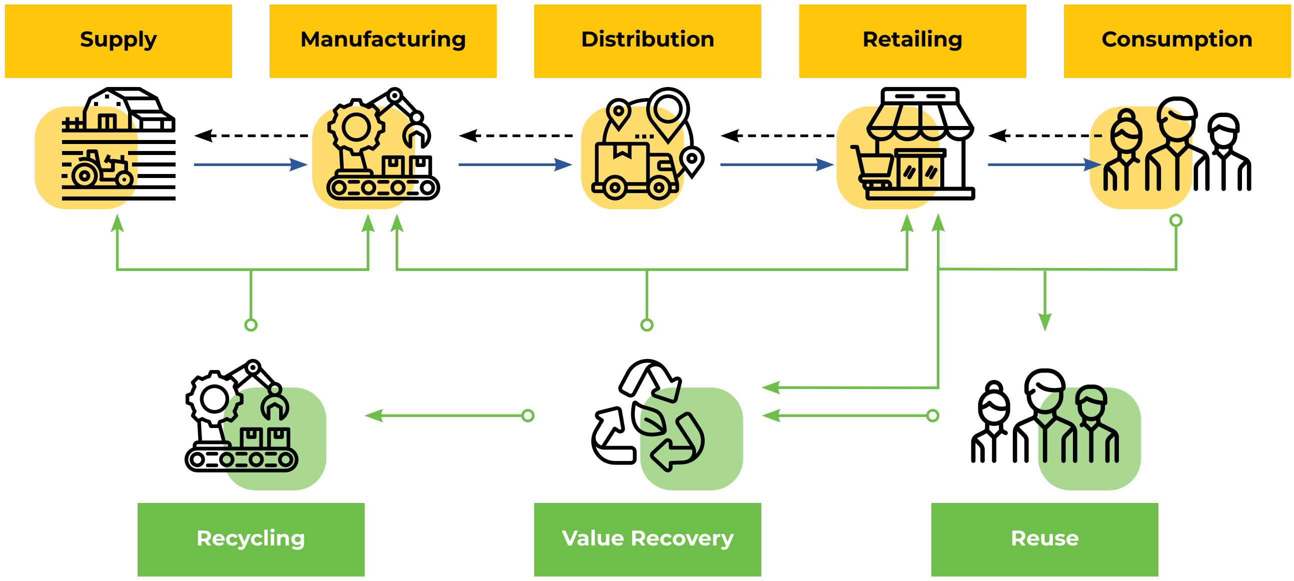

Fig 5.7. Sustainable supply chain value mapping

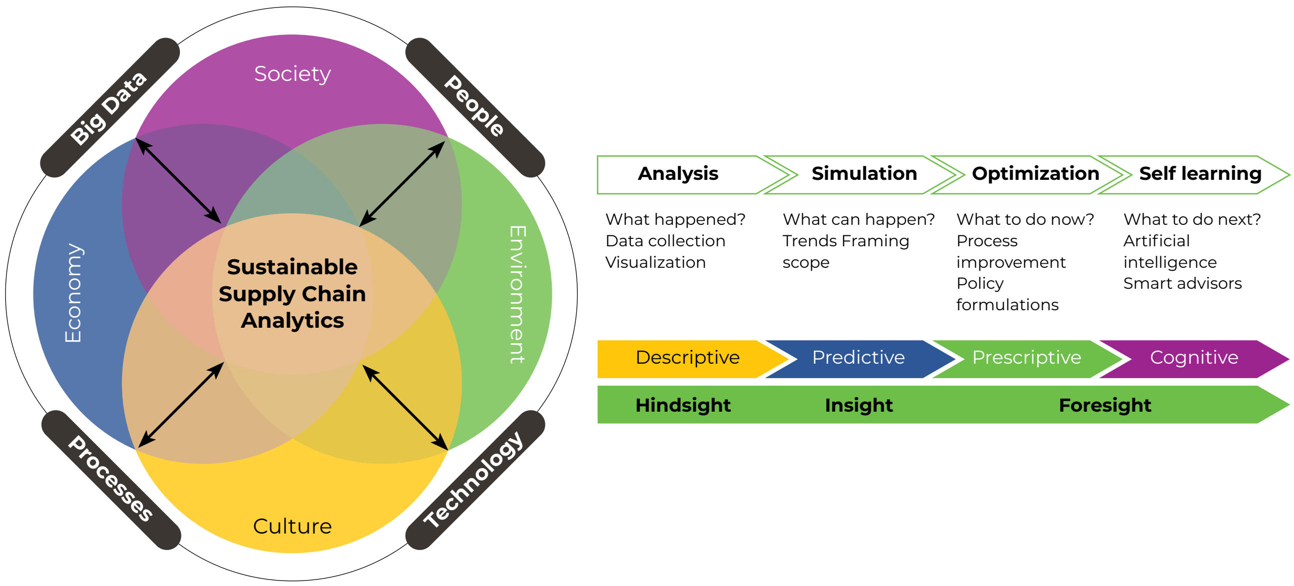

Fig 5.8. Sustainable supply chain analytics

As illustrated in Fig 5.8., people (as consumers and employees), technology, big data, and processes (the transformation of resources/inputs into value-added products/outputs) are the interconnected components of the sustainable supply chain analytics landscape. Furthermore, sustainable supply chain analytics must be able to provide descriptive, predictive, prescriptive, and cognitive analytical capabilities to create a sustainable and robust supply chain.

B. Policy and regulatory framework assessment

The government of Indonesia publishes regulations about setting renewable energy targets. These targets, which are regulated in the Regulation No. 30 of 2017, set 23% adoption of renewable energy by 2025. However, current progress is lower than the expected target. Indonesia only reached 14% renewable energy adoption per 2024 (HEESI, 2024). This indicates that the government does not have enough ambition to increase the demand for renewable energy. If there is no demand, there will be no market for renewable energy technology. Furthermore, the demand for batteries only showed by EV adoption, which reached 200,000 units of EV sales (E4W and E2W) in 2024 (GAIKINDO,2024). Demand for energy storage is only planned in the National General Electricity Plan. The government of Indonesia has to push the demand for renewable energy, EV, and energy storage so the supply chain can be developed.

The current regulations on developing supply chains have been focused on some areas. For the solar PV supply chain, Indonesia is not capable of manufacturing solar cells, although there have been a few solar module manufacturers. Solar module manufacturers will need the solar cell as it is the key component for solar PV. The government should push more investors to invest more in solar cell production. For batteries, currently, the development of refining and mining of nickel has been going in a good direction since there are nickel refining plants that process nickel to battery raw materials.

In recent years, the solar and battery supply chain policies have experienced inconsistencies across various government plans (e.g., RUKN, RUPTL, KEN), especially in terms of LCR regulation. Ideally, there must be a target alignment between LCR regulation and renewable energy planning.

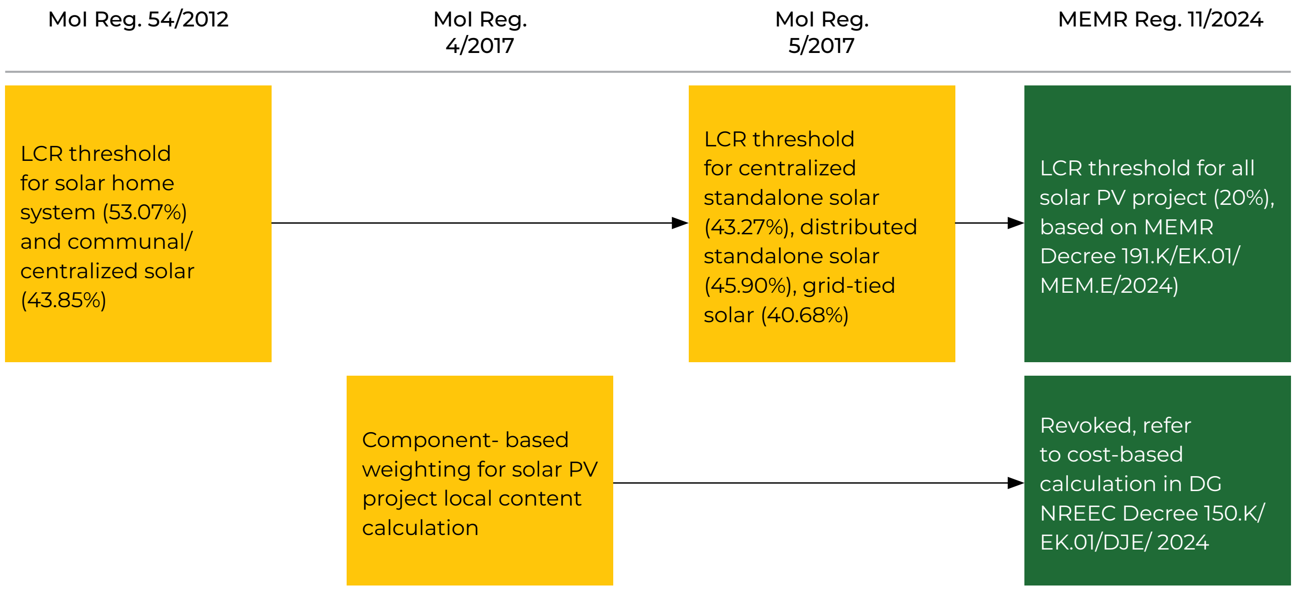

Fig 5.9. Indonesia’s solar PV project local content requirement policy timeline

In recent years, the government has set several minimum LCRs for solar panels. In regulation number 54/2012 issued by the Minister of Industry (MoI), the LCR threshold for solar panels was 44%. Then, in 2017, it was regulated with additional terms for centralized standalone solar (43.27%), distributed standalone solar (45.90%), and grid-tied solar (40.68%). In 2024, the Ministry of Energy and Mineral Resources issued new regulations that relaxed the LCR regulation No. 11 of 2024, which not only regulates solar panels but also wind turbines. This regulation was then revoked; refer to cost-based calculation in DG NREEC Decree 150.K/EK.01/DJE/ 2024, which addresses the minimum LCR for each power plant project. The minimum LCR for solar panel projects is 20%, and for wind turbine projects is 15%. The latest regulation does not mention a specific clause on the minimum proportion of RE main components like solar modules and wind turbines. These main components have higher value-added but do not have special weight on LCR calculation in current regulation. Without relying on the LCR for the main component, the project can still fulfill the LCR requirement by calculating the contribution of supporting services and components. This regulatory inconsistency has led to complaints from several manufacturers. It can also cause investors to hesitate when considering investments in the industry, resulting in delayed investment.

MEMR regulation No. 11/2024 also mentions incentives. The regulation introduced incentives to boost renewable energy technology projects. However, these incentives only address the price preference of components for the project. They do not support the supply chain itself. As a result, the project can gain incentives without noticing the development of the main components' industries.

The current regulation (MEMR regulation No. 11/2024) only concerns the minimum LCR percentage needed to build the power plant. It has not yet adequately addressed technology transfer, infrastructure financing, or access to capital for domestic players. To accelerate domestic production of renewable energy technology, it is crucial for the government to provide financial support alongside technical and operational assistance.

The adoption of LCR in Indonesia is also doubted because the certification only considers the required content. Some of them even have lower quality than the imported components, which could decrease the competency of local products.

The current regulatory framework for energy transition does not mention skilled workforce development. Although the Indonesian Ministry of Planning has released an occupation map on green jobs, which the Ministry of Manpower then translated into a national standard for working competence, this standard only discusses developing green jobs. It does not state the development of technical ability to work in renewable energy manufacturing (Ministry of Manpower, 2025; BAPPENAS, 2022).

C. Benefits of establishing the supply chain

The development of a domestic manufacturing industry to produce solar PV, wind turbines, and batteries has many benefits. There are at least five main benefits that can be taken into consideration and need to be maximized, especially in the domestic utilization of natural resources, and human resources. These benefits encourage economic life and community welfare, increase national energy security, and promote the country's economic resilience as explained below:

1. **Greater control over product markets and supply chains while empowering domestic raw materials and industrial growth.**

   Occasionally, market creation can be initiated or supported by the government through government spending in the form of gross investment or domestic consumption. This can be done simultaneously to make domestic manufacturers more competitive or to foster expansion in the manufacturing sector. Market formation for the manufacturing industry can be initiated through the establishment of the obligation to adopt renewable energy, use of electric vehicles, and the like.

   Understanding the specifications, design, and product quality standards assurances, as well as the impact of climate, weather, and environmental variances across countries compared to Indonesia, is critical (UN 2024; ISO, 2024). Depending on the climate, weather, and environmental conditions, there will be differences in the specifications of the materials and designs required. Incompatibility thereof can cause a decrease in performance, durability, and service life. In addition, there is a potential for incompatibility with government policies regarding technical, environmental, and economic aspects in meeting domestic needs as well as in building an industrial manufacturing domestic ecosystem for renewable energy and its supply chain. The government has more enforcement power when imposing standards and specifications for products. It can provide incentives directly or indirectly depending on compliance, accompanied by more binding supervisory controls on domestically produced products than imported products. Therefore, the creation and distribution of renewable energy technology products may more readily meet domestic market demand in accordance with government policies.

The availability of domestic raw materials and components at affordable or low prices will significantly reduce production cost and make products more competitive and affordable for the users in domestic and international markets (IMF, 2024). By sourcing materials domestically, these manufacturers can decrease their reliance on overseas production (Pas, 2025; DEG, 2018). This is particularly important to maximize the potential of local raw materials, which will undoubtedly be followed by the development expansion in the industrial sector of the mining, extraction, and other industrial processing sectors in line with the Indonesian government's downstream program. The utilization of local natural resources can be controlled by the government to deliver the highest potential advantages for domestic demands, particularly in terms of national energy security and economic resilience. This will be further explained in Sub-chapter 5.a., which addresses the four factors constituting risks of the supply chains.

2. **Potential savings from imports to the domestic scope and trade administration control**

Import products normally have longer lead times due to the need for customs approvals. When items are manufactured overseas for domestic consumption, the cost of getting them to market is also significant. Exorbitant transportation expenses relative to the items' worth have an effect. As a result, imports from distant nations are difficult to compete with locally produced items (IMF, 2024). In terms of carbon footprint impact, overseas manufacturing often has a much higher carbon impact and sometimes with unknown credibility (Raab, 2023). Challenges emerge due to renewable energy adoption challenges, less rigorous carbon objectives, and long-distance transportation with a high carbon footprint, which may decrease the value of renewable energy adoption in reducing carbon emissions.

Customs play a key role in determining whether to manufacture a product domestically or overseas, even if qualified manufacturers abroad may assist their domestic customers in managing these costs. The prospect of conserving foreign exchange by establishing industries to manufacture products that were previously imported is one of the most potent incentives (IMF, 2024).

3. **Potential to optimize the recycling industry integrated with the manufacturing industry**

The collaboration between the recycling and manufacturing industries for renewable energy technologies like solar PV, wind turbines, and batteries is vital. These technologies rely on materials such as rare earth metals, lithium, and silicon, which are not only finite but also environmentally challenging to extract. By creating a strong recycling system alongside production, the industry can extend the lifecycle of materials and ensure a more sustainable supply chain. This approach transforms the manufacturing ecosystem into a more resilient and self-sufficient model, balancing production and recycling as complementary processes.

To a greater extent, the manufacturing sector has the capacity to manage its own waste, which may originate from rejected products during the manufacturing process, product claims from end users, and end-life waste collected from end users. The collected waste will be recycled and converted into raw materials for the production of new products. In order to maximize component reuse, recycling, and remanufacturing, the manufacturing sector designer may alter the product's interfaces or structure (Shahhoseini et al., 2023). The design approach for this purpose is expected to minimize waste while maximizing economic value and reducing GHG emissions in an effort to implement a circular economy.

The recycling industry can be integrated with the manufacturing industry so that recyclable materials can be reused and become part of the production cycle. If not integrated, the manufacturing sector may enter into a partnership with recycling companies that specialize in bridging the divide between the creation of waste byproducts and collecting recyclable waste from end users. This partnership enables producers to identify acceptable refuse markets and establish new relationships that may influence future business models. This can certainly minimize the potential for raw material shortages that may arise if relying solely on the mining and extraction sector.

4. **Reducing vulnerability to global fluctuation price**

   Some of the factors that compel suppliers to increase prices include abrupt surges in demand, raw material shortages, supply chain disruption, and natural disasters (Stecke et al., 2009; Oracle, 2023). When a country relies on international markets through imports, the fluctuations in international market prices can lead to unexpectedly higher prices, which will result in difficulties in acquiring the required technology. The global market demand is impossible to control by the government except under an agreement. This certainly needs to be taken into consideration amidst the global issue of carrying out an energy transition to renewable energy to reduce GHG emissions and fulfill international commitments made by all countries in the world. In situations where demand factors and conflicts of interest from global countries can result in unreasonable high price fluctuations.

5. **The benefits of job creation, economic circulation movement, and ease of access to technology**

   The development of the domestic manufacturing sector would help to increase the economic circulation movement in the domestic market from job creation opportunities, industrial activities of manufacturing sectors for renewable energy, and its supply chains, as well as activities in the ecosystem (Fig 1.3.) (OECD, 2014; Unido, 2023; ECB, 2024). The potential value of economic circulation movement from renewable energy market size assessment of Indonesia is further explained in Sub-chapter 5.d. while job creation is described further in Sub-chapter 5.e. A further benefit includes easy access to technology for adoption both by communities and the country. Due to a more established labor/skilled worker, technology logistics, and infrastructure, the economic power gained by individuals, communities, and countries minimizes the burden of renewable energy adoption. Moreover, with the control through government regulations, domestic users' access to technology can be more easily fulfilled with the DMO mechanism.

D. Renewable energy market size assessment

The calculation for the cost of project elements and job creation is conducted by referring to the demand projection of 2020-2030 RUPTL business as usual (BAU) scenario and the Official 2024 RUKN, as shown in Table 5.2. However, it should be noted that this value is only limited to the assembly process as a unit manufacturing industry for project needs until the project is up and running. There is still greater potential for the development of the supply chain and industry ecosystem in the energy sector (Fig 1.3.).

Table 5.2. Cumulative demand projection referenced to 2020-2030 BAU RUPTL and Official 2024 RUKN

BAU (2020-2030 RUPTL)	**Technology**	**in GW**
	Solar energy	84.5
	Wind energy	55.7
Cumulative 2060 target (Official 2024 RUKN)	**Technology**	**in GW**
	Solar energy (Primary energy mix only)	109.4
	Solar energy (Primary energy mix plus green hydrogen production)	267
	Wind energy (Primary energy mix only or plus green hydrogen production)	73.2

Apart from targeting the domestic market, Indonesia's manufacturing industry for renewable energy can also target the Southeast Asian export market. In early 2024, solar energy installed capacity reached 19 GW while wind energy reached 9 GW (Carbonbrief, 2024; Bhandari, 2024). These numbers are still far from the Southeast Asian regional target of 2025, let alone 2040. The ASEAN Action Plan for Energy Cooperation (APAEC) Target Scenario projects that the solar PV capacity in ASEAN will increase from 32 GW to 83 GW from 2020 to 2025, and wind will reach up to 9 GW by 2025. The APAEC installed capacity target will continue to increase until solar energy capacity additions reach 51 GW and wind energy of 9 GW by 2040 (ASEAN, 2023a-b; Ember, 2024). The ASEAN market potential is expected to exceed 115 GW of solar energy and 9 GW of wind energy by 2040, according to the implementation of the APAEC target.

B.1. Solar PV supply chain market size

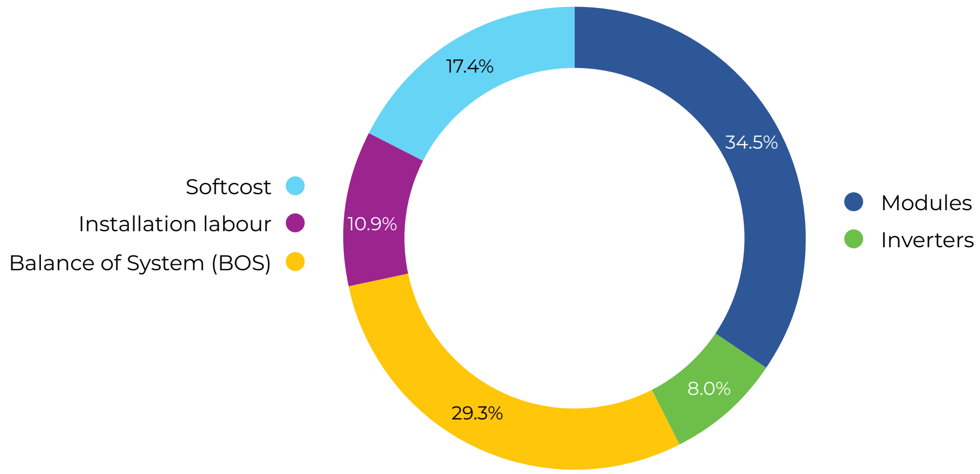

Fig 5.10. Element cost for solar project construction processes

The primary components of every solar farm construction are always the same despite variations in size, solar PV type, construction design, geography, and installed capacity. Numerous elements may influence the project's value. Fig 5.9. depicts the components of the solar project's construction with four primary groups: solar modules, inverters, soft costs, installation labor, and BoS. Maintenance, operational activities, and periods of operational inactivity have been excluded due to their inherent unpredictability and dependence on factors such as geographical location, technological advancements, and the stability of economic markets. Consequently, these costs may fluctuate significantly.

Taking into account the projection of Indonesia's needs to satisfy the need for renewable energy electricity from BAU (2020-2030 RUPTL), Official 2024 RUKN, and Cumulative 2060 Target (announced by MEMR). The economic value anticipated to be disseminated in conjunction with solar PV costs is estimated to be USD 962/kW. As shown in Table 5.3., the economic value driven by Indonesia's demand ranges from USD 72.0 billion to 110.6 billion. Referring to the previous discussion in Sub-chapter 2.b., Indonesia's industrial sectors have the potential to fulfill market requirements for module, soft cost, BoS, and installation labor, accounting for 92% of the total solar project construction process. This potential value is due to the consideration of solar module assembly process that has already taken place in Indonesia (Table 2.4.). Furthermore, solar modules can be made from silicon/quartz through an integrated process (Adani, 2025; Business Standard, 2024). Meanwhile, BoS, installation labor, and soft costs are categories of market elements that inevitably have to be carried out for domestic project work. Citing information from ISEO-IESR 2024, Indonesia does not yet have an industry with the required capability for inverter manufacturing, making this technology unable or having limited capability for development to be supplied from the domestic industry. Therefore, the domestic industry's potential coverage of the economic value flowing in the market might range from USD 74.6 billion to USD 236.3 billion (Table 5.3). It is essential, however, to encourage an ecosystems that is appropriate and acceptable, particularly with the goal of bolstering renewable energy for the solar PV supply chain. Further research is needed in an effort to maximize the benefits of the solar PV manufacturing industry and its supply chain in meeting domestic demand.

Table 5.3. Indonesia's demand value for solar PV based on projection 2020-2030 RUPTL, Official 2024 RUKN, and Cumulative 2060 Target (announced by MEMR)

Domestic Demand (Cumulative by 2060 Target)	Share (%)	BAU (2020-2030 RUPTL)	Official 2024 RUKN	
			Primary energy mix only	Plus green hydrogen production
		84.25 GW	109.4 GW	267 GW
Total Value*	962 USD/kW			
Modules	34.51%	USD 28.0 billion	USD 36.3 billion	USD 88.6 billion
Inverters	8.00%	USD 5.5 billion	USD 8.4 billion	USD 20.6 billion
BoS	29.26%	USD 23.7 billion	USD 30.8 billion	USD 75.2 billion
Installation labor	10.86%	USD 8.8 billion	USD 11.4 billion	USD 27.9 billion
Softcost	17.36%	USD 14.1 billion	USD 18.3 billion	USD 44.6 billion
Total of Indonesia's Demand Value	100.00%	USD 81.1 billion	USD 105.2 billion	USD 256.9 billion
Total Potential Coverage by Domestic Industry	92.00%	USD 74.6 billion	USD 96.8 billion	USD 236.3 billion

**based costs reported in 2022 USD exchange rate*
Sources: Adapted from ISEO-IESR, 2024; IRENA, 2019-2023

Considering the Southeast Asian export market potential of 115 GW of solar energy until 2040 from APAEC implementation, there will be a potential of another USD 101.8 billion economic value that Indonesia's domestic industry can cover.

B.2. Wind turbine supply chain market size

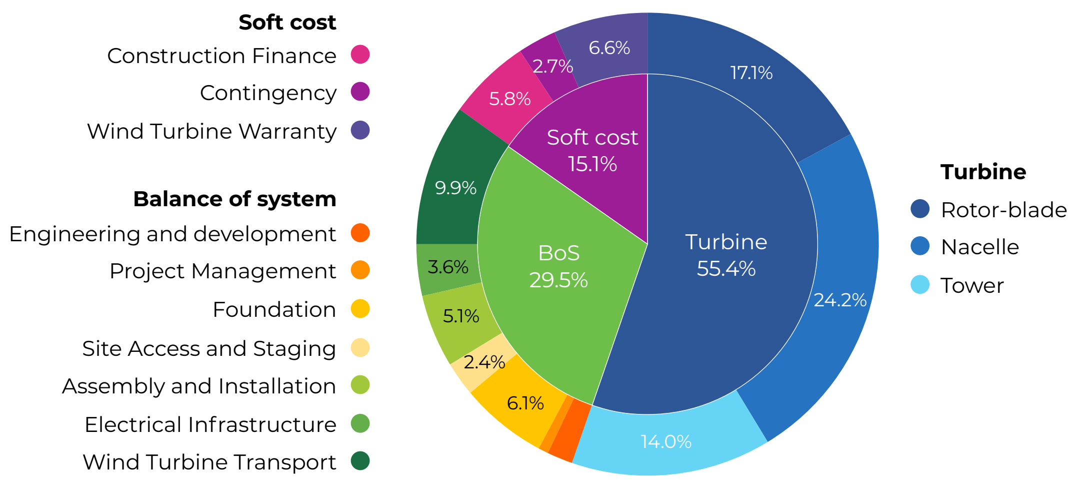

Fig 5.11. Component cost for wind project construction processes

The cost of a wind turbine construction project can vary based on numerous factors, including size, capacity, location, construction process, and technological advancements. Hence, there are many factors that can change the value of the project. According to NREL, the components of the wind turbine construction are depicted in Fig 5.11., which consist of three main groups: wind turbines, soft costs, and BoS. Similar to solar PV, maintenance and operation as well as operational downtime are not excluded.

Referring to the projection of Indonesia's demand to meet the need for renewable energy electricity from BAU (2020-2030 RUPTL) and Official 2024 RUKN, the potential circulated economic value is predicted by assuming the cost of a wind turbine reaches USD 1,750/kW. Based on the calculations that have been carried out, it is estimated that there will be a circulating economy from Indonesia's demand of USD 47.4-97.3 billion, as shown in Table 5.4. It is anticipated that, out of all the wind turbine project breakdown construction processes, Indonesia may participate and contribute to domestic fulfillment in the supply of BoS, soft costs, towers, and foundations, which accounts for 58.7% of the overall construction expenses referring to the previous discussion in Sub-chapter 3.b. This potential value is due to the consideration that the tower can be produced in Indonesia. Meanwhile, soft costs and BoS, similar to the case of solar PV, are market elements that inevitably must be carried out for domestic project work. In principle, they are similar to the needs of other power plants but with different complexity. Rotor blades and nacelles, as well as gear boxes and generators, although they have the same principles as gas turbines, steam power plants, and hydropower plants, which all can generate electrical energy from converting mechanical energy, have not yet been developed or are difficult to develop in Indonesia (Table 3.5). Thus, the economic value circulating in the domestic market may reach USD 57.1-75.2 billion if it can be covered by supply from the domestic manufacturing industry for renewable energy and its supply chains (Table 5.4). However, this certainly requires efforts to encourage the required ecosystem to be adequate and conducive, especially in building national independence in the wind turbine manufacturing supply chain. Further studies are needed in an effort to maximize domestic profits and contribute to meeting the domestic demand for wind turbines.

Table 5.4. Indonesia's demand value for wind turbine based on projection 2020-2030 RUPTL, Official 2024 RUKN and, Cumulative 2060 Target (announced by MEMR)

Domestic Demand (Cumulative by 2060 Target)	Share (%)	BAU (2020-2030 RUPTL)	Official 2024 RUKN
		55.6 GW	**73.2 GW**
Total Value*	1,750 USD/kW		
Rotor-blade	17.10%	USD 16.6 billion	USD 21.9 billion
Nacelle	24.20%	USD 23.5 billion	USD 31.0 billion
Tower	14.00%	USD 13.6 billion	USD 17.9 billion
Engineering and Development	1.80%	USD 1.8 billion	USD 2.3 billion
Project Management	0.70%	USD 0.7 billion	USD 0.9 billion
Foundation	6.10%	USD 5.9 billion	USD 7.8 billion
Site Access and Staging	2.40%	USD 2.3 billion	USD 3.1 billion
Assembly and Installation	5.10%	USD 5.0 billion	USD 6.5 billion
Electrical Infrastructure	3.60%	USD 3.5 billion	USD 4.6 billion
Wind Turbine Transport	9.90%	USD 9.6 billion	USD 12.7 billion
Construction Finance	5.80%	USD 5.6 billion	USD 7.4 billion
Contingency	2.70%	USD 2.6 billion	USD 3.5 billion
Wind Turbine Warranty	6.60%	USD 6.4 billion	USD 8.5 billion
Total of Indonesia's Demand Value	100.00%	USD 97.1 billion	USD 128.1 billion
Total Potential Coverage by Domestic Industry	58.70%	USD 57.1 billion	USD 75.2 billion

*based costs reported in 2022 USD exchange rate
Source: Adapted from NREL, 2023

Indonesia's domestic industry has the potential to generate an additional USD 9.25 billion in economic value by 2040, given the Southeast Asian export market potential of 9 GW wind energy from the implementation of the APAEC target scenario.

B.3. Battery pack supply chain market size

The cost of manufacturing batteries plays a crucial role in Indonesia's competitiveness within the global battery market.

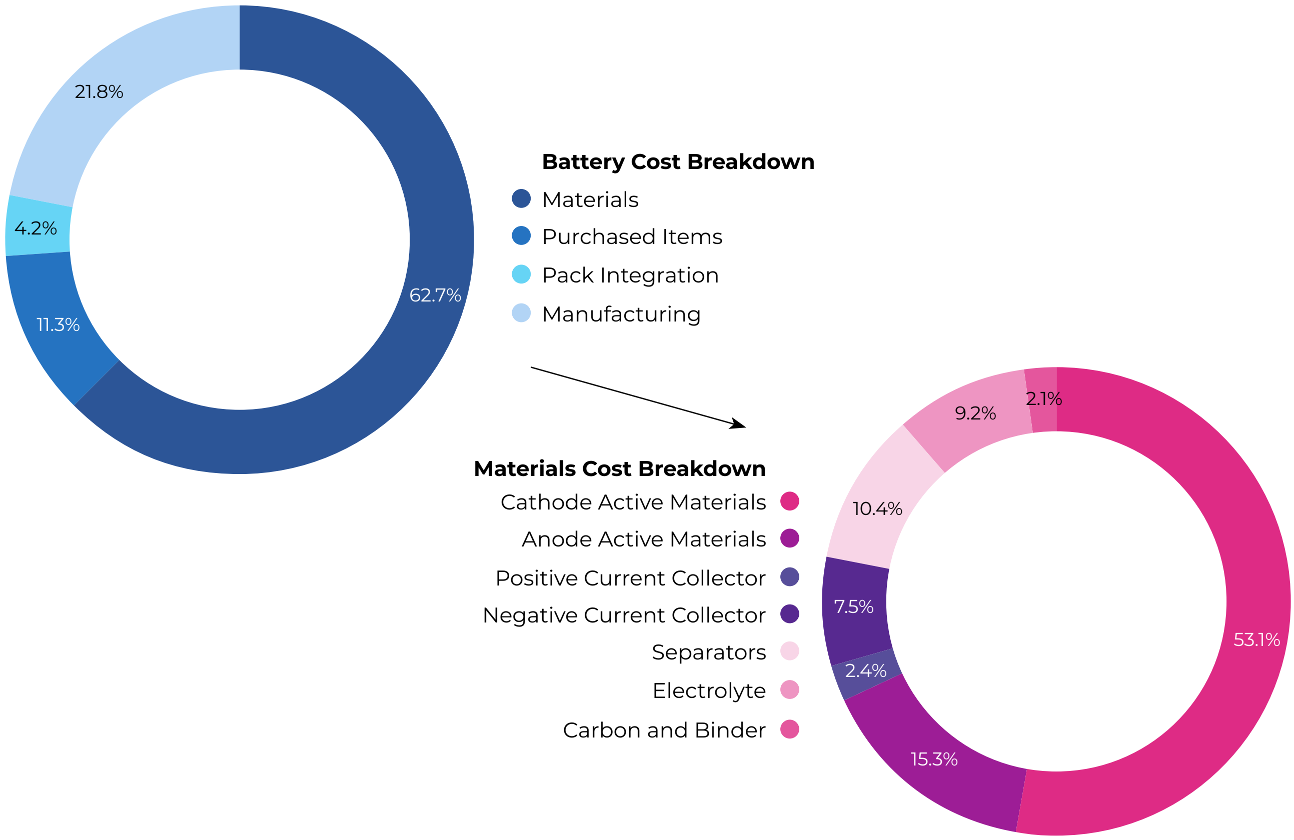

Fig 5.12. Battery pack and material cost breakdown of low-cost LFP 75 KWh BEV pack

The two pie charts presented in Fig 5.12. provides a detailed breakdown of the battery pack and material costs. In the left chart, materials account for the largest share (62.7%) of the overall battery pack cost, followed by purchased items (21.8%). This breakdown gives insight into the major cost components involved in manufacturing a battery pack for EVs. The right pie chart further details the materials cost breakdown, highlighting the individual material contributions within the material cost segment of the battery pack. Cathode active materials represent the largest percentage (53.1%), followed by anode active materials (15.3%). Other key components include positive current collectors, negative current collectors, separators, electrolytes, and carbon/binder materials, each contributing to the total materials cost. This breakdown emphasizes the significant impact of cathode materials on the overall battery cost, reinforcing the importance of material selection and optimization in reducing battery prices for EVs. The pack price to the original equipment manufacturer (OEM), is around 110 USD/kWh in 2024, while the materials account for up to 69.3 USD/kWh (Argonne National Lab, 2024).

GoI has set E4W and E2W target sales in 2060 at 38.3 million and 135 million units, respectively (MEMR, 2024). Assuming that for 1 E4W unit, the average battery capacity is 79 kWhAssuming that for 1 E4W unit, the battery capacity averaging to 79 Kwh (Europe Commission, 2024), and for 1 E2W unit, the average battery capacity is 3 kWh and 1 E2W unit the battery capacity averaging to 3 Kwh (Suwignjo et al., 2023), the total battery demand for both E2W and E4W is around 3228.2 GWh means that total battery demand for both E2W and E4W is around 3228.2 GWh. Looking to what Indonesia have and capable of to make the battery as discussed in Chapter 4, where Indonesia have nickel and able to make it the battery manufacturer which account for 61% of the overall battery pack cost thus the economic value circulating in the domestic market may reach USD 203 billion - USD 215 billion.

Table 5.5. Indonesia's demand value for battery EV based on Government target in 2030

Domestic Demand (2060 Target) in GWh	Share (%)	Electric 4-Wheelers	Electric 2-Wheelers
		3025.7	**202.5**
Value*	**110 USD/Kwh**		
Materials	63.00%	USD 209.6 billion	USD 14 billion
Purchased items	11.30%	USD 37.6 billion	USD 2.5 billion
Pack integration	4.20%	USD 13.98 billion	USD 0.9 billion
Manufacturing	21.90%	USD 72.93 billion	USD 4.9 billion
Indonesia's demand value	100.00%	USD 332.8 billion	USD 22.2 billion
Possible coverage by domestic industry	61%	USD 203.2 billion	USD 13.6 billion

**based costs reported in 2024 USD exchange rate*
Source: Adapted from Argonne National Lab, 2024

As for energy storage, a component cost breakdown for constructing a utility system is shown in Fig. 5.13 below. The battery itself holds the majority of the cost, followed by BOS and installation labor. The total cost of engineering Procurement construction of the battery storage is 872 USD/kW (NREL, 2021). Referring to RUKN, the total battery demand by 2060 is 52 GW. As discussed previously, Indonesia is able to cover 61% of battery manufacturing. For the construction costs, Indonesia can cover the overall cost components except the battery central inventer. Since there is no inverter manufacturing in Indonesia yet, the possible coverage by domestic industry is up to 57%. Thus, the economic value of battery energy storage construction that circulates in Indonesia may reach USD 26 billion.

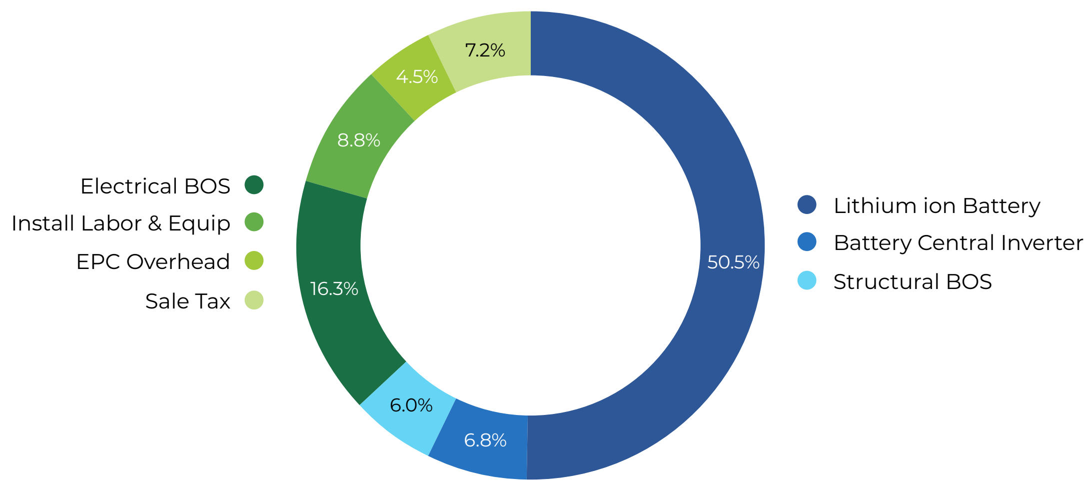

Fig 5.13. Battery storage construction cost for utility scale

Table 5.6. Indonesia demand value's for battery energy storage construction based on Government target in 2060

Domestic Demand (2060 Target) in GWh	RUKN
	52 GW
Value*	872 USD/k
Indonesia's demand value	USD 45.3 billion
Possible coverage by domestic industry	USD 25.9 billion

**based costs reported in 2021 USD exchange rate*
Source: Adapted from NREL, 2024

The market size of battery manufacturing and battery energy storage construction is expected to escalate, driven by rising EV sales and the adoption of energy storage. The manufacturing for EV battery demand alone is projected to grow by USD 350 billion, with the possibility of coverage by domestic industry of USD 220 billion. Meanwhile, the market size of battery energy storage construction is anticipated to reach USD 45.3 billion, with the possibility of coverage by domestic industry of USD 25.9 billion, as the government invest heavily in large-scale storage infrastructure. Together, these industries will form a USD 240 billion market.

E. Job creation opportunities

The advancement and implementation of renewable energy derived from solar and wind energy, and the battery manufacturing industry will positively influence job opportunities. The types of jobs can be divided into several fields, namely manufacturing, construction, installation, operations, maintenance, decommissioning, and recycling. The calculation of employment projections may vary depending on various aspects such as investment-economic value, technology-manufacturing used, design and installation system, and amount of demand (in MW).

Domestic labor is an essential part and may contribute to the country's economy in a number of ways. The utilization of domestic labor has the potential to alleviate poverty and maintain a high standard of living and prosperity by propelling the economy through a variety of economic activities and transactions within the country. Further, domestic labor costs are arguably lower due to lower living cost requirements and standards than foreign workers and their families. (UNCTAD, 2009; ANU, 2015; Unido, 2019; DOD, 2022; DOE, 2024; Raab, 2023. The summary of the estimated potential employment opportunities is based on different estimates of the industry types and the possible potential, resulting in different job potential factors and scope (Tables 5.5. and 5.6.).

Table 5.5. Job potential per MW from solar and wind energy

Demand projection reference	Technology	Year	Manufacturing, construction, installation (in thousand job-yrs)		Operations and maintenance (in thousand job-yrs)		Total (in thousand job-yrs)	
			Low	High	Low	High	Low	High
BAU (2020-2030 RUPTL)	Solar PV	2026-2030	95.62	103.09	19.92	79.68	115.54	182.77
		2031-2040	165.02	177.92	34.38	137.52	199.40	315.44
		2041-2050	224.64	242.19	46.80	187.20	271.44	429.39
	Total		**485.28**	**523.19**	**101.10**	**404.40**	**586.38**	**927.59**
	Wind turbine	2026-2030	1.85	10.82	1.16	1.16	3.02	11.98
		2031-2040	12.08	70.52	7.59	7.59	19.67	78.10
		2041-2050	9.96	58.13	6.25	6.25	16.21	64.38
	Total		**23.89**	**139.47**	**15.00**	**15.00**	**38.89**	**154.47**
Official 2024 RUKN	Solar PV (a)	2026-2030	57.60	62.10	12.00	48.00	69.60	110.10
		2031-2040	120.96	130.41	25.20	100.80	146.16	231.21
		2041-2050	305.28	329.13	63.60	254.40	368.88	583.53
		2051-2060	115.20	124.20	24.00	96.00	139.20	220.20
	Total		**599.04**	**645.84**	**124.80**	**499.20**	**723.84**	**1,145.04**
	Solar PV (b)	2026-2030	57.60	62.10	12.00	48.00	69.60	110.10
		2031-2040	172.80	186.30	36.00	144.00	208.80	330.30
		2041-2050	789.12	850.77	164.40	657.60	953.52	1,508.37
		2051-2060	535.68	577.53	111.60	446.40	647.28	1,023.93
	Total		**1,555.20**	**1,676.70**	**324.00**	**1,296.00**	**1,879.20**	**2,972.70**
	Wind turbine (a)	2026-2030	2.15	12.55	1.35	1.35	3.50	13.90
		2031-2040	9.46	55.22	5.94	5.94	15.40	61.16
		2041-2050	15.48	90.36	9.72	9.72	25.20	100.08
		2051-2060	4.30	25.10	2.70	2.70	7.00	27.80
	Total		**31.39**	**183.23**	**19.71**	**19.71**	**51.10**	**202.94**
	Wind turbine (b)	2026-2030	3.01	17.57	1.89	1.89	4.90	19.46
		2031-2040	8.60	50.20	5.40	5.40	14.00	55.60
		2041-2050	17.20	100.40	10.80	10.80	28.00	111.20
		2051-2060	3.01	17.57	1.89	1.89	4.90	19.46
	Total		**31.82**	**185.74**	**19.98**	**19.98**	**51.80**	**205.72**

Note: Solar PV (a): Solar energy for primary energy mix only; Solar PV (b): Primary energy mix plus green hydrogen production; Wind Turbine (a): Wind energy for primary energy mix only; Wind Turbine (b): Primary energy mix plus green hydrogen production
Source: IESR Analysis with the basis of industrial condition calculations referring to Elfani (2011)

Table 5.10. highlights limitations in determining the number of potential job opportunities, specifically for the manufacturing industry. However, if the manufacturing, construction, and installation industries are taken into consideration, it is estimated that solar PV can provide almost 1.7 million jobs-yrs opportunities. This job opportunity, when added to the projected operations and maintenance, will generate a potential of up to 3.0 million jobs-yrs opportunities. On the other hand, wind turbines can provide up to 205,000 jobs-yrs opportunities. Further, Indonesia has the potential to increase its employment creation by up to 1.3 million jobs-yrs opportunities from solar energy and 25,200 jobs-yrs opportunities from wind energy, stemming from the projected domestic demand until 2040, if Indonesia can capitalize on the opportunities within the ASEAN market under APAEC target scenario.

Table 5.6. Job-yrs potential from solar and wind energy

Demand projection reference	Technology	Year	Manufacturing (in thousand job-yrs)	Construction and installation (in thousand job-yrs)	Operations and maintenance (in thousand job-yrs)	Decommission-ing (in thousand job-yrs)	Total (in thousand job-yrs)
BAU (2020-2030 RUPTL)	**Solar PV**	**2026-2030**	111.2	215.8	11.6	13.3	351.9
		2031-2040	192.0	372.5	20.1	22.9	607.4
		2041-2050	261.3	507.0	27.3	31.2	826.8
	Total		**564.5**	**1,095.3**	**59.0**	**67.4**	**1,786.1**
	Wind turbine	**2026-2030**	67.2	34.5	0.9	3.1	105.7
		2031-2040	438.3	224.8	5.6	20.2	688.9
		2041-2050	361.3	185.3	4.6	16.7	567.9
	Total		**866.8**	**444.5**	**11.1**	**40.0**	**1,362.4**
Official 2024 RUKN	**Solar PV (a)**	**2026-2030**	67.0	130.0	7.0	8.0	212.0
		2031-2040	140.7	273.0	14.7	16.8	445.2
		2041-2050	355.1	689.0	37.1	42.4	1,123.6
		2051-2060	134.0	260.0	14.0	16.0	424.0
	Total		**696.8**	**1,352.0**	**72.8**	**83.2**	**2,204.8**
	Solar PV (b)	**2026-2030**	67.0	130.0	7.0	8.0	212.0
		2031-2040	201.0	390.0	21.0	24.0	636.0
		2041-2050	917.9	1,781.0	95.9	109.6	2,904.4
		2051-2060	623.1	1,209.0	65.1	74.4	1,971.6
	Total		**1,809.0**	**3,510.0**	**189.0**	**216.0**	**5,724.0**
	Wind turbine (a)	**2026-2030**	78.0	40.0	1.0	3.6	122.6
		2031-2040	343.2	176.0	4.4	15.8	539.4
		2041-2050	561.6	288.0	7.2	25.9	882.7
		2051-2060	156.0	80.0	2.0	7.2	245.2
	Total		**1,138.8**	**584.0**	**14.6**	**52.6**	**1,790.0**
	Wind turbine (b)	**2026-2030**	109.2	56.0	1.4	5.0	171.6
		2031-2040	312.0	160.0	4.0	14.4	490.4
		2041-2050	624.0	320.0	8.0	28.8	980.8
		2051-2060	109.2	56.0	1.4	5.0	171.6
	Total		**1,154.4**	**592.0**	**14.8**	**53.3**	**1,814.5**

Note: Solar PV (a): Solar energy for primary energy mix only; Solar PV (b): Primary energy mix plus green hydrogen production; Wind Turbine (a): Wind energy for primary energy mix only; Wind Turbine (b): Primary energy mix plus green hydrogen production
Source: IESR Analysis with the basis for calculating industrial conditions referring to LPEM-FEB UI working Paper-081 2024

Based on the present adoption demand projections, the adoption of solar PV (assuming a 100% utility scale) has the potential to generate up to 1.8 million jobs-yrs from manufacturing industrial processes and up to 5.7 million jobs-yrs opportunities from all stages, from manufacturing to decommissioning (Table 5.6.). Adoption of wind turbines may provide job opportunities ranging from up to 1.2 million jobs-yrs for manufacturing industrial processes and up to 1.8 million jobs-yrs from all stages. These numbers illustrate that the development of the manufacturing industry for solar PV and wind turbine adoption in Indonesia provides job opportunities. However, the numbers may be lower or higher depending on the implementation scenario. At the same time, Indonesia could create up to 2.5 million and 173,500 more jobs-yrs than its domestic demand target for the adoption of solar and wind energy until 2040 if it can take advantage of the possibilities in the ASEAN market under the APAEC scenario target.

Battery

Table 5.7 Job-yrs potential from battery energy storage development

Demand projection reference	Technology	Year	Manufacturing (in thousand job-yrs)	Construction and installation (in thousand job-yrs)	Operations and maintenance (in thousand job-yrs)	Decommission-ing (in thousand job-yrs)	Total (in thou-sand job-yrs)
Official RUKN 2024	Battery Energy Storage (a) (Utilityscale)	**2026-2030**	50.7	32.4	1.2	3.6	87.9
		2031-2040	101.4	64.8	2.4	7.3	175.9
		2041-2050	304.5	194.6	7.2	21.8	528.0
		2051-2060	118.3	75.6	2.8	8.5	205.2
	Total		**574.9**	**367.4**	**13.6**	**41.2**	**997.0**
	Battery Energy Storage (b) (Utilityscale)	**2026-2030**	28.2	18.0	0.7	2.0	48.9
		2031-2040	112.7	72.0	2.7	8.1	195.4
		2041-2050	479.3	306.3	11.3	34.3	831.2
		2051-2060	281.7	180.0	6.7	20.2	488.5
	Total		**901.8**	**576.3**	**21.3**	**64.6**	**1564.0**

Note: Battery Energy Storage (a): Solar energy for primary energy mix only; Battery Energy Storage (b): Primary energy mix plus green hydrogen production
Source: IESR Analysis with the basis for calculating industrial conditions referring to LPEM-FEB UI working Paper-081 2024

The projected employment in the battery manufacturing sector is presented in Table 5.7., which was based on 2024 RUKN (for battery storage). The calculation takes into account the manufacturing, construction, O&M, and decommissioning of Li-ion batteries. The adoption of renewable energy in the forms of solar and wind will require massive amounts of energy storage because of their intermittency. According to RUKN, demand for energy storage in 2060 will rise up to 53 GW, which will create around 1 - 1.5 million job opportunities.

The government of Indonesia also targets EV sales of 135 million units of E2W and 38.3 million units of E4W by 2060 (MEMR, 2024). The high target of EV sales will also open 25,000 job opportunities in 2030. The detailed job opportunity calculation is shown in Table 5.8.

Table 5.8 Job opportunities in EV battery manufacturing

Category	E2W (Electric Two-Wheelers)	E4W (Electric Four-Wheelers)	Total
Target Unit Sales	135,000,000	38,300,000	173,300,000
Average Battery Capacity per Unit (Kwh)	1.5	71.9	-
Total EV Battery Demand (GWh)	202.5	2753.77	2956.27
Job Opportunities : 100–150 workers per GWh)	20,250 – 30,375 workers	275,377 – 413,066 workers	50,625 – 688,443 workers

Source: IESR Analysis with the basis for calculating industrial conditions referring to MEMR, Cotterman et al., 2024

By 2060, both demand from EV battery and Battery Energy storage are expected to generated significant number job opportunities, driven by implementation of renewable energy and the rising sales of EV. the demand for EV battery alone is expected to create approximately 688,433 jobs in battery EV manufacturing. Similarly, demand from battery energy storage is estimated to contribute around 1 million - 1.5 million jobs, including positions in manufacturing, construction and installation, O&M, and decommissioning. Together these demands will provide total of 2.2 million jobs reinforcing their role as key driver in sustainable development.

F. SWOT analysis

In order to support its energy transition, Indonesia has to accelerate the renewable energy and battery manufacturing industry to maximize benefits from potential resources and demand for economic growth and job creation. This section utilizes strengths, weaknesses, opportunities, and threats (SWOT) analysis to capture the logical framework to see the potential of establishing the manufacturing industries. The analysis is divided into general analysis, as it has common features (Table 5.9.) and specific analysis for solar PV (Table 5.10.), wind turbine (Table 5.11.), and battery technologies (Table 5.12.). The mapping focus is limited under the following scope:

1. Demand potential/market is classified through the market view approach and its influence, which becomes important when businesses must adapt and gain market share to thrive. This covers market potential, formation, and pressure.
2. Sources of raw materials are classified by considering Indonesia's domestic potential in terms of natural, human, and mineral resources. This is important to ensure sustainable value and supply resources amidst global disruption.
3. Manufacturing industry and R&D are classified based on the perspective of technological readiness and potential, as well as the industrial supply chain. This also includes cost considerations and the industrial ecosystem in maintaining the sustainability of the industrial industry.
4. Planning, policies, and regulations are classified as such by considering existing conditions and analyzing gaps from conditions considered ideal or best practice.

Table 5.9. SWOT analysis for general renewable energy manufacturing

General manufacturing industry			
SWOT	**Focus of mapping**		**Details**
Strength	Demand potential/market	1	Unutilized potential. There is still a large untapped potential for renewable energy technology as well as domestic and export market demand, especially for solar PV, wind turbines, and batteries
		2	Economic stability. The average GDP of 5.05% (2023) and 5% in the last 8 years (excluding 2020 and 2021 due to the COVID-19 pandemic) shows stable national economic growth.
		3	Policy and plan target. Renewable energy is becoming a necessity to develop, especially with the high interest in green hydrogen generated with renewable energy such as solar PV and wind turbines. The green hydrogen demand in Indonesia could refer to Indonesia's national hydrogen strategy and official 2024 RUKN.
	Source of raw materials	4	Availability of raw materials and natural and human resources. Indonesia has big advantages in the amount of natural, mining, and human resources that can be empowered in the manufacturing supply chain as explained in Sub-chapter 5.a.i. Almost all types of critical mineral raw materials needed in the manufacture of renewable energy technology are available. Under the downstream program supported by the government's strong will to industrialize program-mined mineral products, the domestic demand for raw materials can be fulfilled.
	Manufacturing industry and R&D	1	Lack of core technology. Some technologies have not yet been developed to meet the adequate Technological Readiness Level (TRL) of domestic manufacturing industry for renewable energy and its supply chain in Indonesia, and these need to be supported by foreign knowledge transfer and partnership.
		2	Lack of expertise. Indonesia has limited domestic expertise, and most experts in renewable energy manufacturing technology are from abroad, such as China, Singapore, and the Republic of Korea (RE Invest, 2021; Perdana, 2024; ADB, 2020).
		3	Investment, Innovation and R&D. The cost of investing in business development in Indonesia is quite high, especially for costs related to investment, R&D and innovation purposes, compared to importing renewable energy technology products for sale (GoI, 2024; BRIN, 2022).

General manufacturing industry			
SWOT	Focus of mapping		Details
	Demand potential/market	4	Lack of support for domestic industry development due to the cost of the product. The LCR regulation is often considered to hinder the adoption of renewable energy technology, even though it is intended to encourage the development of the domestic manufacturing industry for renewable energy. Either non-LCR but cheaper or LCR but more expensive (Kumparan, 2024; Dian, 2024). The development of specific domestic markets with labelling/certification for domestically manufactured products with certain controlled criteria and standards can be considered.
		5	Limited financial mechanisms and incentives. Financing and investment in the development of the manufacturing industry for renewable energy are still limited, and incentive benefits are not yet optimum for end users (GoI, 2022)
		6	Lack of supply and value chain. The supply chain needed to support the manufacturing industry for renewable energy, which is still limited in number and production and innovation capabilities. This limitation occurs in almost all manufacturing industry components, including solar PV, wind turbines, and batteries. The downstreaming program for critical minerals is still in the nascent stage.
		7	Lack of supporting regulation for adopting renewable energy and developing manufacturing industry for renewable energy.
Opportunity	Demand potential/market	1	The adoption potential is still endless. Renewable energy technology adoption has not yet reached saturation because only a few sectors have started to adopt it. It is not yet optimal in Indonesia, as well as in other countries. If there is a limitation, it is the issue of investment value and the amount of renewable energy technology supply.
	Planning, policy, and regulation	2	Global or international support. Efforts are underway to achieve NZE by 2060 or earlier, with a strong international push to adopt clean renewable energy.
		3	Awareness development. The awareness of environmental sustainability and carbon reduction targets propels policymakers, key stakeholders, and local communities to adopt renewable energy.
		4	Market development. To satisfy local and global emission reduction objectives for NZE, market growth will be driven by the renewable energy technology product adoption.
		5	Economic development. Domestic and local economic development triggers national economic growth.
		6	Job creation. The development of the manufacturing industry for renewable energy will generate new jobs.
		7	Sustainable development. Domestic availability of technology and resources with lower cost may encourage greater adoption, especially for remote, frontier, and outermost regions, and also aligned with the National Energy Policy.
		8	The development of the manufacturing industry for renewable energy and its supply chain can adjust and diversify the energy structure for sustainable national energy security.
	Manufacturing industry and R&D	9	Creating technology transfer opportunities, exchanging knowledge, and forming partnerships with international manufacturers.
		10	Interregional and international cooperation. Cooperation in business development, products, research, and innovation can be carried out between regions or countries.
Threat	Demand potential/market	1	Low-priced competitive technologies. For example, coal receives greater regulatory and political support with domestic market obligation (DMO) and market cap prices.
		2	Benefits of technology. There is a potential for certain demands on specific performance, quality, service life, and price of renewable energy technology. Along with technological developments, innovations will emerge, improving performance, quality, service life and efforts to lower prices. This also includes market views on specific issues such as ESG.

General manufacturing industry			
SWOT	**Focus of mapping**		**Details**
	Planning, policy, and regulation	3	Unclear sectoral planning direction. This includes unclear regulations, roadmaps, and business protection, especially for the protection of domestic industry and markets from imported products.
		4	Climate change issue. Climate change is occurring at an increasingly rapid pace, requiring mitigation efforts to be adopted quickly, along with a set of regulations and standards that must be met. This requires the manufacturing industry for renewable energy and its supply chain to meet certain minimum ESG standards, which may not always be possible and can be costly. If ESG is not implemented properly, negative stigma will emerge from society, which can become an obstacle in developing and meeting targets.
		5	Public perception. There is still public behavior that shows indifference to the need to adopt renewable energy, the issue of global warming, and the threat of climate change. Coupled with the negative stigma related to ESG from the manufacturing industry for renewable energy and its supply chain, which is considered no different from the use of fossil fuels.
	Manufacturing industry and R&D	6	Industry risk in globalization and competition. There are potential risks in business development and the impact of globalization and competition. These potential risks can cause great losses and become a caution for industry players in starting and running a business.
		7	Lower market price. In the global market, renewable manufactured technologies are facing price pressures and competition from other products.

Sources: Adapted from many sources, including interviews and FGDs

Table 5.10. SWOT analysis for solar PV manufacturing and its supply chain

Solar PV manufacturing industry and its supply chain			
SWOT	**Focus of mapping**		**Details**
Strength	Demand potential/market	1	Availability of several industries from the manufacturing supply chain. Indonesia already has several manufacturing industries that are already running (Table 2.4). This can be interpreted as indicating that TRL technology has been sufficiently developed in the domestic manufacturing industry ecosystem.
		2	Indonesia's sun energy potential. The potential for solar energy is very large because Indonesia is located in a tropical region with almost hot weather and constant sun intensity. Solar energy is also a major development focus of all renewable energy in the official 2024 RUKN.
		3	High demand in the market. There is already a high momentum seen from the high desire and demand for solar PV use in various sectors, such as power plants, industry, buildings, transportation, and daily life. Many key stakeholders from companies, universities, research institutions, and government initiatives also support this demand.
Weakness	Demand potential/market	1	Global competition. Competing with established solar PV industry players and importers around the globe, especially in terms of price and cost, performance, and innovation, requires experience and knowledge.
	Manufacturing industry and R&D	2	Inadequate domestic TRL. Under the present conditions, Indonesia still struggles and does not yet have an adequate domestic TRL for the whole process due to complex manufacturing technology to fulfil LCR regulation.
Opportunity	Demand potential/market	1	Growing ecosystem. Solar energy utilization is still developing because Indonesia is still in the early stages of the energy transition. This is an opportunity for the manufacturing industry for solar PV and its supply chain as well as for industries included in the industrial ecosystem for the energy sector.

Solar PV manufacturing industry and its supply chain			
SWOT	**Focus of mapping**		**Details**
	Demand potential/market	2	Domestic and global growing demand. There is a growing demand for solar energy solutions in Indonesia and Asia Pacific. Indonesia is located in Southeast Asia, with access to regional markets and trade routes.
		3	Lack of recycling industry. There is no good and integrated recycling system for solar PVs that have reached the end of their useful life. The development of the recycling industry can be an opportunity where demand for raw materials will continue to increase and has the potential to reduce raw material costs.
		3	International trade restriction. The USA has restricted trade in solar photovoltaic power by minimizing imports of solar PV from China due to the low competitiveness of the USA domestic industry in its own market with tariffs and import quotas. In addition to China, the restriction also applied to various countries that receive funding from China. Despite restrictions applied to various countries, Indonesia may have an export opportunity through the development of cooperation and partnerships between countries.
Threat	Manufacturing industry and R&D	1	Foreign technology dependency. Most solar PV technology is still imported, and it is almost completely controlled by foreign countries. This dependency is dangerous in the provision of sustainable technology and can impact national energy security.
	Demand potential/market	2	Cheaper import product. There is a reliance on imported solar PV equipment, technologies, and components, as they can be cheaper than domestically produced solar PV. Moreover, the domestic manufacturing industry has made large investments that need to return its CapEx in RoI form.

Sources: Adapted from many sources, including interviews and FGDs

Table 5.11. SWOT analysis for wind turbine manufacturing and its supply chain

Wind turbine manufacturing industry and its supply chain			
SWOT	**Focus of mapping**		**Details**
Strength	Demand potential/market	1	Wind energy potential. Indonesia and Southeast Asia have great potential for wind energy, both onshore and offshore. This is a potential market for Indonesia to supply wind turbine technology and its components.
		2	Role in transition energy. For the energy transition to NZE, wind energy can be used as a cost-effective, clean, sustainable energy source with minimal space.
	Manufacturing industry and R&D	3	Simplicity of wind turbine technology. Wind turbine technology is a relatively simple technology and has a fairly adequate level of technological readiness.
Weakness	Demand potential/market	1	Fluctuation issue. Wind energy has not received much attention because it is considered a renewable energy that is less environmentally friendly and less promising for providing stable power generation due to its fluctutation.
		2	Pollution issue. Wind technology has some setbacks, especially noise and aesthetic pollution.
	Planning, policy, and regulation	3	Little interest. The use of wind energy has not been widely encouraged from a policy framework because there is still little interest in it.

Wind turbine manufacturing industry and its supply chain			
SWOT	**Focus of mapping**		**Details**
Opportunity	Demand potential/market	1	Potential for industrial manufacturing, logistics and infrastructure. This can be an opportunity with the government's seriousness in preparing and developing a policy framework, roadmap, and industrial ecosystem in the energy sector. This need will always exist in the use of wind turbines domestically. State-owned companies and even non-business state institutions can also be involved in developing community service contexts with one target for making and fulfilling the demand market. Moreover, it is a government target.
	Planning, policy, and regulation	2	Global initiative. There are efforts made by the government and global initiatives to promote renewable energy, and wind energy is one of the renewable energy sources that is always encouraged to be adopted just next to solar PV.
		3	Cheaper for broader reach. Through technology learning and economies of scale, renewable energy technologies have become more affordable and provide a wider range of adoption and market. This also includes wind turbines as LCOE depicted in Sub-chapter 3.b.
Threat	Demand potential/market	1	Cost issue. Though the running costs of wind power generation are minimal, the initial investment is still high, which may lower its demand.
		2	Ecosystem issue. Wind energy technologies have been found to adversely affect wildlife and endanger them.

Sources: Adapted from many sources, including interviews and FGDs

Table 5.12. SWOT analysis for battery manufacturing

Battery manufacturing industry and its supply chain			
SWOT	**Focus of mapping**		**Details**
Strength	Demand potential/market	1	High demand for vehicle batteries, both in Indonesia and the world, where there is a transition from fossil fuels to electric and hydrogen vehicles.
	Source of raw materials	2	Indonesia has abundant nickel resources, holding 52% of the world reserve as discussed in Sub-chapter 5.b.i.
Weakness	Planning, policy, and regulation	2	Regulatory challenges like LCR. LCR regulation inconsistency can cause investors to hesitate when considering investments in the industry as discussed in Sub-chapter 5.b.
	Manufacturing industry and R&D	1	Supply chain gaps. Indonesia has an abundant nickel reserve and has started to build refineries for it. However, the next step of supply chain, like battery cell manufacturing, has not yet been established.
		3	There is no good and integrated recycling system for batteries that have reached the end of their useful life.
Opportunity	Source of raw materials	1	Robust raw materials attracting foreign investment. With 52% of the world's nickel reserves, Indonesia can attract battery manufacturer from other countries to invest in manufacturing facilities.
	Demand potential/market	2	Global market demand. The growing demand from the power and transport sectors open the opportunity for Indonesia to expand the nickel industry and develop domestic manufacturing.
Threat	Demand potential/market	1	Global competition, especially from China. Currently, China's battery manufacturing capacity has exceeded demand from all countries making it hard for indonesia to compete in global market (BNEF, 2024).
		2	Performance, battery replacement costs, and waste management that user experiences.

Sources: Adapted from many sources, including interviews and FGDs

Based on the results of the SWOT analysis, the three technologies—solar PV, wind turbines, and batteries—have sufficient potential to be promoted so that the manufacturing industry can be developed in Indonesia. However, further research is needed to determine whether this product should be created as a ready-to-use or supply chain component. As with any business, the manufacturing industry of renewable energy and its supply chain rely on market demand; no demand, no business. Establishing and sustaining an industrial ecosystem requires feasibility studies, market research, business development, market penetration via technical advances and collaboration.

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6 Key enablers

A. Policy framework for domestic markets formation

Implementing renewable energy and managing natural resources are highly dependent on energy and natural resources policy along with its control. Rules and demands for more participation and openness from the parties involved become crucial in this situation, especially in investment. The government should prioritize harmonizing energy plans (RUKN, RUPTL, KEN) along with national short- and long-term economic plans and goals. With the goal of facilitating the promotion of the necessary ecosystem, it is essential to have at least two roadmaps consisting of:

1. Road map to advance sustainable renewable energy adoption in Indonesia (in all sectors) as domestic market creation. This roadmap must outline the clear vision, periodic and final targets, key stakeholder commitment and initiatives, potential collaborative projects under government or key stakeholder initiatives, and the predicted energy, social, economic, and environmental impact of integrating with the country's economic and population growth under controlled data monitoring and management (ClimateWork, 2023; ICLEI, 2021; C40 knowledge, 2021):

2. Road map for the development of the renewable energy manufacturing supply chain industry as a part of the government's "downstream" program. Similar outline content as No. 1. above but in the context of the development of the renewable energy manufacturing supply chain industry with the addition of the policy framework for ESG compliance, targeted technology, and investment and finance strategy for state-owned or private investors.

The existence of this roadmap will provide certainty to business actors regarding the policy direction and targets desired by the Indonesian government. The renewable energy adoption roadmap, as the name suggests, is a roadmap that describes the adoption efforts planned and targeted by the government with detailed mechanisms regulated by government regulations and policies.

Another important road map is the government's "downstream" program, which depicts the development of a renewable energy manufacturing supply chain industry plan. This plan gives guidance for creating intermediate and finished goods from minerals by utilizing raw materials classified as critical minerals. Critical minerals that are limited in quantity have the potential to have very high value, and with the value-added process carried out domestically, it will benefit domestic economic circulation and national economic growth. An essential element of this is the expansion of the domestic supply chain propelled by continuously growing and adaptable LCR legislation (IEA, 2024a). Other policies and regulations must continue to be developed to facilitate Indonesia's ideals in adopting integrated energy and developing the country's energy resilience.

B. Access to renewable energy and resources

The ease of access to the availability of critical raw materials and utilization of clean energy is a key issue in the manufacturing industry for renewable energy. This is important to increase the competitive value of adopting manufactured products of renewable energy in domestic and global markets.

Manufacturing industries cannot carry out manufacturing processes without access to critical raw materials. Likewise, critical raw materials are inaccessible due to high prices resulting from fluctuations in world mining commodity prices along with their derivative products. The occurrence of price fluctuations, without any attempt to establish fixed and stable prices through short- and long-term contracts, will pose a challenge for industry participants.

However, fixed and stable pricing does not necessarily ensure the smooth operation of the industry. Favorable conditions for the manufacturing industry occur when prices are lower in the present and higher in the future, which can lead to increased revenue. Conversely, higher prices now and lower prices in the future create unfavorable conditions, potentially resulting in financial losses. The manufacturing industry may face the risk of being trapped by higher prices from past transactions, making it unable to sell its products in the present due to potential losses on current and future sales.

This has always been a problem in any manufacturing industry that needs to be facilitated by regulations and policies in the form of access guarantees. A lesson learned for Indonesia in response to a similar issue from Sweden, i.e., a credit guarantee mechanism ensures raw material availability for bank-supported businesses (EKN, 2024; IEA, 2023).

The EU, through the CRM Act, will guarantee a secure and continuous supply of vital raw materials to meet climate and technological targets. (EU, 2025). The Indonesian government can guarantee this access by strengthening the policy and regulatory framework, which must be strengthened with technical implementation in all industrial sectors referring to the guarantee of raw materials as stated in Government Regulation (GR) No.28/2021 concerning the Implementation of the Industrial Sector which has been partially updated through GR No.46 /2023 concerning Amendments to GR No.28/2021 concerning the Implementation of the Industrial Sector. Such access guarantees can also be formed through cooperation or a consortium that benefits both industry players and the Indonesian government as shareholders. Primarily, it can be employed to satisfy domestic renewable energy technology requirements.

C. Market priority for domestic manufacturing industry

Support in access to domestic and international markets and company growth is an important factor to be facilitated. Within the domestic context, all domestic manufacturing industries for renewable energy must be given priority in sales (especially for government, government institutions, and state-owned company procurement) and ease in terms of administrative legality. More specifically, to receive subsidies and incentives, projects must meet sufficient LCR per project for both government and domestic commercial/private projects. It is important to acknowledge that economies and businesses have the potential to expand in areas with high demand, including the manufacturing industry for renewable energy and its supply chain. The amount of demand and the satisfaction of customer demand are closely associated with corporate growth. Thus, it is essential to establish a home market for the domestic manufacturing sector.

In addition, there must be a distinction between the treatment of commodities produced by domestic manufacturing industries and imported commodities, where the amount of government assistance in the form of incentives and subsidies must be more focused on domestic manufacturing. This distinction is essential since the industrial sector has made large investments in the domestic market and directly supported the advancements in the social and economic growth of the society. Furthermore, due to the necessity for a RoI, domestically manufactured products of renewable energy are not always less expensive than imported ones. Therefore, domestic manufacturing industries for renewable energy and its supply chain must be prioritized and nurtured to support domestic development and energy security.

In this case, the domestic manufacturing industry for renewable energy needs to be obliged to fulfill a specific portion of domestic demand while adhering to certain price limits set within the market. Enforcement of this obligation is important as a form of building national independence and resilience in adopting renewable energy and providing opportunities for the manufacturing industry to develop its business and portfolio in the domestic market along with the implementation of (Fig 6.1.):

1. Tariffs and Quotas: In order to discourage domestic customers from purchasing imported products, governments might implement high trade restrictions such as high tariffs and low quotas for imported products. This allows domestic producers to boost their output since they become more competitive. This approach is a lesson learned from the USA that did something similar with the purchased solar energy product supplies. Solar polysilicon, wafers, and cells from China are subjected to a 60% tax tariff in early 2025 (Kennedy, 2025). Imports from Southeast Asian countries are also imposed with tax tariffs ranging from 21.31% to 271.2% (Energy monitor, 2024).

2. Subsidies and incentives: Domestic manufacturers may increase their competitiveness and affordability in the domestic and global markets by receiving subsidies and incentives from the government. Redirecting subsidies and incentives away from fossil fuels and toward renewable energy development is another important consideration in the context of promoting renewable energy. Based on insights from ongoing global practices, specifically solar PV developers in the USA, the manufacturers must use panels containing 40% or more LCR in 2024 to be eligible for the incentive, with the requirement rising to 55% by 2026 (Jossi, 2024).

   Ordinances that promote incentives for renewable energy have many advantages, including economic, environmental, and health benefits.

There are three categories to split renewable energy incentives that can also be considered by the Indonesia government (Tryndina et al., 2022; Kenkang et. al., 2022; Gfoa, 2025):

Policies generate incentives to encourage the fulfilment of government targets in renewable energy adoption and its manufacturing industry and supply chain.

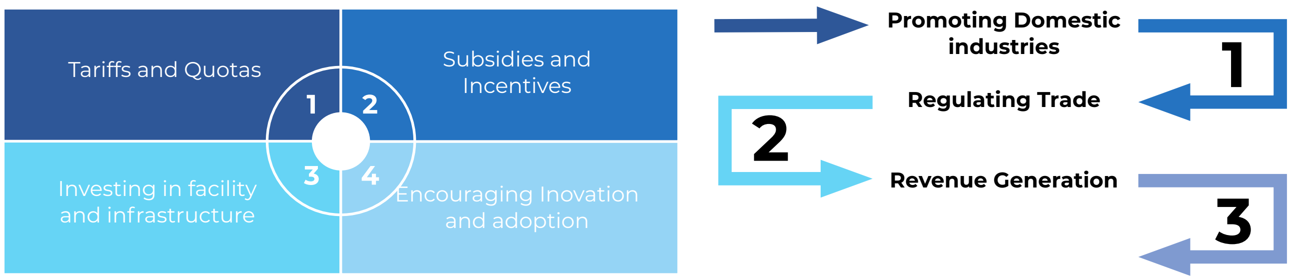
Market interactions generate incentives to make ecosystem interaction between supply and demand in the market, and or

Energy-efficient finance generates incentives based on policies to encourage the fulfillment of government targets for investments in energy efficiency.

3. Investing in facilities and infrastructure: To lower manufacturing costs and increase commodity delivery, governments might invest in facilities and infrastructure like highways, ports, and airports. The government investment in facilities and infrastructure can also utilize the potential of domestic industry, thereby directly encouraging economic growth.

4. Encouraging innovation and adoption: Governments might provide incentives, subsidies, and mandatory regulation to domestic industry innovation and accelerate societal adoption. This can also be done by fostering collaboration and cooperation in the innovation and development of technological products between industry (I), universities (U), and research (R) in the I-U-R cooperation scheme (Yang et al., 2023; Pu et al., 2021). This cooperation mechanism has been developed in various countries, including China, the EU, and Korea (Yao, 2021; Yang et al., 2023).

   Currently, Indonesia already has a system that focuses on R at the National Research and Innovation Agency (BRIN) under National Research and Innovation Agency Regulation No.7/2022 derived from Presidential Regulation (PR) No.78/2021. At the same time, BRIN can bridge I and U for collaboration as BRIN can give individual or collaboration research grants for I, U and R in doing research for innovation development (BRIN, 2024).



Source: Adapted from Faster Capital, 2024a-b

Fig 6.1. Encouragement in domestic production and import decrease

D. Conducive local community support with the active role of government.

One of the important factors in ensuring smooth industrial activities is the role of government in providing conducive domestic support, especially support from the local community. This role is crucial, particularly in the industrial sector of the upstream supply chain, such as exploration and mining, which have many negative impacts on social and environmental issues. Further, this industrial sector has the potential for conflicts of interest with local communities. Maintaining ties with the surrounding community is essential for a business since it affects the company's ability to survive. There are a number of potential community disruptions or protests that concern the business, including:

1. Support for the development of community well-being,
2. Employment opportunities for local residents,
3. Business activities that are considered to be disruptive to the surrounding environment, including traffic jams, damaged roads, noise, and pollution,
4. Conflict of interest from economic and social perspectives.

Carrying out company activities need to be made as conducive as possible so that it does not disrupt the company's activities. This is particularly true when it comes to conflicts of interest that may arise from the aspirations of certain people or organizations that may exceed legitimate bounds. The circumstance may also be more challenging if associated with power or position and criminal acts such as corruption, bribery, nepotism, and slander. Defined limits with equitable and legally binding clarity are crucial as a form of protection for companies and the company's obligations to society. Thus, the manufacturing industry must be able to facilitate community-based assistance in building local communities. The assistance is directed and regulated by statutory policies to:

1. Boost the local economy by absorbing labor, empowering community capabilities within the necessary limits.
2. Establish a community based on mutual aid and cooperation. The goal of mutual help is to bring communities together to confront common environmental, social, and economic issues and collaborate to discover answers. The readiness of the populace to revive the mutual-help mentality is essential to the country's future and the establishment of a fair and thriving society.
3. Contribute to sustainability development and future, which can be done by helping to facilitate the formation of sustainable and future development through outreach, education, training, and access to funding.
4. Foster a sense of community. People who have a strong sense of community often work together or are friendly with each other. They feel emotionally connected to the place and the people who live there.
5. Promote diversity and creativity. In order to create a more just and peaceful society, it is imperative that communities embrace variety and inclusiveness.

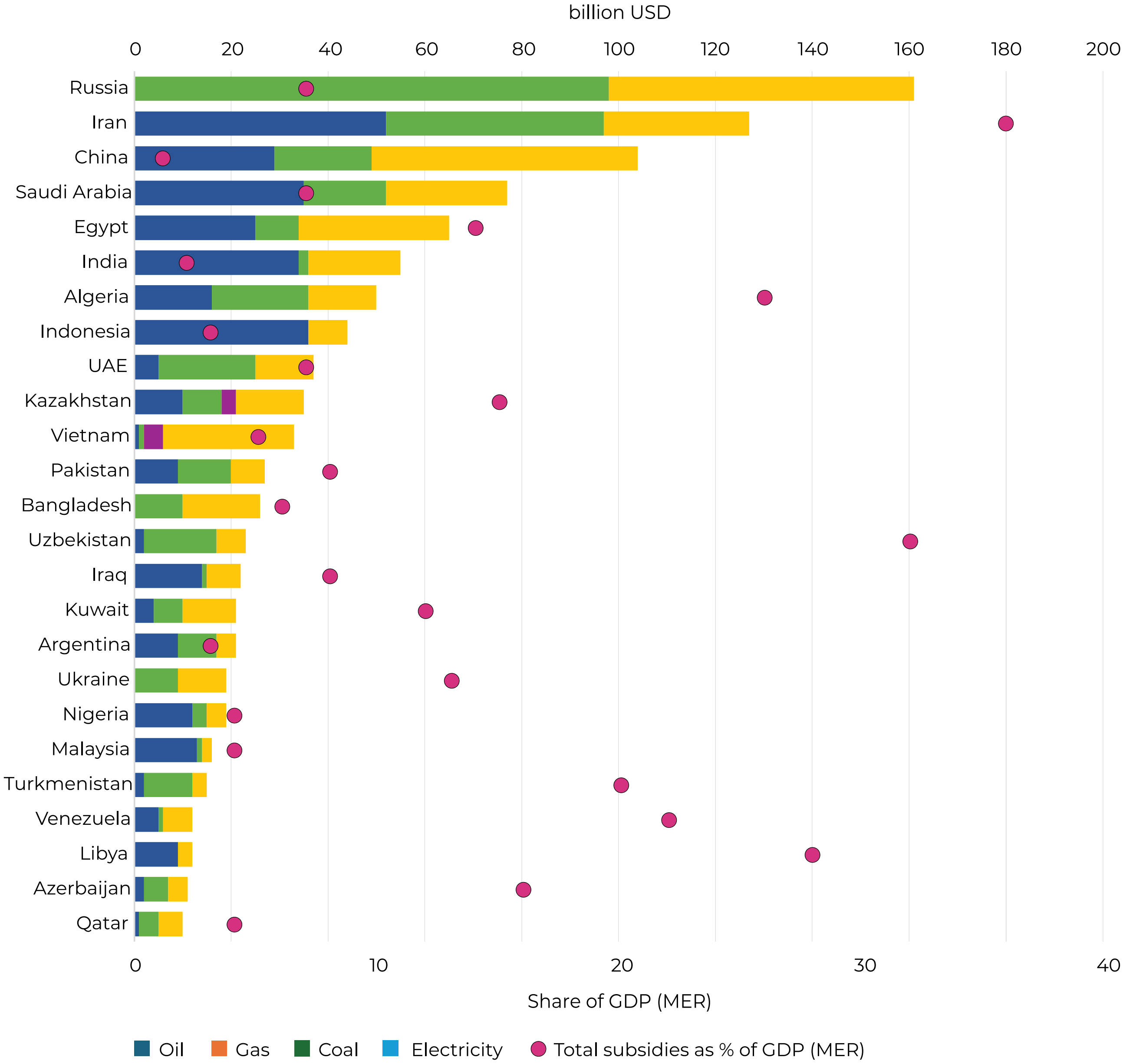
E. Promotion with incentives and benefits

To increase demand for renewable energy sources and develop its manufacturing industry, efforts should be made to increase demand for solar PV, wind turbines, and battery energy storage systems. A supply ecosystem and investment climate can be formed if there is high interest and demand. As a result, the life-cycle process, including the industrial ecosystem in the energy sector, as well as the acceptance of its use in society, must be encouraged in order to promote adoption and growth.

The insight gained from Vietnam has shown that the country experienced rapid growth in solar and wind power installations in recent years. The rapid growth of Vietnam was propelled by a confluence of advantageous policies, including appealing high rates of feed-in tariffs, ease in the adaptation of initiatives, and provision of fiscal incentives for energy production and producers of renewable energy (Acosta, 2024; SOA, 2024; Ngoc et al., 2024).

This rapid adoption of solar energy in Vietnam reached 18.6 GW, accounting for 1.2% of the global total cumulative capacity by 2023 (REN21, 2024). This rapid growth has also driven the growth of the solar module manufacturing industry in Vietnam, contributing almost 5% or ranking 2nd of the total global supply (Table 2.4.).

In the global context, the utilization of fossil fuels has been a long-running polemic, even more so by providing subsidies, which has increased its demand as a low-cost energy source in many countries, including Indonesia. The IEA has long argued that subsidies for fossil fuels should be eliminated or, at the very least, reduced since they distort markets, give consumers false pricing signals, increase budget deficits in growing and developing nations, and deter the deployment of cleaner renewable energy sources. According to IEA data, Indonesia provides fossil fuel subsidies, reaching USD 36 billion in 2022, ranking 8th globally (Fig 6.2.) (IEA, 2024b).



Source: IEA, 2024b

Fig 6.2. Top 25 nations for fossil fuel subsidies in 2022 by fuel type

Eliminating fossil fuel subsidies can limit fossil fuel demand and minimize GHG emissions. Eliminating all energy subsidies will increase government revenues by 3.6% of the world's GDP, prevent 1.6 million air pollution-related deaths annually, and limit global warming to less than 2° Celsius by 2100 (per the Paris Climate Agreement) (World bank, 2023 adapted from IMF 2023; IPCC 2023). The EU has already started the initiative to eliminate fossil fuel subsidies. According to the EU's Eighth Environment Action Programme, which took effect on May 2, 2022, fossil fuel subsidies must be phased out quickly to meet international and EU responsibilities. This means the EU will eliminate fossil fuel subsidies worth an average of EUR 56 billion from 2015 to 2021 (2022 prices) and more than double value in 2022. (EEA, 2023).

Indonesia must be ready to cut and redirect fossil fuel subsidies without long-term socioeconomic damage to support climate action, including the adoption of renewable energy and the effort of decarbonization. The important target is to make the adoption of renewable energy cheap and affordable so that it can be an alternative to fossil fuels. Gradual redirecting of fossil fuel subsidies for the development of manufacturing industry for renewable energy and adoption of renewable energy via an integrated roadmap as stated in Sub-chapter 6.a. could be one option to achieve this target.

F. Labor and skilled worker preparation

Preparing and providing labor and skilled workers is important to all green jobs, including for the manufacturing industry for renewable energy and its supply chain. Specified and specialized education and training may be needed for reskilling/upskilling to prepare future workers and the present workforce, which might move from fossil fuels to sustainable energy (OECD, 2024). Technical workers and high-skilled professionals must expand their skills to generate new employment or innovate old ones.

Lesson learned from the EU, i.e, a 'Pact for Skills' in the third pillar of the Green Deal Industrial Plan was approved on February 1, 2023, showing the importance of labour and skilled workers in transitioning to an NZE economy (EU, 2023). The pact aims to build multi-stakeholder public-private partnerships in the industrial ecosystem and value or supply chain (EU, 2024). This partnership will enable collaboration and investment in up-/re-skilling for all workers in the industrial ecosystem.

Referring to the conditions in Indonesia, there are already several ecosystems for preparing labor and skilled workers, such as through the national certification body (BSN), the national accreditation committee (KAN), the Ministry of Manpower (MoMP), the BPSDM of the Ministry of Energy and Mineral Resources (MEMR). Furthermore, educational institutions, such as universities, institutes, and other educational and training institutions have also begun to participate in preparing labour and skilled workers. Nonetheless, all educational institutions need optimization to achieve uniform standards and excellence in terms of implementation and subjects to be learned. This is particularly true for diverse work areas that require specialized skills, such as the manufacturing industry for renewable energy and its supply chain, including mining, manufacturing, sales, procurement, construction, and engineering.

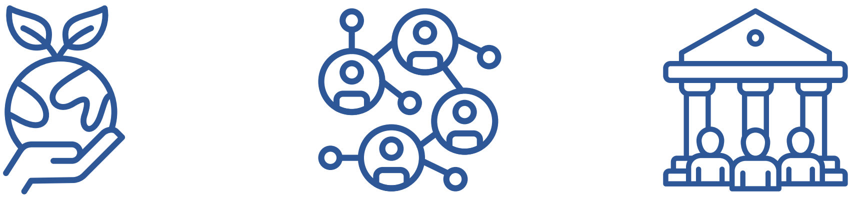
G. ESG and environmental management

ESG directly relates to policy, reporting, and government. The implementation of the ESG framework in the manufacturing industry for renewable energy provides a systematic approach to assessing associated risks, opportunities, and impacts. A framework for reporting ESG information enables the manufacturing industry for renewable energy to demonstrate how it addresses ethical and sustainable issues. Aside from advocating for fairness, accountability, and ethical corporate practices, these ESG frameworks also address diversity and human rights.

The government has an obligation to to develop robust and consistent ESG reporting throughout the jurisdiction, not only for the manufacturing industry for renewable energy but alsoacross businesses, sectors, industries, and government agencies, as well as across several levels of government. By providing a common vocabulary and structure, consistency helps all parties communicate more effectively and convey a consistent narrative when competing internationally.

ESG is also important in facilitating the monitoring and reporting of GHG emissions. The GHG emissions are required to be tracked and controlled in the manufacturing industry for renewable energy under the approach of life cycle assessment (LCA). This can be used to promote carbon emission footprint control and reduce the footprint gradually to achieve NZE in the manufacturing industry and its supply chain. ESG and LCA need to be implemented in other business entities to promote the adoption of renewable energy. This is important to ensure that good ESG ecosystem practices as a national image can be developed in Indonesia. ESG, as the national image, is one of the important indicators that attract investors to invest in Indonesia. Due to investor concerns over Indonesia's ESG rules, a USD 2.6 billion nickel-cobalt refinery venture was canceled in mid-2024 (CRI, 2024, Belseran, 2024). As solar PV, wind turbines, and battery energy storage employ nickel to improve their performance, longevity, and energy storage capacity (IEA, 2025; Nickel Institute, 2025), the investment cancellation gives a setback for Indonesia's potential economic benefits as well as leaving behind a bad national image.

The spread of mandated ESG guidelines around the world, with many more to come, has played a significant role. As depicted in Fig 6.3., from 2023 onwards, ESG reports will be required in 35 countries and regions, which account for 56% of the world's GDP (Pyrgioti, 2023). Climate change is already having a noticeable detrimental effect on companies across all industries, and investors are realizing the need to consider ESG risks when making investments. As a consequence, investors are increasingly pressing businesses to make their data public. In this situation, Indonesia must standardize its ESG framework and execute the same actions. Lastly, the alignment of domestic standards with international standards and accountability will make Indonesia's supply chain competitive in the global market.



Environmental
Renewable fuels
Climate risk
Greenhouse gas emissions
Energy efficiency
Water management
Recycling processes
Population growth
Emergency preparedness

Social
Health & safety
Human rights
Working conditions
Employee relations
Inclusion & diversity
Impact on local communities

Governance
Ethical standards & corporate behaviour
Board diversity & structure
Stakeholder engagement
Executive compensation
Shareholder rights

Mandatory ESG Reporting

35 nations and regions representing 56% of the global GDP are rolling out mandatory ESG reporting

Fig 6.3. ESG considerations in investing decisions (left) and mandatory ESG reporting by country (right)

H. Strategically support the supply chain development

1. By taking advantage of the existing potential, Indonesia can focus on developing several types of manufacturing industries, consisting of:

    i. Manufacturing industry for renewable energy of complete assembly or unit assembly of technology products for solar PV, wind turbines, and batteries. Limiting unit imports as per Sub-chapter 6.a., and encouraging that if imports occur, the imports must be in the form of components. In addition, with the implementation of periodic and continuous LCR, procurement of general components will be carried out from the nearest local location to reduce purchasing and logistics costs. The existence of this unit assembly process, along with LCR, will also provide the privilege to determine whether the components will be obtained domestically or imported. For wind turbines, as the size can be very massive, the unit assembly can be limited to a micro- to medium scale, while large to giga scales can be in ready-to-assembly components.

    ii. The development of manufacturing industries for components and their supply chains can vary widely for each technology, from solar PV to wind turbines and batteries. As for the development manufacturing industry, components that can be a priority can consist of:

        1. Common components derived from copper, nickel, cobalt, iron, and steel that align with Indonesia's downstream programs are:
            a. Material cathode and anode
            b. Cable and its wire,
            c. Bolt, nut, screw, nail, and other fastening products
            d. Structural products from steel, aluminum, cement, and other commonly available domestic resources or currently available manufacturing industries.
        2. Specific components for solar PV and products derived from silica/quartz, which may include polysilicon, silicon ingots, solar wafers, solar cells, and solar modules, as they can be integrated into a solar PV production process.
        3. The tower, the foundation, and the support system can be options, as they are made for the structural system. Other than that, specific components for wind turbines, such as the rotor-blade and the nacelle systems and their components, may have similarities with gas turbines. Developments in Indonesia are still in their early stages, and they still need to be monitored.
        4. Specific components for batteries that are derived from nickel, cobalt, copper, and other priority downstream mineral commodities.

2. Other than the manufacturing industry, it is also essential to develop a domestic support service industry for energy that includes:

    i. Engineering, procurement, and construction (EPC). It is important to develop a reliable and highly reputed EPC in Indonesia. EPC allows the privilege of selecting where the products are sourced from. This means that if a domestic or foreign market wants to hire Indonesia's EPC, Indonesia's EPC can supply the technology produced domestically as long as it fulfills the performance requirement, cost, and feasibility study.
    ii. Operation and maintenance (O&M). The service industry for O&M is important to lessen reliance on foreign professional labor. In particular, maintenance in the form of inspections, monitoring systems, calibration and repair services are quite common using services from outside the company.
    iii. Recycling industries, where it is important to minimize waste and recycle mineral resources from renewable energy technologies. As the feedstock amount for recycling is unknown, recycling industries should become an integrated part of the renewable energy manufacturing industries. So, the recycling process can be done along with waste or rejected products during the production process.

3. Last but not least, the development of the industry in managing and processing important mineral resources. The obligation of the monitoring and control function is the responsibility of the MEMR, the MoI, the MoEF, and the Ministry of Investment/BKPM in managing Indonesia, which is blessed with abundant important mineral resources through the downstream program. It is important to note that all components are either in components form or assembled in unit form, and they are all derived from the mineral resources processing business. Therefore, the mastery of mineral resource processing industry technology becomes a very important part of the supply chain for the formation of a manufacturing industry for renewable energy ecosystem.

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7 Recommendations

1. To meet the demands of the Indonesian and worldwide markets, it is essential to establish a manufacturing sector for renewable energy, namely in solar PV systems, wind turbines, and batteries—at a minimum, the complete assembly or unit assembly and EPC industries. Developing a comprehensive supply chain requires further feasibility studies from Indonesia and global market trends and prioritization based on government targets. Further mapping potential can be explored with the involvement of key stakeholders in Indonesia and globally to invest in Indonesia.

2. Under the motivation and industrial strategy of the downstream program, it is crucial to develop an integrated policy and regulatory framework. This should include a roadmap to advance sustainable renewable energy adoption and another roadmap to strengthen the renewable energy manufacturing supply chain industry. Certainly the formulation and the planning in both renewable energy growth should align with strenghening the renewable energy manufacturing supply.

3. For the industrial strategy to be transformed into an economic strategy, it is necessary to have a high-level commitment from the government in initiating and maintaining actions and policies. Derivatives thereof provide access to incentives, financing, and other support to build an ideal ecosystem for the manufacturing industry and its supply chain, from upstream to downstream industries. The adherence to the execution of GoI policies, commitments, and targets will consistently be subject to scrutiny and criticism from all stakeholders and the community.

4. Preparing the ecosystem to produce labor and skilled workers for the present and future supported by well-aligned policies. This effort should run in parallel with the strengthening of the manufacturing industry ecosystem. Policies have an impact on labor markets, job opportunities, and skills. Workers must learn green-specific skills as their professions shift to more sustainable ones in their respective job areas. Talent, skill, and knowledge demand prediction are crucial to reducing bottlenecks from renewable energy adoption, the manufacturing industry for renewable energy, and their supply chains.

IESR
Institute for
Essential Services
Reform

Jalan Tebet Timur Raya 48 B
Jakarta Selatan, 12820, Indonesia
T: +62 21 2232 3069 | F: +62 21 8317 073

www.iesr.or.id | iesr@iesr.or.id