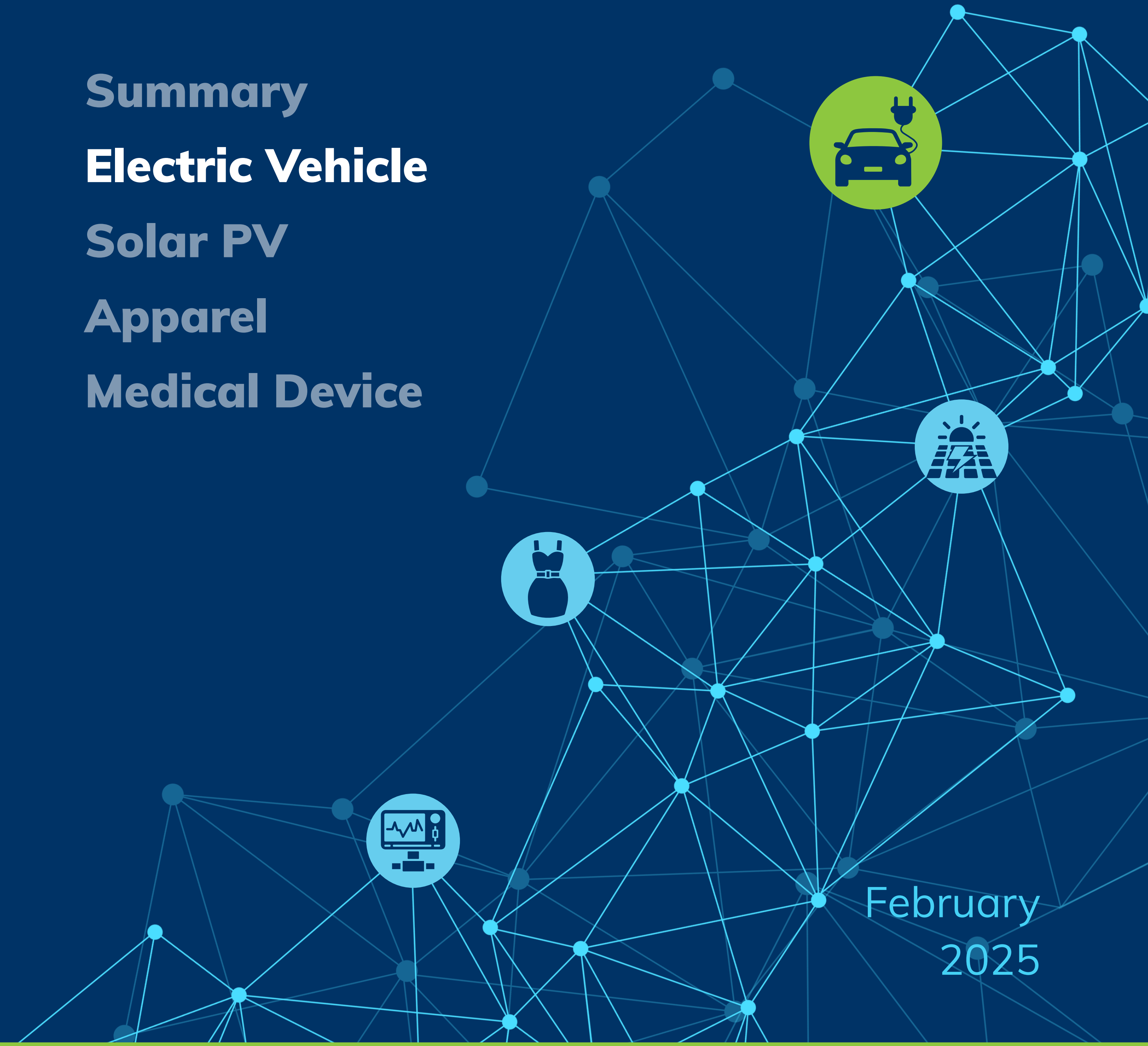
Global Supply Chain Report



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HKUST LI & FUNG
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Charged Up: The Rise of Electric Vehicles and the Race for Critical Minerals and Components

Executive Summary

The global electric vehicle (EV) market has experienced robust growth during the past decade, especially in China, Europe and North America. Government support and policy incentives have been the primary drivers behind this expansion, channelling significant investment into EV research and development. This has led to technological advancements and reduced prices. With the enhancement of charging infrastructure in major markets, battery electric vehicles (BEVs) have emerged as the leading model due to their simpler design, lower maintenance costs, and environmental advantages.

EVs differ fundamentally from traditional internal combustion engine vehicles (ICEVs) in their powertrains. While ICEVs rely on petroleum fuels, EVs are powered by electricity, necessitating different powertrain components. Batteries, a critical part of the EV powertrain, account for around half of the total direct costs of an EV, primarily due to the high costs of raw materials, particularly critical minerals. Similarly, electric motors in EVs require rare earth elements, making these minerals essential. On average, an electric car requires about six times the mineral inputs of a conventional internal combustion engine car.

The supply of critical minerals such as lithium, cobalt, nickel, and rare earth elements is unevenly distributed globally. Mining is concentrated in countries like Australia, Chile, and the Democratic Republic of Congo, while China leads in processing and refining these materials. As demand for these minerals surges, securing a stable supply becomes crucial. Countries are diversifying their sources and exploring substitutes to mitigate supply risks.

Electronics, particularly chips, also play a crucial role in EVs. While the technology for these chips is mature, manufacturing capabilities remain a bottleneck. Developed economies like those in Western Europe and the US excel in this area, while China is rapidly catching up, though there is still a gap compared to top-tier suppliers.

In the highly globalized automotive industry, leading companies have developed extensive global manufacturing networks. This is particularly significant for vehicle assembly, which is closely related to the local industrial policies and trade policies in both import and export countries. The choice of assembly location greatly influences logistics costs and other indirect expenses. EV assembly is spread across various continents, predominantly situated along coastal areas that connect major trade routes.

However, ongoing geopolitical tensions are raising concerns about supply chain stability. In response, manufacturers are increasingly bringing the production of critical components in-house, leading to a trend of onshoring manufacturing. This shift reduces reliance on external suppliers, improves control over production costs and quality, and mitigates supply chain disruptions. Additionally, EV brands are implementing localization strategies in both material supply and product offerings to enhance supply chain resilience and better meet local demand.

Alongside raw materials, critical components, and assembly locations, manufacturing capacity and labour costs are important factors for the EV supply chain. China stands out in these aspects, offering relatively low labour costs and high efficiency, while also fostering clusters of related industries. These advantages, combined with a robust domestic market primed for the adoption of electric vehicles, create a competitive environment that bolsters China's leadership in the global EV market.

In the realm of EV supply chain management, the relationship between EV brands and suppliers is shifting towards a flatter structure compared to the traditional ICEV model. Suppliers of critical components now play a more influential role, and the integrated nature of EV systems necessitates closer collaboration between brands with upstream suppliers on technological specifications. This evolution is expected to lead to a more vertically integrated supply chain, moving away from the conventional tree-shaped model.

Geopolitics will be the major external factor and source of uncertainty for the EV supply chain over the next decade. As countries increasingly focus on building their own EV supply chain capabilities, this may lead to segregation and regionalization of the supply chain. However, countries will likely struggle to strike a balance between cost-effectiveness and supply chain control. Achieving the necessary technological advancements to alter supply chain dynamics will also take time. Additionally, the uneven distribution of raw materials and the fact that many global markets are not prepared for self-reliant EV manufacturing indicate that a shift toward a fully self-sufficient EV supply chain is economically impractical.

While global cooperation remains essential, countries and companies are increasingly investing in EV-related technologies to enhance their competitiveness and secure leadership in this sector. Like its ICEV predecessor, the EV industry reflects technological advancement and the capabilities of high-end manufacturing, impacting numerous companies across the supply chain. Furthermore, it serves as a significant indicator of a country's influence on the global economy. Therefore, we can reasonably anticipate rapid advancements in EV-related technologies in the coming years.

Despite rising trade barriers and intense competition, China's leadership in the EV supply chain is expected to remain, thanks to its established manufacturing capacity and ongoing efforts to develop a comprehensive supply chain. Additionally, domestic acceptance and demand for electric vehicles continue to grow, supported by substantial government investment in technology and infrastructure. However, challenges such as vulnerabilities in the supply of raw critical minerals and advanced chips, along with the need for sustainable practices, may impact its future trajectory.

I. Introduction

The electric vehicle (EV)[2] industry is undergoing a transformative period of rapid growth and innovation, driven by a confluence of technological advancements, supportive government policies, and increasing consumer demand for sustainable transportation solutions. This report delves into the emerging trends within the EV supply chain, highlighting the critical factors that are shaping the industry's landscape.

China has emerged as the largest market for EVs, benefiting from robust government support and policy incentives that have accelerated adoption. In 2023, China alone accounted for nearly 60% of the world's new electric car registrations, underscoring its pivotal role in the global EV market. Europe and North America are also significant players, with strong policy frameworks and growing consumer interest driving market expansion.[3]

The report provides an overview of the EV consumer market, examining the landscape of EV adoption across key regions. It explores the dynamics of the EV value chain, from raw material extraction to battery manufacturing and vehicle assembly, and identifies the major players and their strategic locations. The analysis extends to the challenges and opportunities within the supply chain, including the critical role of minerals such as lithium, cobalt, nickel, and rare earth elements.

Furthermore, the report addresses the evolving nature of supply chain management in the EV industry, highlighting the shift towards a more integrated and flexible model. It also considers the impact of geopolitical factors, environmental regulations, and technological innovations on the future of the EV supply chain.

II. An Overview of the EV Consumer Market

1. EV Consumer Market Landscape

The global EV market has been experiencing robust growth during the past decade, with increasing sales of electric cars, particularly in regions like China, Europe, and North America, resulting in total of 40 million electric cars on the roads worldwide (See Figure 1).[4]

Electric cars made up around 18% of all cars sold in 2023, an increase from 14% in 2022 and just 2% in 2018. The trend is even more pronounced in China, with the share of electric car sales raised from 5% in 2018 to 38% in 2023. (See Figure 2) The new electric car registrations

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[2] In this report, unless noted otherwise, "electric vehicles" (EVs) include all modes of road transport, specifically referring to battery electric (BEV) and plug-in hybrid (PHEV) vehicles, while excluding fuel cell electric vehicles (FCEV). Unless otherwise specified, "electric cars" refers to both battery electric and plug-in hybrid cars.

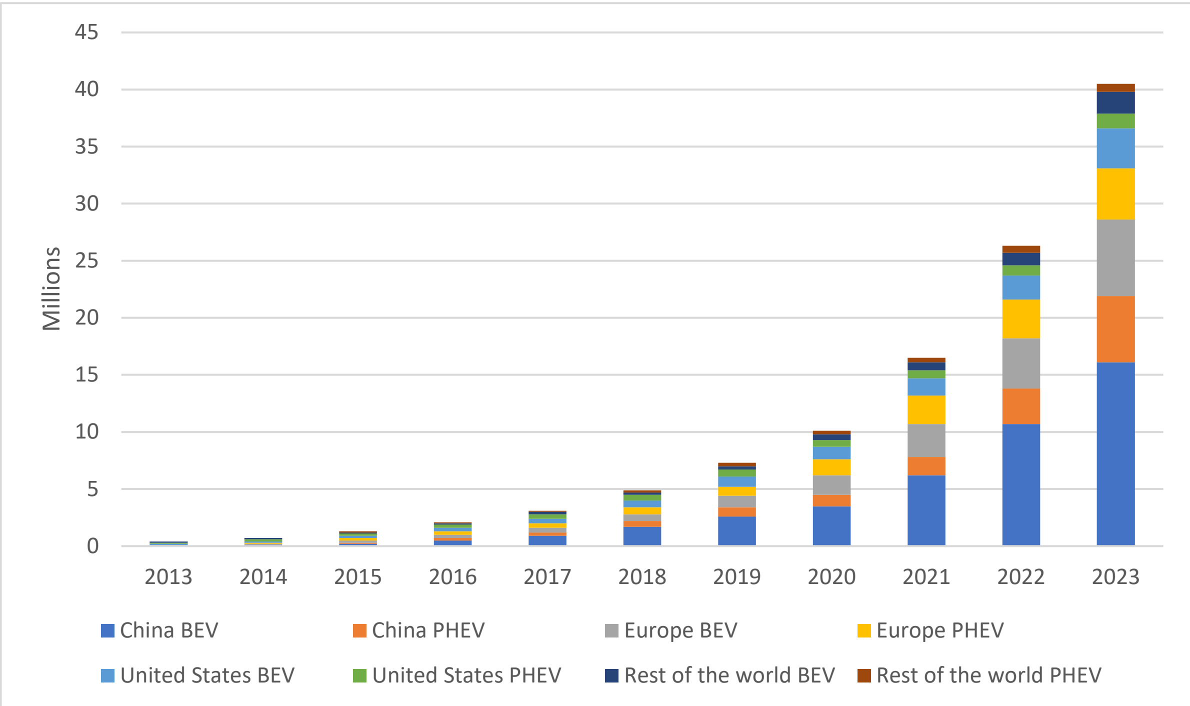
[3] IEA. (2024). *Global EV Outlook 2024: Moving towards increased affordability*. https://www.iea.org/reports/global-ev-outlook-2024

[4] Ibid.

per week in 2023 were more than the annual total twenty years ago in 2013. Battery electric cars, which are cars operate solely on electric power, constituted 70% of the electric car stock in 2023.[5]

In 2023, electric car sales neared 14 million units globally, with 60% of those sales occurring in China, 25% in Europe, and 10% in the United States (See Figure 2). Among different models, battery electric vehicles (BEVs), which are fully powered by electricity, outsold plug-in hybrid vehicles (PHEVs), which combine an electric motor with a gasoline engine (See Figure 3).[6]

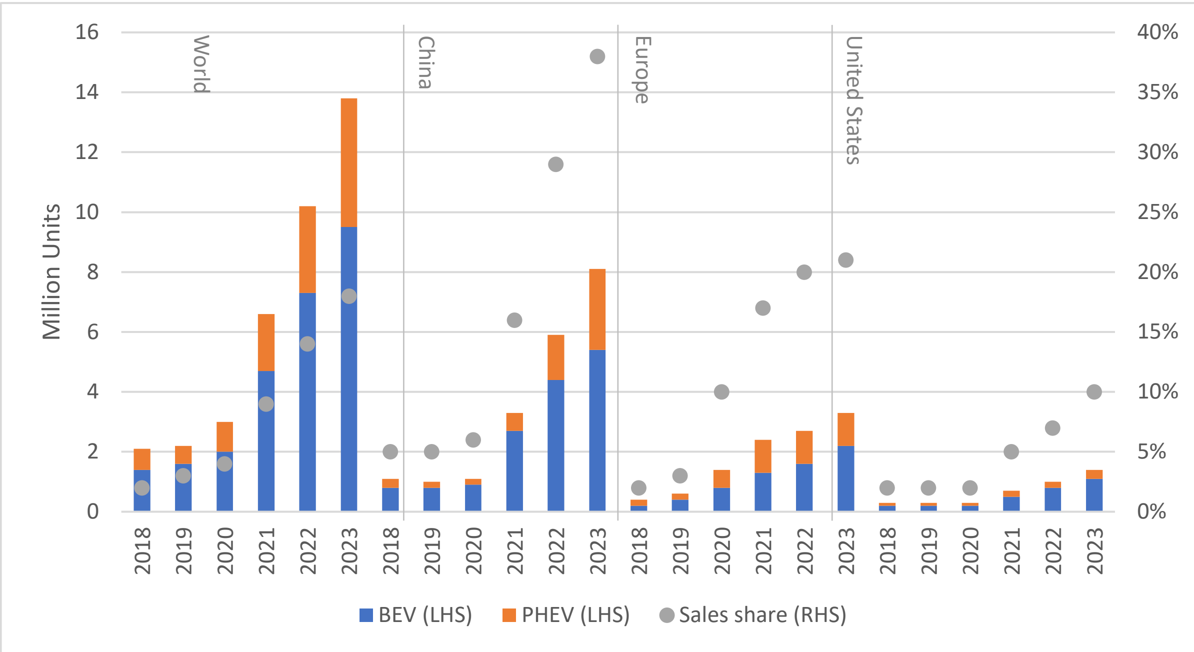
Figure 1: Global electric car stock, 2013-2023



Source: IEA

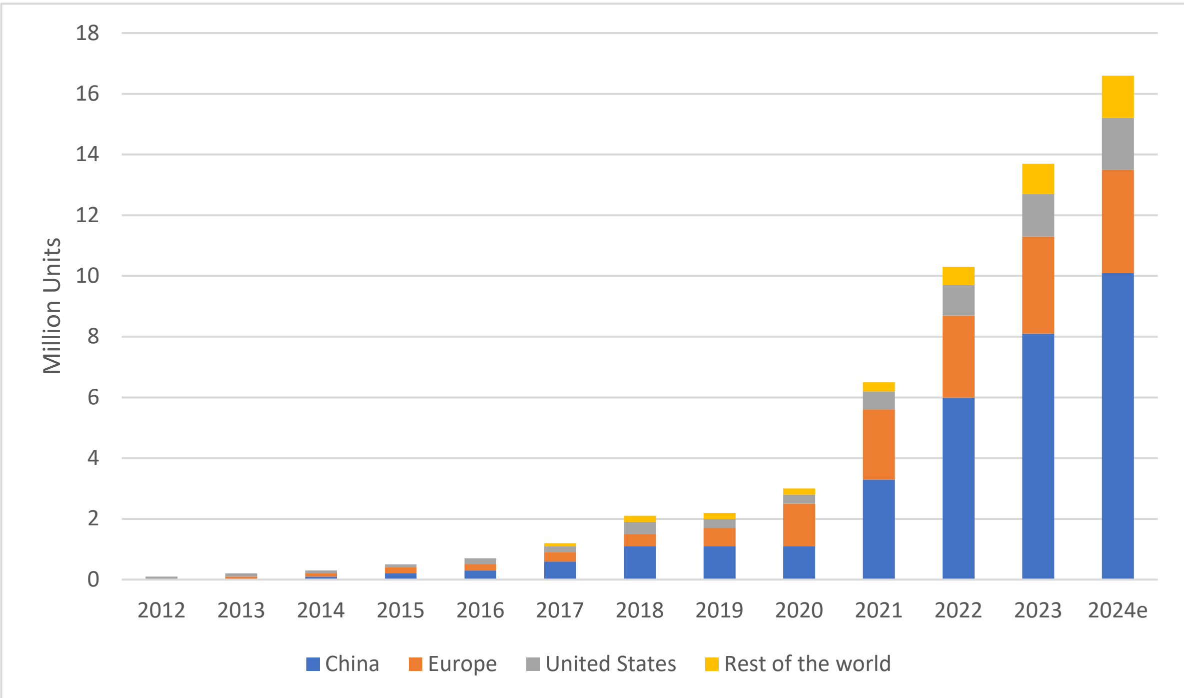
[5] Ibid.
[6] Ibid.

Figure 2: Electric car registrations and sales share in China, United States and Europe, 2018-2023



Source: IEA

Figure 3: Electric car sales, 2012-2024

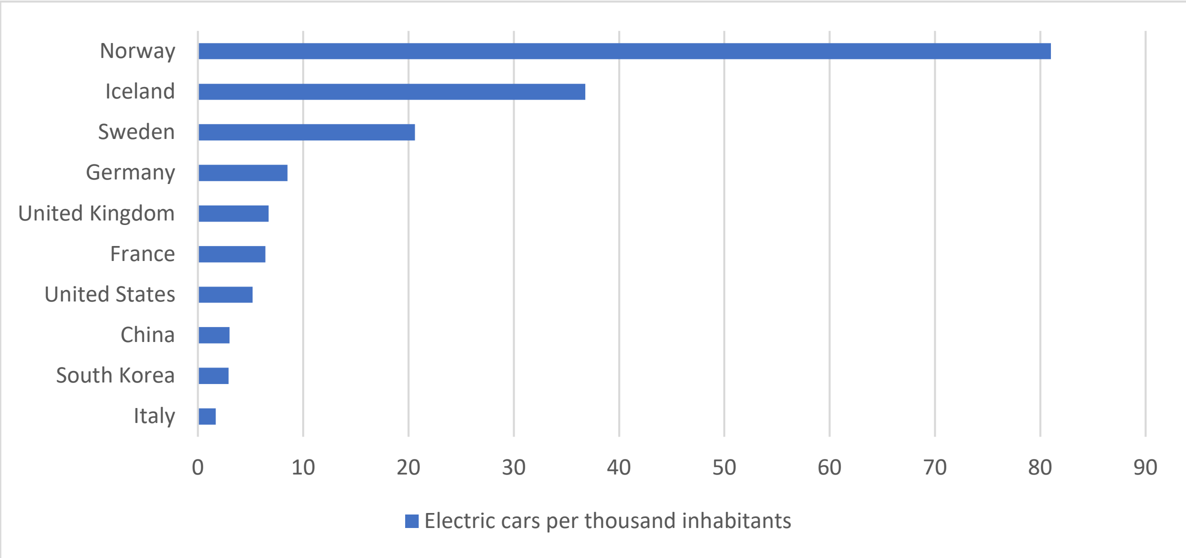


Source: IEA

Despite its relatively small population of 5.4 million, Norway has the highest per capita electric car ownership in the world (See Figure 4). The country also leads in the share of electric car sales and stock as a percentage of total car sales and stock (See Figure 5 and

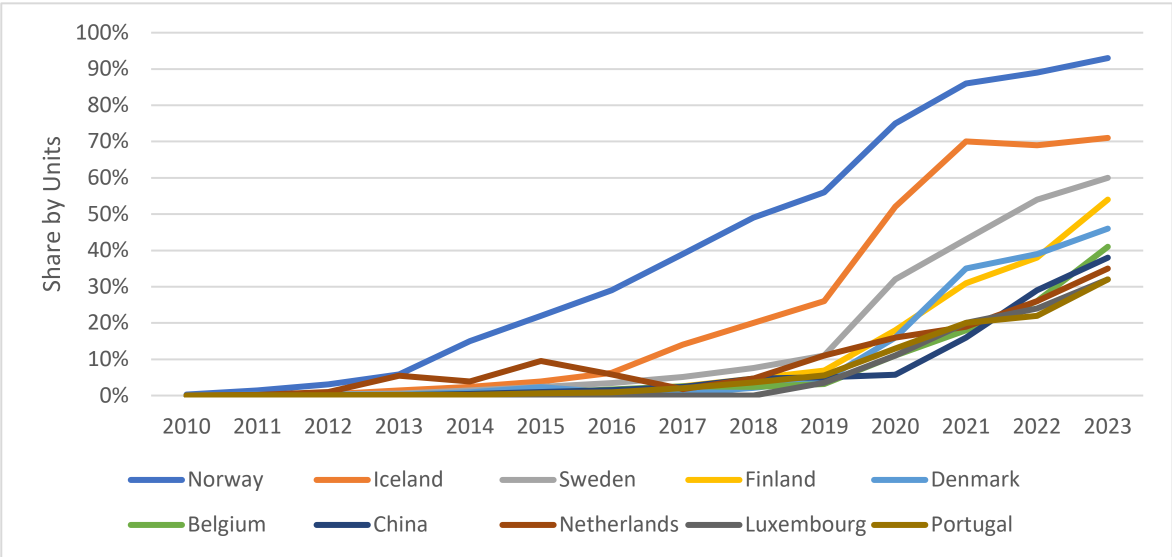
Figure 6). This is largely attributed to the Norwegian government's extensive policy incentives and support measures for EV adoption.[7]

Figure 4: Electric cars per population in leading countries worldwide, 2020



Source: Statista

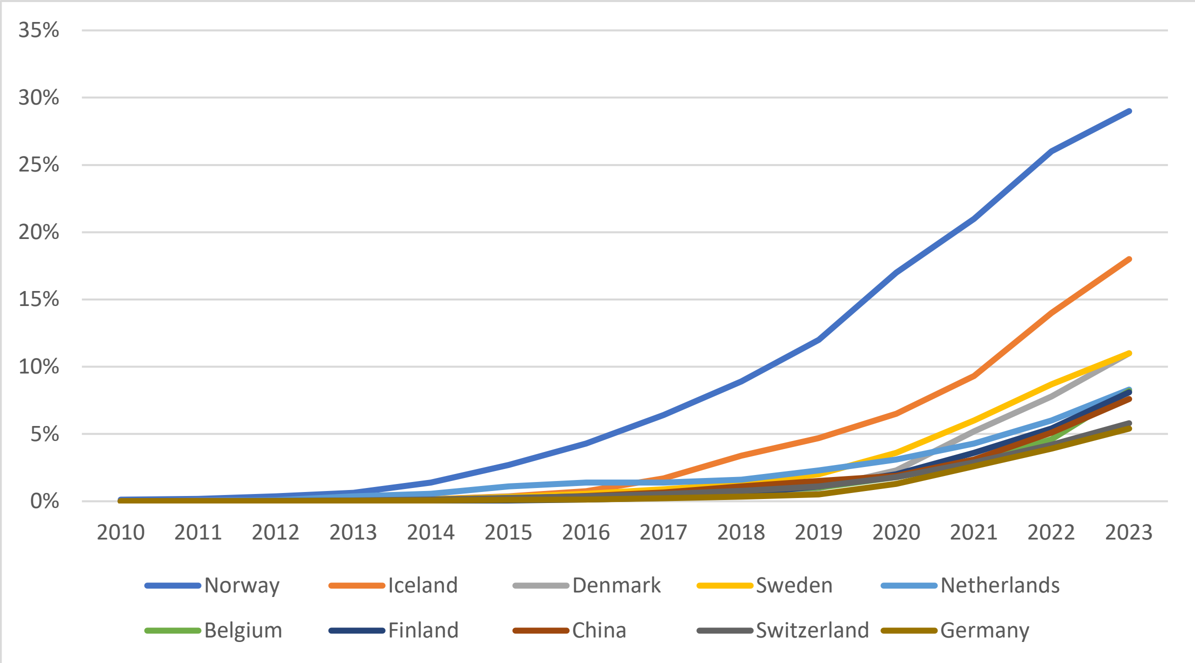
Figure 5: Top 10 countries in electric cars sales share in 2023



Source: IEA

[7] Bauck, W. (2023, March 16). Norway has the most EVs per capita, and the most chargers per EV. Here's how they did it. *Fast Company*. https://www.fastcompany.com/90866220/norway-has-the-most-evs-per-capita-and-the-most-chargers-per-ev-heres-how-they-did-it

Figure 6: Top 10 countries in electric cars stock share in 2023



Source: IEA

While developed countries are rapidly adopting electric cars, the electric two- and three-wheelers sector is experiencing significant growth in developing countries, particularly in India, China, and ASEAN countries. In 2023, India surpassed China to become the global leader in electric three-wheeler sales, with more than 580,000 units sold.[8]

2. Leading Brands in EV Markets

Globally, six of the top 10 EV brands in BEV sales in 2023 were from China (See Figure 7). BYD, a leading Chinese automaker, is expected to surpass Tesla in BEV sales by 2024.[9] In the fourth quarter of 2023, BYD sold 526,409 BEVs, over 20,000 more than Tesla's 485,507.[10]

Affordable Chinese EVs are particularly popular in developing countries that rely on foreign carmakers, such as Thailand, Brazil, Indonesia, Mexico, and Malaysia. While the amount Chinese EVs sales are considerable in India and Türkiye, domestic carmakers continue to lead in these markets. In Vietnam, the strong local brand VinFast has enabled the country to largely rely on its own automotive industry. (See Figure 8)

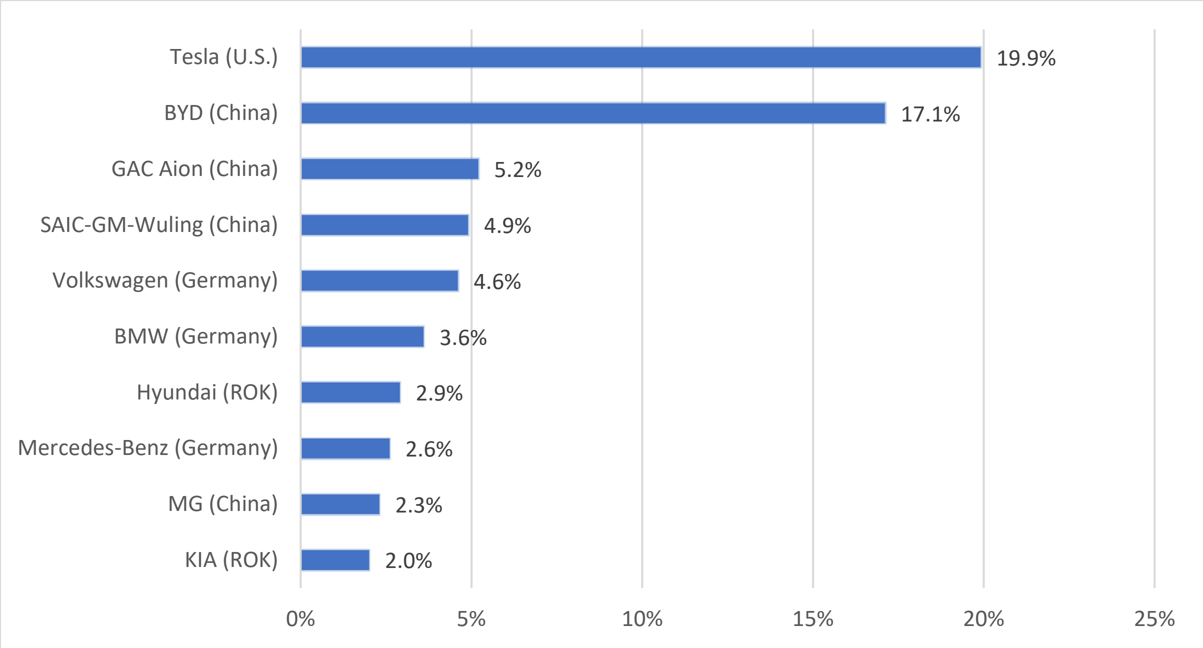
[8] IEA. (2024). *Global EV Outlook 2024: Moving towards increased affordability*. https://www.iea.org/reports/global-ev-outlook-2024

[9] Lu, M. (2024). Visualizing Global Electric Vehicle Sales in 2023, by Market Share. In *Visual Capitalist*.

[10] Sriram, A. (2024, January 3). Tesla delivers record Q4 cars, but China's BYD steals top EV spot. *Reuters*. https://www.reuters.com/business/autos-transportation/teslas-fourth-quarter-deliveries-beat-estimates-2024-01-02/

Developed markets tend to favour their own brands. In the US, Tesla dominates the EV market with over half of the total EV sales in units.[11] The Texas-based brand also leads in the EU market, closely followed by European brands such as BMW, Mercedes-Benz, Volvo, and Volkswagen.[12]

Figure 7: Market shares of top 10 companies in BEV sales (2023)

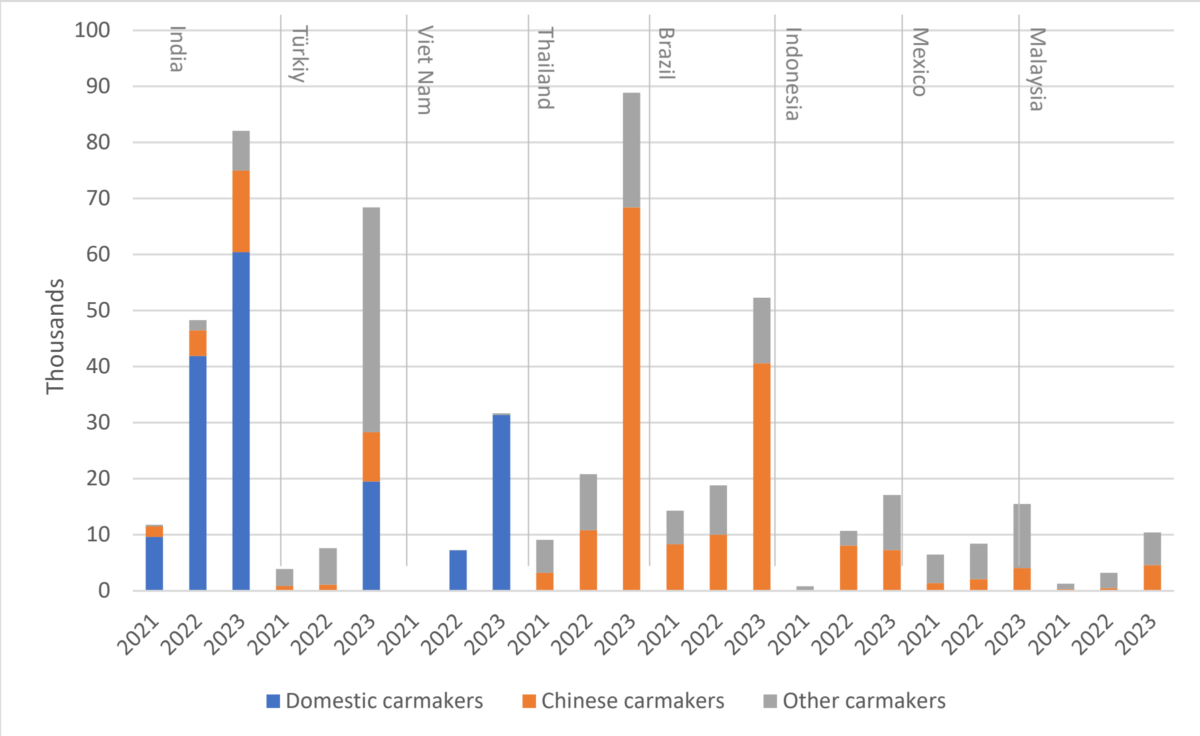


Source: TrendForce

[11] KBB. (2024). *Electric Vehicle Sales Report Q4 2023* (https://www.coxautoinc.com/wp-content/uploads/2024/01/Q4-2023-Kelley-Blue-Book-Electric-Vehicle-Sales-Report.pdf

[12] Pontes, J. (2024, September 27). Europe EV Sales Report — EV Sales Down in August, But Less Than Some People Might Lead You To Believe. https://alternative-fuels-observatory.ec.europa.eu/general-information/news/europe-ev-sales-analysis-key-insights-june-2024-registrations

Figure 8: Electric car sales in selected countries, by origin of carmaker, 2021-2023



Source: IEA

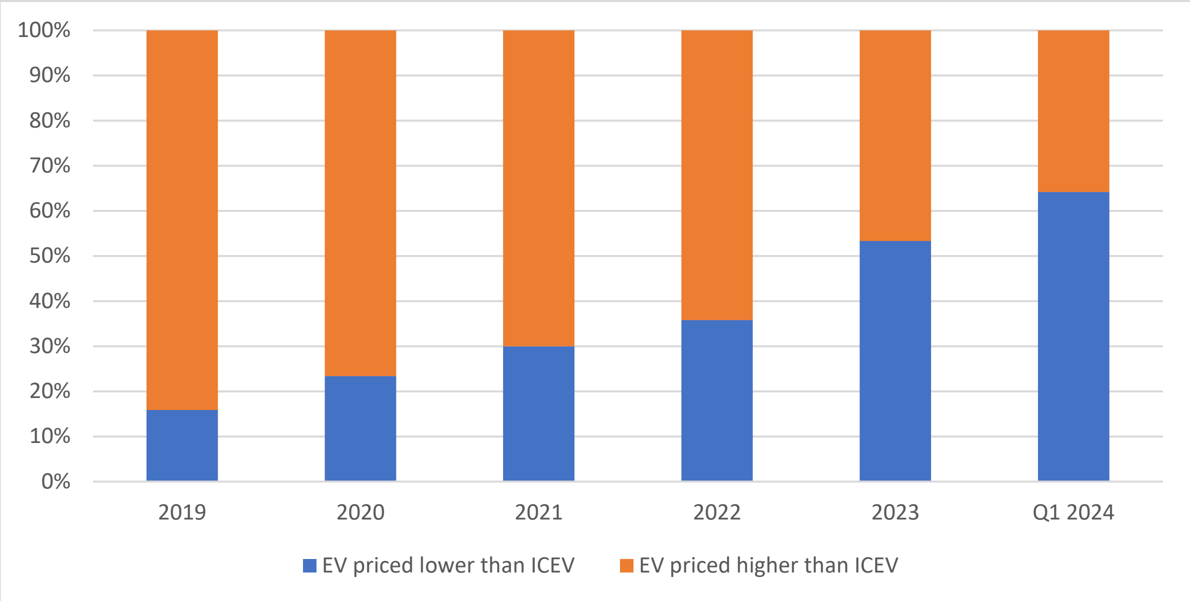
3. Outlook of EV Consumer Market

The EV market is poised for continued strong growth in the coming years, driven by the increasing commitment of governments and major automotive manufacturers to electrification strategies. This optimism is further bolstered by the continuous decline in EV prices. By 2023, the average price of EVs has dropped below that of ICEVs (See Figure 9).[13] S&P estimated that the sales of BEV will surpass ICEVs by 2030 and become the most popular automotive model.[14]

[13] McKerracher, C. (2024). China's Batteries Are Now Cheap Enough to Power Huge Shifts. *Bloomberg*. https://www.bloomberg.com/news/newsletters/2024-07-09/china-s-batteries-are-now-cheap-enough-to-power-huge-shifts

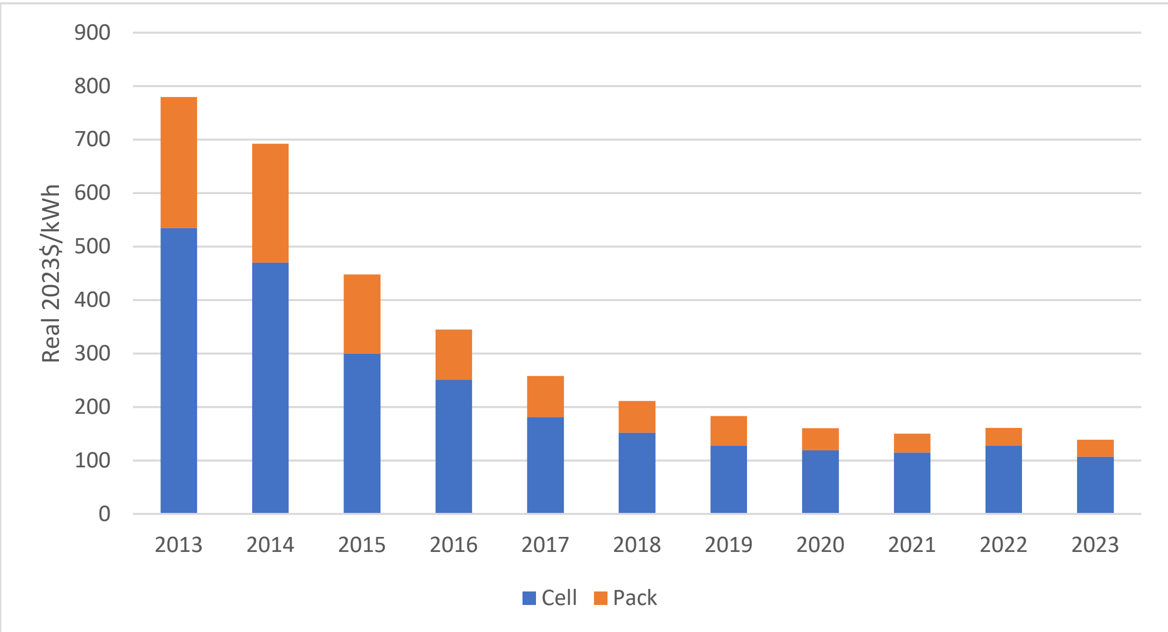
[14] Vildozo, G., & Brinley, S. (2024). *US Election: Calculating the Impact on the Automotive Ecosystem*. https://www.spglobal.com/mobility/en/events/us-election-calculating-the-impact-on-the-automotive-ecosystem/overview.html

Figure 9: Share of EV models priced above or below combustion equivalents



Source: Bloomberg

Figure 10: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023[15]



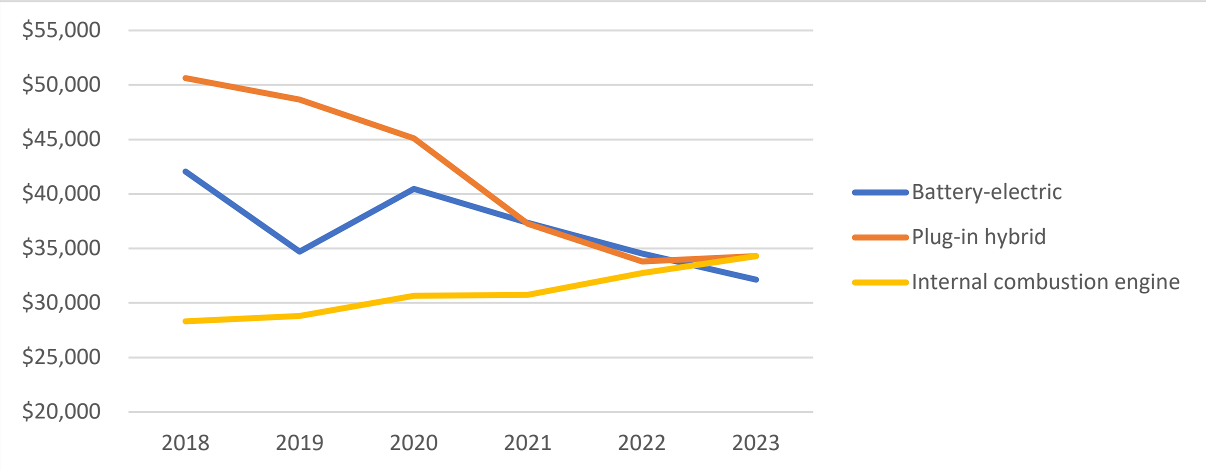
Source: BloombergNEF

[15] Note: Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles, and stationary storage.

This remarkable shift of price competitiveness has been driven primarily by the rapid decline in lithium-ion battery prices (See Figure 10).[16] Ongoing advancements in battery energy density, manufacturing processes, and economies of scale are all making EVs a more cost-competitive choice relative to traditional ICEVs. This favourable pricing trajectory is expected to significantly accelerate the adoption of EVs in the years ahead.

Compared to PHEVs, BEVs are seen as the more promising and viable EV option for the future, given their simpler design, lower maintenance costs, supportive infrastructure, and environmental benefits.

Figure 11: Average vehicle transaction price by drivetrain (USD) [17]



Source: Bloomberg

However, the pace and scale of this growth will depend on several key factors. Continued technological advancements in battery capacity, charging speeds, and powertrain efficiency will be crucial. Meanwhile, ensuring adequate supply of critical components like semiconductors and lithium-ion batteries will be essential. The development of comprehensive charging infrastructure, both public and private, will play a pivotal role in addressing range anxiety and facilitating wider EV usage. Moreover, the effectiveness of government policies, such as subsidies, tax incentives, and emissions regulations, will significantly influence the trajectory of the EV market's expansion. Ultimately, the confluence of these technological, supply chain, infrastructure, and policy considerations will determine the future growth and mainstream acceptance of electric vehicles.

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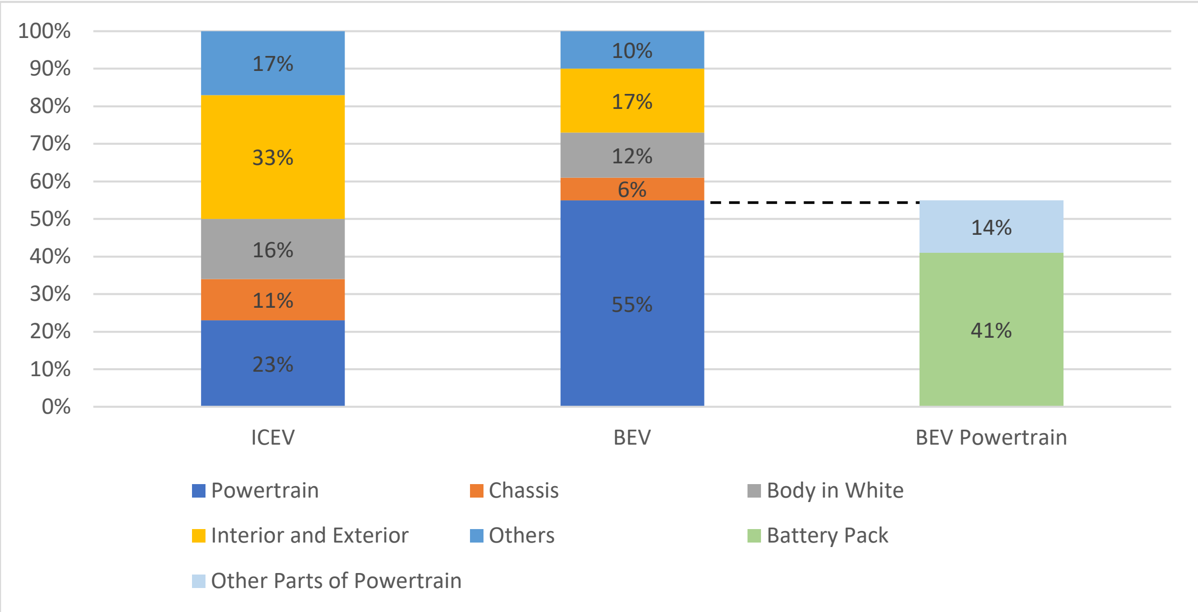
[16] McKerracher, C. (2024). China's Batteries Are Now Cheap Enough to Power Huge Shifts. *Bloomberg*. https://www.bloomberg.com/news/newsletters/2024-07-09/china-s-batteries-are-now-cheap-enough-to-power-huge-shifts

[17] Note: Battery-electric vehicles exclude mini cars.

III. Breaking Down the EV Value Chain

The primary difference between EVs and ICEVs lies in their powertrain, which is responsible for converting energy into motion that propels the car. In ICEVs, the powertrain consists of an internal combustion engine and a fuel system. In contrast, EVs replace some or all of these components with an electric motor, battery pack, and supporting power electronics. Despite this key distinction, both EVs and ICE vehicles require a chassis, vehicle body, and various interior and exterior components.

Figure 12: Cost breakdown of ICEV, BEV and BEV powertrain[18]

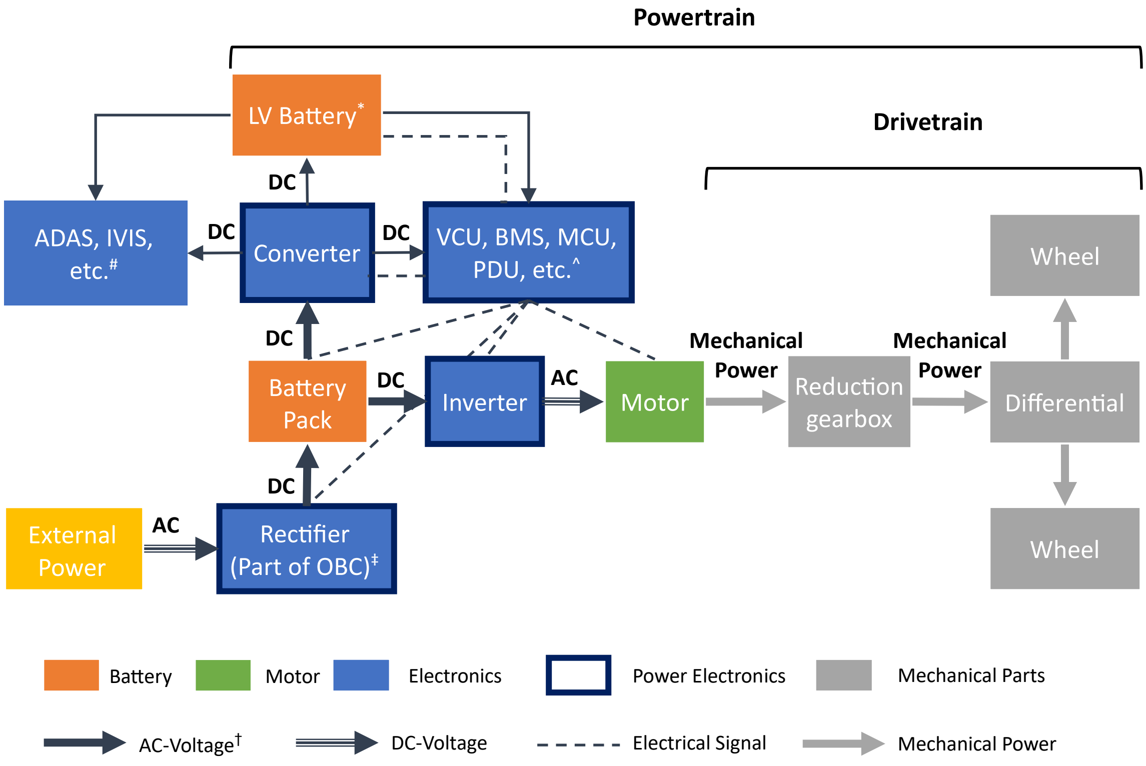


Source: S&P Global, HKUST Li & Fung Supply Chain Institute

A typical EV powertrain contains a battery pack that stores the power, a motor that converts the stored energy into the mechanical power that moves a vehicle, a power electronic system that manages the voltage and signal flows, and a drivetrain that delivers the mechanical power from motor to the wheels. The powertrain makes up more than half of the total costs of an EV. [19]

[18] The exact percentage breakdown may vary depending on the specific make, model, and design of the BEV.
[19] In some cost analyses or breakdowns of electric vehicles (EVs), the battery pack is considered separately from the electric powertrain. This separation allows for a more granular understanding of the individual cost drivers within the EV, as the battery pack is often the single most expensive part of the vehicle. However, in a comprehensive view of the EV value chain, the battery pack is an integral part of the overall electric powertrain system.

Figure 13: General schematic of a BEV powertrain



* LV Battery: Low-voltage Battery
^ VCU: Vehicle Control Unit; BMS: Battery Management System; MCU: Motor Control Unit; PDU: Power Distribution Unit
# ADAS: Advanced Driver Assistance Systems; IVIS: In-Vehicle Infotainment Systems
‡ OBC: On-Board Charger;
† The weight of the lines roughly represents the electric power strength

Source: HKUST Li & Fung Supply Chain Institute

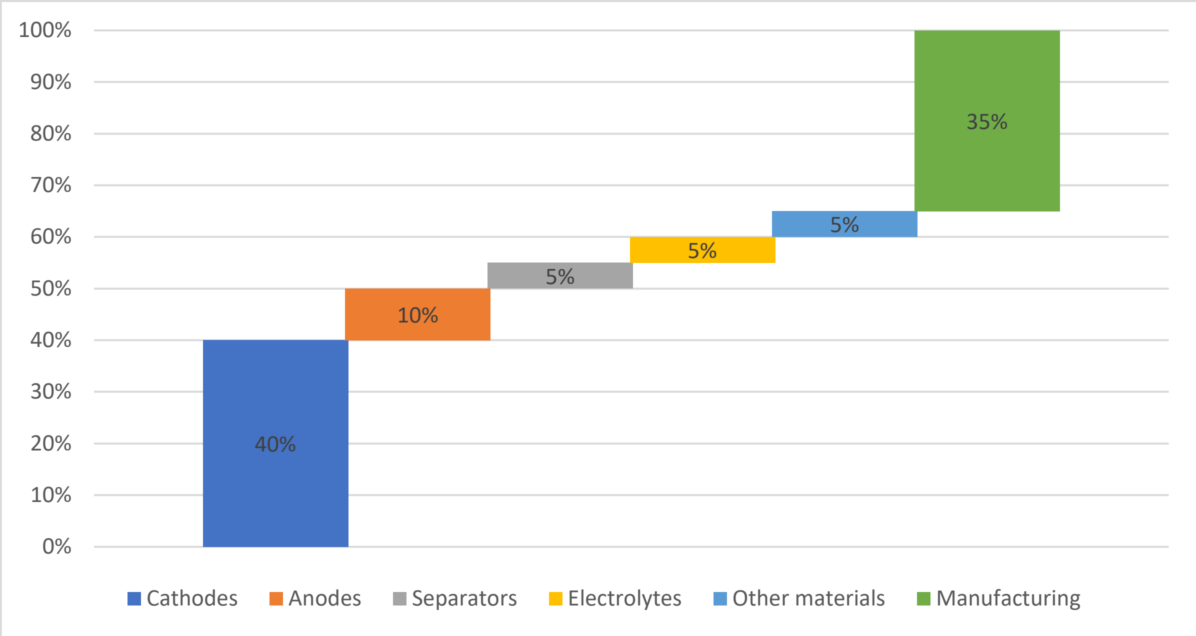
1. Batteries

To date, battery pack remains the single largest cost component, accounting for about 41% of the total cost of an electric car (see Figure 12). However, projected declines in battery cost are expected to reduce its share of the overall BEV cost over time.[20] A critical factor in the battery's price is the cost of the minerals required for its manufacturing, which represents about 60% of the battery's expense.[21]

Batteries for EVs, like other batteries, are comprised of four main components: cathodes, anodes, separators, and electrolytes.

[20] Lutsey, N., & Nicholas, M. (2019). *Update on electric vehicle costs in the United States through 2030*. https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf (Vehicle technology costs for conventional and electric vehicles in 2018 and 2025 for cars, crossovers, and SUVs)
[21] Roberts, G. (2022b, December 28). Cost of minerals vital for electric vehicle batteries soars. *FleetNews*. https://www.fleetnews.co.uk/news/latest-fleet-news/electric-fleet-news/2022/12/28/cost-of-minerals-vital-for-electric-vehicle-batteries-soars

Figure 14: Cost breakdown of typical lithium-ion battery cells[22]



Source: McKinsey & Company

A cathode is an electrode at which a reduction reaction occurs during discharge, resulting in the gain of electrons by the electroactive species. During discharge, the cathode is the positive electrode, while during charging, the cathode is the negative electrode. It is a critical component that significantly impacts the battery's capacity and voltage. The material used for the cathode determines the type of battery. Lithium-ion batteries are widely adopted in the EV industry. The cathode accounts for approximately 40% of the total cost of an EV battery. The most popular types are ternary lithium batteries (combinations of nickel, manganese, and cobalt [NMC] or nickel, cobalt, and aluminium [NCA]) and lithium iron phosphate (LFP) batteries. Other materials used for cathodes include lithium cobalt oxide and lithium manganese oxide.

An anode is an electrode at which an oxidation reaction occurs during discharge, resulting in the loss of electrons from the electroactive species. During discharge, the anode is the negative electrode, while during charging, the anode is the positive electrode. It is typically made from graphite and plays an essential role in the battery's charging capabilities and lifespan. It constitutes about 10% of the total cost of an EV battery.

Separator is a thin, porous membrane that isolates the cathode from the anode while allowing lithium ions to pass through during charging and discharging. This component is

22 Note: The figures provided are based on a sample NMC811 battery production in Europe in 2023. The calculation for the anodes includes current collector. The "Other materials" category includes solvents, packing, binders, etc. The "Manufacturing" cost component encompasses capital expenditure depreciation, operating expenditures (labour, energy, logistics, R&D, SG&A, etc.) and yield loss.

crucial for both safety and efficiency. Polyolefins, specifically polyethylene (PE) and polypropylene (PP), are the most common materials for separators in EV batteries. PE is mainly used in ternary lithium batteries, while PP is used in LFP batteries. The manufacturing process for separators is complex and capital-intensive, favouring established companies in the industry.

Electrolyte facilitates the movement of lithium ions between the cathode and anode during battery operation. Typically, lithium salts, such as lithium hexafluorophosphate ($LiPF_6$), are dissolved in organic solvents. The costs of electrolyte components vary significantly, with lithium salts being the most expensive due to their essential role in battery function and the technological challenges associated with their production.

Lastly, the assembly of these components into battery cells requires advanced technological capabilities. This stage accounts for around 35% of the battery's total cost (See Figure 14).

2. Electric Motor

The electric motor, considered as the "heart" of an EV, converts electric power into mechanical power. It comprises two main components: the rotor, which is the moving part connected to the output shaft, and the stator, the stationary part with copper windings that generate a rotating magnetic field when electrified. Operating on the principle of electromagnetic induction, the interaction between the stator's rotating field and the rotor's magnetic field produces the force necessary for rotational torque, effectively transforming electrical energy into mechanical energy.

While there are several technology paths for EV motors (see Table 1), the permanent magnet synchronous motor (PMSM) is the predominant choice for electric passenger vehicles. Unlike other electric motors, the PMSM incorporates permanent magnets in its rotor, resulting in greater efficiency in power generation. However, it is more costly than alternative motor types.

Table 1 Comparison of different types of electric motor

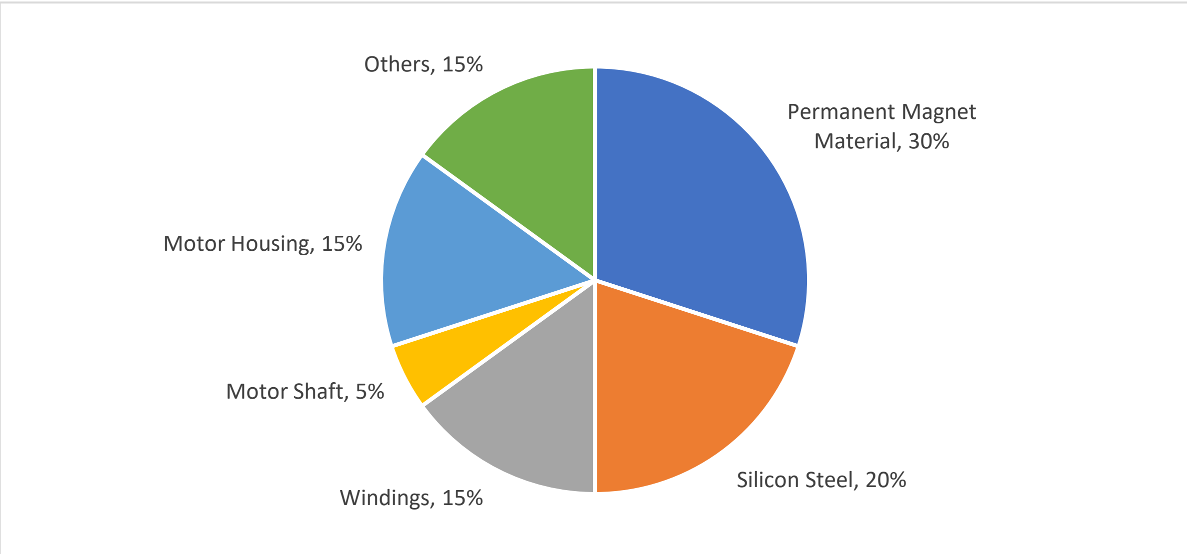
Attribute	**Direct Current Motor**	**Switched Reluctance Motor (SRM)**	**Induction Motor (a.k.a. Asynchronous Motors)**	**Permanent Magnet Synchronous Motor (PMSM)**
Power Density	Low	High	Medium	Very High
Torque Density	Medium	High	Low	Very High
Reliability	Medium	High	High	Very High
Structural Rigidity	Low	Very High	Very High	High
Dimension/Weight	Large	Small	Medium	Small

Speed Control Capability	Very Good	Good	Fair	Good
Noise	Low	High	Medium	Low
Cost of Motor	Low	Medium	Medium	High
Cost of Motor Controller	Low	Medium	High	High

Source: Dianji Xinshijie (电机新视界), HKUST Li & Fung Supply Chain Institute

Raw material costs account for over 80% of the total expense in an electric motor. The primary materials used in manufacturing PMSMs include permanent magnets (typically Neodymium-Iron-Boron, or NdFeB), silicon steel sheets, copper, and aluminium. The permanent magnets, essential for the rotor, are the largest cost component, comprising approximately 30% of the total PMSM cost structure (See Figure 15). These magnets are made from rare earth elements, specifically neodymium (Nd), dysprosium (Dy), and terbium (Tb).

Figure 15: Typical cost structure of permanent magnet synchronous drive motors



Source: Dianji Xinshijie (电机新视界)

3. Electronics

Electronics in EVs function like the nervous system of a vehicle. Among them, power electronics are the most critical to an EV's basic function, as they manage and convert electrical power within the powertrain, enabling the movement of an EV.

The main components of power electronics are power converters and controllers.

Power converters adjust the voltage, current, or frequency of the power supply to meet various needs within an EV. The main types of power converters include rectifiers, inverters, and converters. Rectifier converts alternating current (AC) from an external power source into direct current (DC) to charge the batteries. Inverter transforms DC power from the battery into AC power required by the electric motor. Converter reduces the battery's DC voltage for use by other vehicle systems.

Insulated gate bipolar transistors (IGBTs) in inverters are essential in power electronics and can account for 7-10% of the total cost of a vehicle due to the complex semiconductor fabrication techniques and the need for precise control and reliability.[23] These semiconductor devices are used as the main switching devices to control the conversion of DC to AC. They are responsible for the high-speed switching that generates the desired AC waveform from the DC input.

Controllers in a powertrain are part of the whole car's electronic control units (ECUs). ECUs regulate the operation and performance of an EV, while the controllers specifically manage the functions of the EV's powertrain. Central to ECU is vehicle control unit (VCU), often referred to as the "brain" of the EV. The VCU oversees and coordinates the functions of various other ECUs, including the battery management system (BMS), motor control unit (MCU), and power distribution unit (PDU), ensuring optimal integration and efficiency across all systems within the EV.

As technology continuously advances and consumer expectations evolve, the rise of "smart EVs" has become a significant trend in the automotive industry. A smart EV integrates advanced technology and connectivity features, enhancing the driving experience and facilitating interactions with smart infrastructure.

Smart EVs are characterized by its semi- or fully autonomous driving capabilities, connectivity that allows for internet integration, and advanced infotainment systems that add functionality. At the forefront of smart EV transformation is autonomous driving technology, where automakers are increasingly integrating artificial intelligence and advanced sensors into their vehicles. Advanced Driver-Assistance Systems (ADAS), which include features such as adaptive cruise control and collision avoidance, contribute to safer and more efficient driving experiences.

Smart EVs also offer improved energy efficiency through features such as smart energy consumption management, smart charging that optimizes charging times and costs, and vehicle-to-grid (V2G) functions that enable energy transfer back to the grid.

The integration of these smart features necessitates a revolution of traditional supply chains, requiring manufacturers to collaborate closely with technology providers to incorporate advanced chips and software crucial for smart EV functionality. This collaboration also

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[23] Kuke Electronics Limited. (2024, February 21). Introduction to IGBT Development and in EV Uses. *LinkedIn*. https://www.linkedin.com/pulse/introduction-igbt-development-ev-uses-kuke-electronics-qvine

extends to the sourcing and production of semiconductor devices that are essential for EV operations.

As vehicles evolve, the number of chips used in them is increasing significantly. Traditional ICE cars typically contain 500-600 chips, while EVs require more than 1,000. The most advanced smart EVs can incorporate more than 3,000 chips.[24,25] This significant increase in chip usage underscores the critical importance of automotive chip supply chains to EV production and delivery.

Automotive chips must meet rigorous standards for performance, reliability, and safety. These chips are designed to withstand harsh environments, requiring resistance to heat, vibration, and interference. Despite their technological maturity, the barriers to entry remain high, with only a few companies capable of producing these specialized chips.

Globally, automotive chips represent about only 1% of the $300-$400 billion semiconductor industry.[26] Established companies like Infineon, NXP, and Renesas dominate the space of automotive chips. However, new players, including BYD in China, are entering the market, focusing on niche areas and achieving local production.

4. Drivetrain

Drivetrain is the mechanical part of the powertrain. It transmits the mechanical power from the motor to the wheels. Its key components are the reduction gearbox, differential, and axles. The **reduction gearbox**, which is a single-speed counterpart of multi-speed transmission of ICE vehicles, allows for a high wheel torque while keeping the motor in a low speed. The **differential** then distributes the power to the left and right wheels through the **axles**, allowing the vehicle to turn and move.

5. Complete Vehicle Manufacturing

Vehicle manufacturing begins with the automaker selecting suppliers based on production plans and component requirements. Successful automakers excel in areas such as demand planning, vehicle integration, resource management, and supply chain coordination, allowing them to effectively source high-quality components from suppliers.

When sourcing vehicle components, most major auto brands utilize the original equipment manufacturer (OEM) model. In the OEM model, brand owners design the vehicle and provide specifications to manufacturers. This enables the brands to retain significant control

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[24] ATC 汽车技术平台. (2023, July 28). 造一辆车需要多少芯片？（附国内急需的汽车芯片替代清单）. *搜狐汽车*. https://www.sohu.com/a/707097352_100109629

[25] 多部田俊辅. (2024, February 5). 中国车载芯片 9 成靠进口，10 年实现国产替代. *日经中文网*. https://cn.nikkei.com/china/ceconomy/54676-2024-02-05-08-32-39.html

[26] OFweek 电子工程网. (2022, September 28). 一辆车到底需要多少芯片？国产替代有哪些？. *维科网·电子工程*. https://ee.ofweek.com/2022-09/ART-8300-2800-30575301.html

over product development, so that to optimize performance and strengthen brand identity. Conversely, many newer startups tend to adopt the original design manufacturer (ODM) approach. The ODM model involves third-party manufacturers who handle both design and production. While this can reduce development costs and time-to-market, brand owners relinquish some control.

Vehicle assembly is a critical step in automotive manufacturing, as it directly impacts the performance and quality of the final product. More importantly, the location of vehicle assembly determines the origin of the vehicle in international trade, making it heavily influenced by the trade policies of different markets. The assembly process requires advanced production equipment, comprehensive systems, and rigorous quality control measures, all of which require significant investment. Achieving scale is essential for automakers to enhance cost efficiency. Established brands like BYD, Tesla, Volkswagen, Toyota, typically manage assembly in-house.

There are four key manufacturing processes in the final assembly of a complete vehicle.

- **Pressing (a.k.a. Stamping)**: This stage utilizes heavy machinery to press and shape sheet metal into the body panels and structural components that form the vehicle's frame and outer shell. While traditionally a key process in vehicle assembly, pressing is increasingly being supplanted by casting, which involves melting metal and pouring it into moulds, allowing for more complex shapes and greater material efficiency.
- **Welding (a.k.a. Body Assembly)**: In this stage, the stamped or cast metal parts are precisely aligned and joined together using automated systems to construct the complete vehicle body structure. This process ensures structural integrity and durability, facilitating the transition from individual components to a cohesive frame.
- **Painting and Coating**: The assembled body undergoes a thorough painting and coating process, which not only provides the desired exterior finish but also enhances protection and aesthetic appeal. This stage involves multiple layers, including primers and topcoats, to ensure durability and a high-quality appearance.
- **Final Assembly**: In this final stage, the painted body is mated with the powertrain, interior components, electrical systems, and other subsystems to create the complete, ready-to-drive vehicle. This process involves careful coordination to ensure that all components fit seamlessly and function together, culminating in the final product that meets both performance and quality standards.

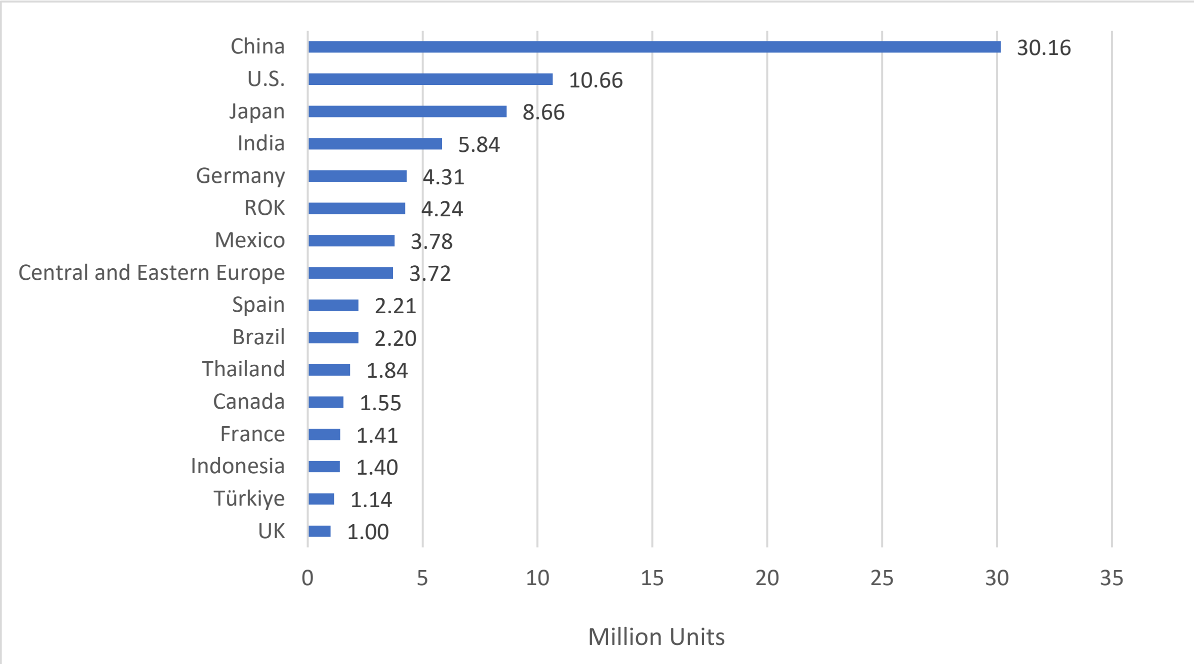
In addition to the key manufacturing processes involved in vehicle assembly, various production approaches play a crucial role in complete vehicle manufacturing. The most common methods include mixed-model production, job shop production, and batch production. Each approach has its own unique characteristics and advantages, allowing manufacturers to optimize efficiency, flexibility, and responsiveness to market demands.

- **Mixed-model production** is a manufacturing approach that allows for the simultaneous production of multiple distinct models—even those as varied as electric, diesel, and liquefied natural gas (LNG) vehicles—on a fixed production line. This method is well-suited for vehicle models with a moderate level of complexity that can be effectively combined on the same line. The mixed-model approach aligns with the principles of lean manufacturing, allowing for greater production efficiency compared to segregated single-model lines. Virtually all modern EV factories employ some form of mixed-model production to leverage economies of scale while maintaining flexibility.
- **Job shop production**, also known as custom production or bespoke production, is a more customized and labour-intensive approach that was common in the early days of the automotive industry, before the advent of mass production assembly lines. In a job shop, vehicles are built one-at-a-time or in very small batches, often relying on highly skilled workers to assemble them. This model offers a high degree of customization, but at the expense of production speed and efficiency. While job shops are rarely used for mainstream EV manufacturing today due to their high costs, this approach can still be useful for low-volume, highly customized vehicles, such as luxury electric models or prototype development.
- **Batch build production** is a hybrid approach that lies between the continuous flow of mixed-model lines and the one-off nature of job shops. In this model, EVs are produced in discrete batches, allowing for some economies of scale without the full rigidity of a dedicated assembly line. Batch build can accommodate a higher level of complexity compared to mixed-model, but at a lower efficiency. This approach may be utilized by EV manufacturers for certain models or variants that do not require the full continuous flow of a mass production line, providing a balance of flexibility and productivity.

IV. Major EV Supply Chain Players and Their Locations

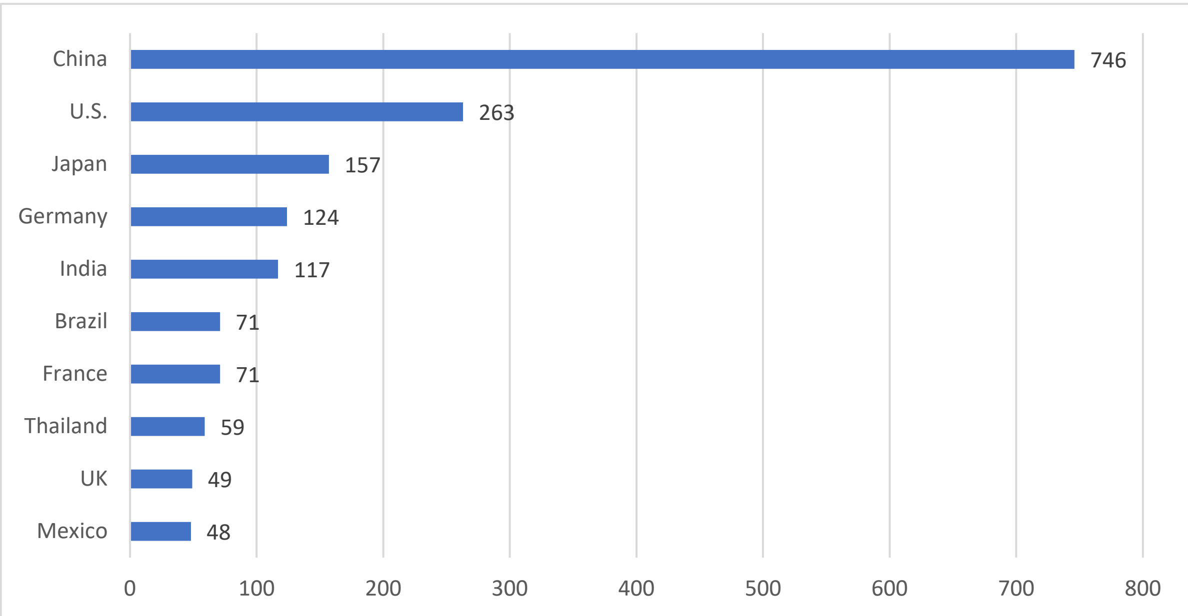
Automotive industry has long evolved into a highly globalized sector. Leading auto parts suppliers have established their operations worldwide. The global automotive OEM landscape is led by China, the US, and Japan, with significant contributions from India, Germany, and South Korea (ROK). Additionally, Mexico and Central and Eastern Europe are emerging as important bases of automotive manufacturing. (See Figure 16 and Figure 17)

Figure 16: Top countries in OEM production volume[27] (2023)



Source: MarkLines

Figure 17: Countries with most automotive OEM locations[28] (2023)



Source: MarkLines

[27] Including automotive parts and vehicle.
[28] Including automotive parts and vehicle.

China plays a crucial role in the EV supply chains, exerting substantial influence in both the upstream and midstream sectors. Recent enterprise search data reveals that China is home to over 600,000 existing new energy vehicle (NEV)-related businesses. In 2022 alone, there were 239,400 newly established NEV-related enterprises, reflecting a year-on-year growth of 40.34%.[29]

1. Raw Materials

China has become the leading supplier of raw materials critical to the EV industry, primarily due to its refining and processing capabilities rather than resource ownership. The country is responsible for 60-90% of the refining and processing of most minerals.[30] It holds a significant position in mining critical minerals and leads in processing and manufacturing, accounting for 85-90% of global rare earth element refining and processing 68% of the world's cobalt, 65% of nickel, and 60% of lithium needed for EV batteries.[31]

According to recent estimates by the International Energy Agency (IEA), except for steel and aluminium, a typical electric car requires about six times the mineral inputs of a conventional ICE car (See Figure 18),[32] highlighting the resource-intensive nature of EV production. The manufacturing of EVs relies heavily on a range of critical raw materials, known as "transition minerals." This diverse collection includes lithium, cobalt, nickel, manganese, phosphate, and graphite, which are crucial for the performance, longevity, and energy density of EV batteries. Additionally, rare earth elements are essential for the permanent magnets used in electric motors.

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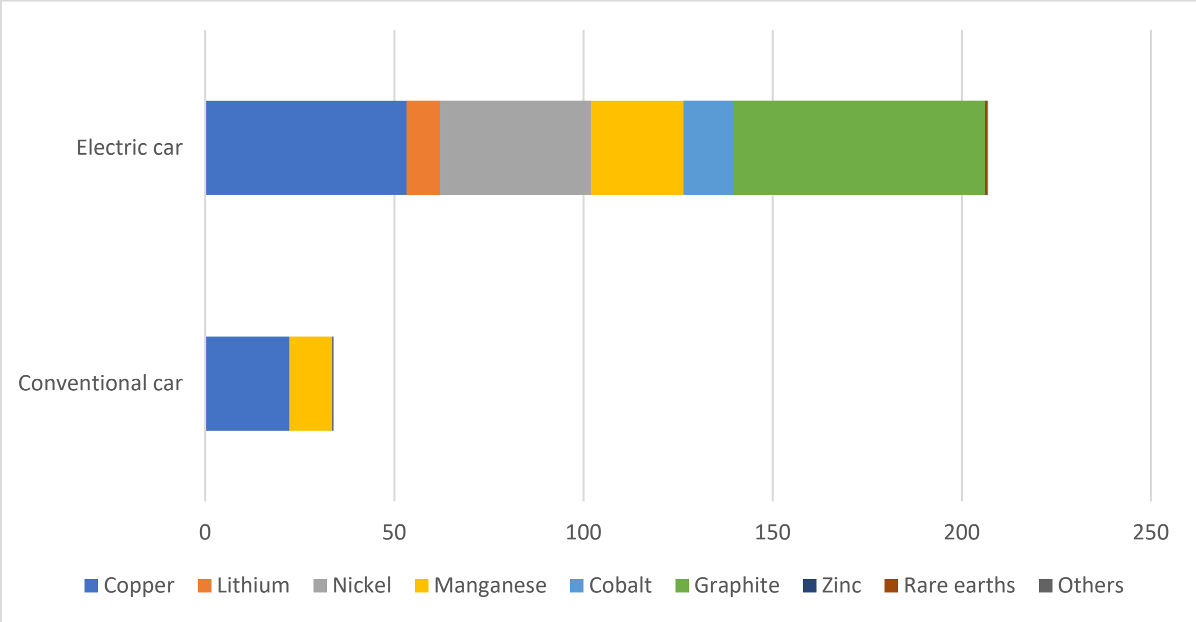
[29] Wu, Y. (2023, August 10). China's Electric Vehicle Supply Chain and Its Future Prospects. *China Briefing*. https://www.china-briefing.com/news/chinas-electric-vehicle-supply-chain-and-its-future-prospects/

[30] Deese, B. (2023). How to Break China's Hold on Batteries and Critical Minerals. *Foreign Policy*. https://foreignpolicy.com/2023/10/04/ev-electric-china-us-batteries-critical-minerals-energy-oil-renewable/

[31] Cohen, J. (2023). *Resource realism: The geopolitics of critical mineral supply chains*. https://www.goldmansachs.com/insights/articles/resource-realism-the-geopolitics-of-critical-mineral-supply-chains.html

[32] IEA. (2022). *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions*. https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

Figure 18: Minerals used in electric cars compared to conventional cars (kg/vehicle) (steel and aluminium not included) [33]



Source: IEA

According to the IEA, achieving the climate goals set by the Paris Agreement[34] will require a significant increase in mineral inputs for clean energy technologies. Specifically, mineral requirements (excluding steel and aluminium) may quadruple by 2040 from 2020 levels. In an even more ambitious scenario targeting global net-zero emissions by 2050, a sixfold increase in these mineral inputs may be necessary.[35] (See Figure 19)

The demand surge is largely driven by EVs and battery storage, which are projected to account for approximately half of the overall mineral demand growth in clean energy technologies over the next two decades from 2020. In these climate-driven scenarios, mineral demand from EVs and battery storage could increase 30 to 50 times by 2040. Minerals including lithium, cobalt, nickel, copper, and rare earth elements will experience significant increase in demand (See Figure 20) and will be consumed mainly in clean energy-related sectors (See Figure 21).[36]

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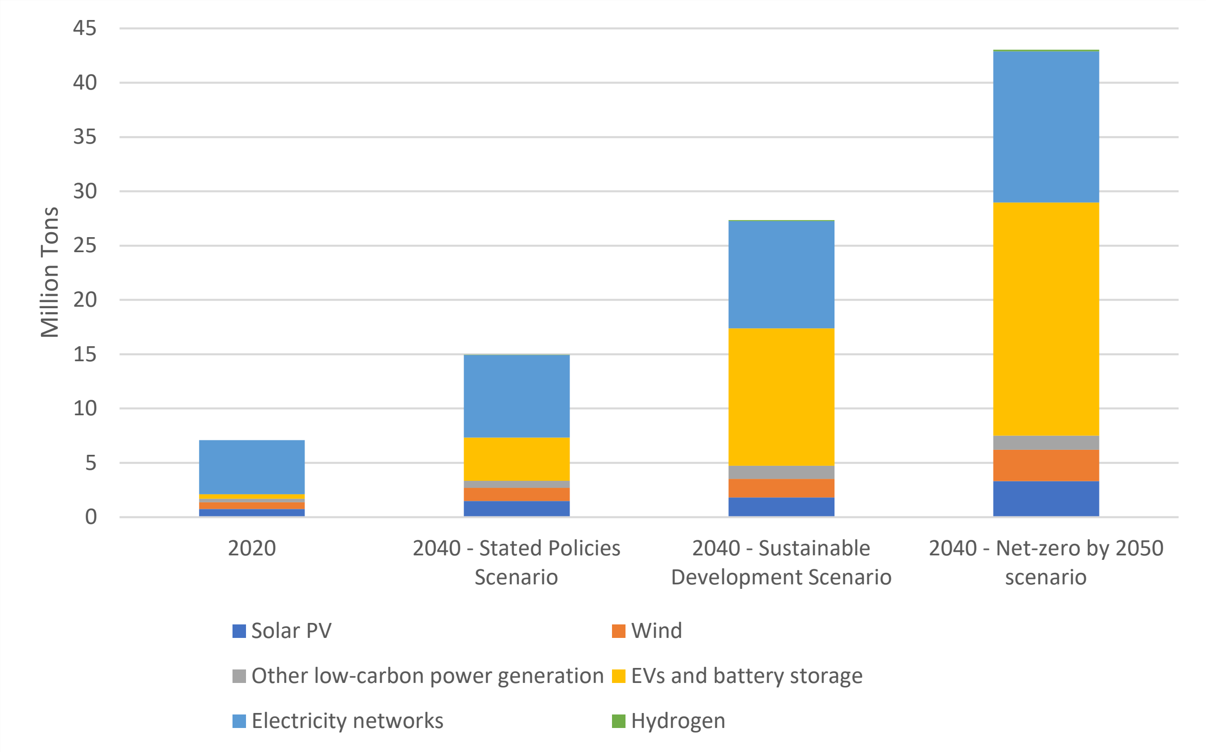
[33] Note from the source: The values for vehicles are for the entire vehicle including batteries, motors and glider. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode. The values for offshore wind and onshore wind are based on the direct-drive permanent magnet synchronous generator system (including array cables) and the doubly-fed induction generator system respectively.

[34] The Paris Agreement, adopted in 2015, aims to limit global temperature rise to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. This goal requires significant reductions in greenhouse gas emissions and a transition to clean energy technologies.

[35] IEA. (2022). *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions*. https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

[36] Ibid.

Figure 19: Total mineral demand for clean energy technologies by scenario, 2020 compared to 2040[37,38]

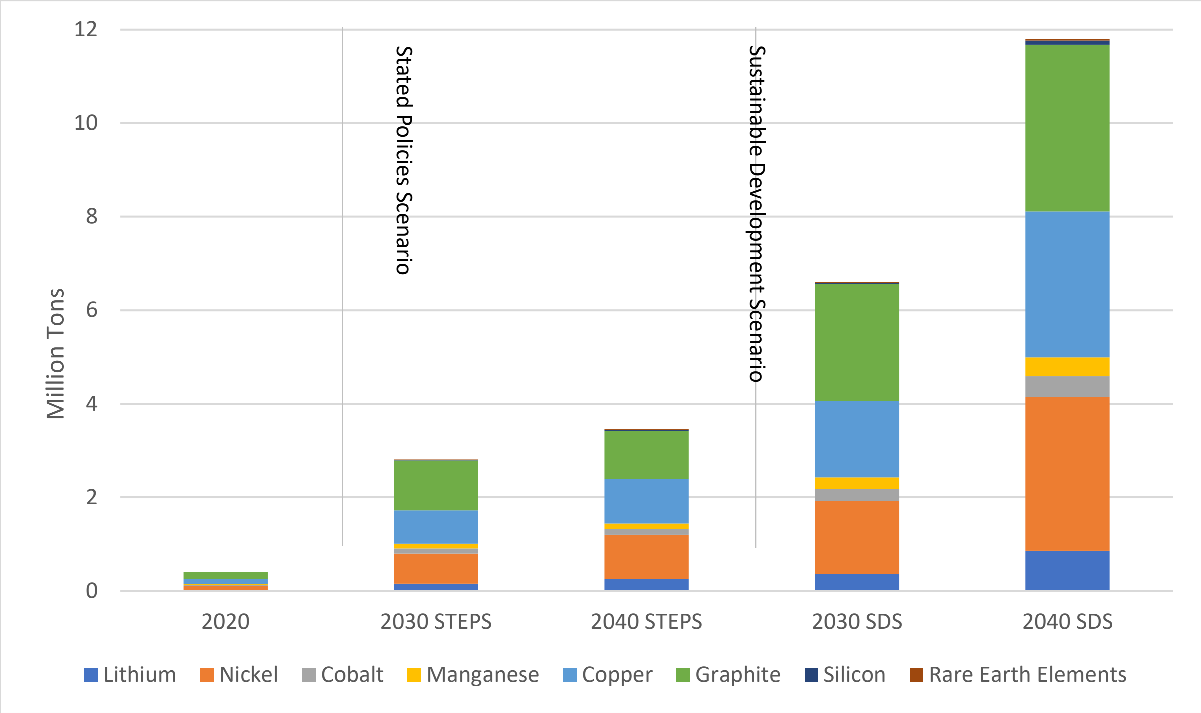


Source: IEA

[37] The minerals reflected in this chart include chromium, copper, major battery metals (lithium, nickel, cobalt, manganese, and graphite), molybdenum, platinum group metals, zinc, rare earth elements and others, but does not include steel and aluminium.

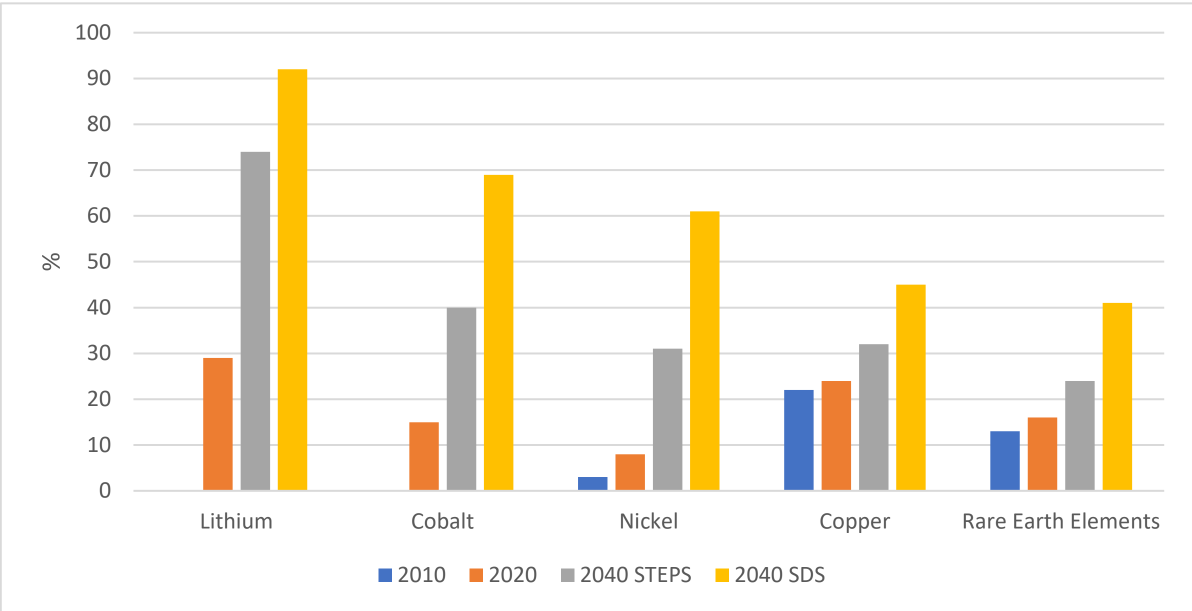
[38] The Stated Policies Scenario (STEPS) provides a forecast of the energy system's trajectory based on an analysis of current policies and announced policy intentions across various sectors; the Sustainable Development Scenario (SDS) outlines the path required to align with the goals of the Paris Agreement, including limiting global temperature rise to well below 2°C above pre-industrial levels. Net zero is the state where the amount of greenhouse gases produced is equal to the amount removed from the atmosphere.

Figure 20: Mineral demand from new EV sales by scenario, 2020 compared to 2040



Source: IEA

Figure 21: Share of clean energy technologies in total demand for selected minerals by scenario, 2010-2040

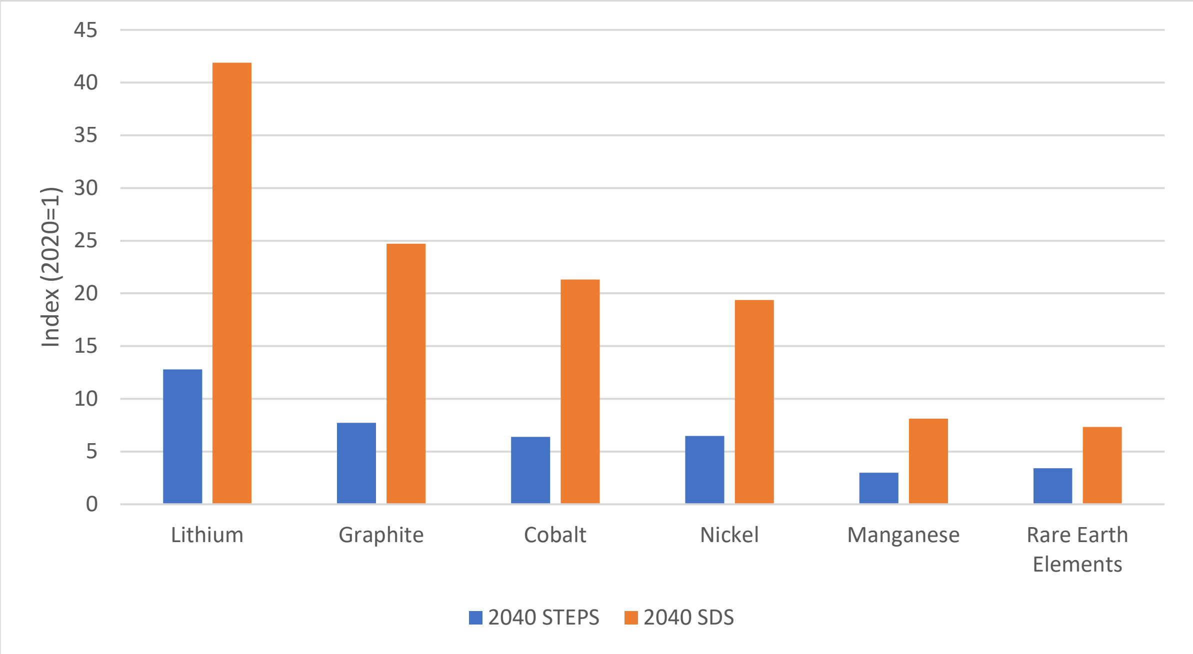


Source: IEA

Among these minerals, lithium demands from both EVs and broader clean energy technologies are projected to see the most rapid growth, potentially increasing over 40 times from 2020 to 2040 to meet the requirements (See Figure 22 and Figure 23).[39]

The projected drastic surge in demand for these materials points to potential supply chain pressures and the need for strategic resource management in the EV industry.

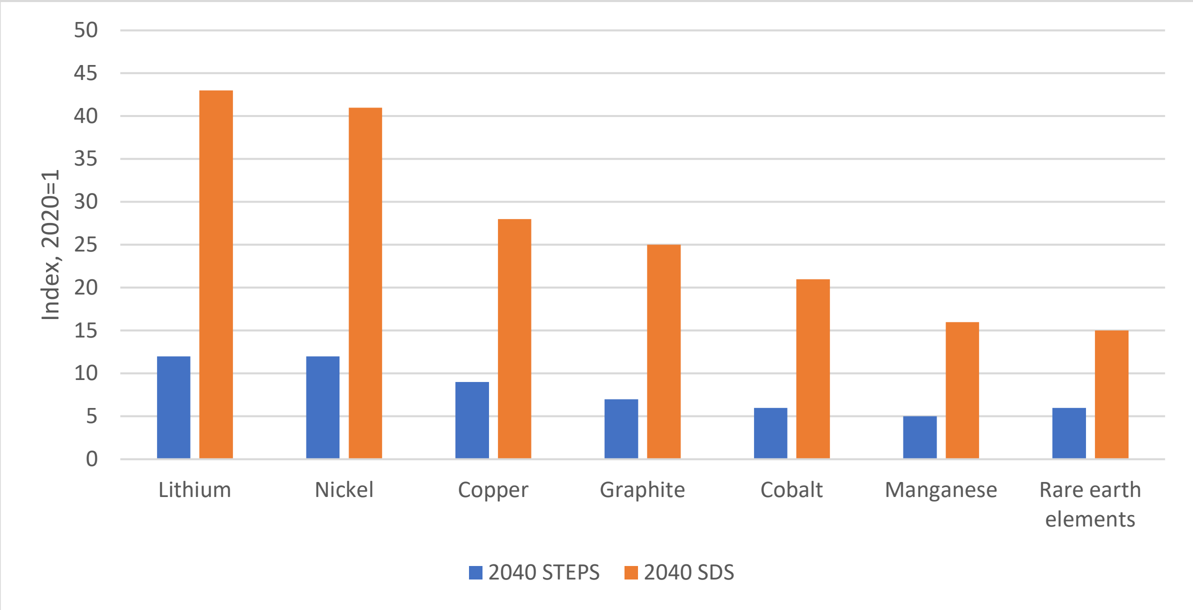
Figure 22: Mineral demand growth from clean energy technologies by scenario, 2020 compared to 2040



Source: IEA

[39] IEA. (2022). *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions*. https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

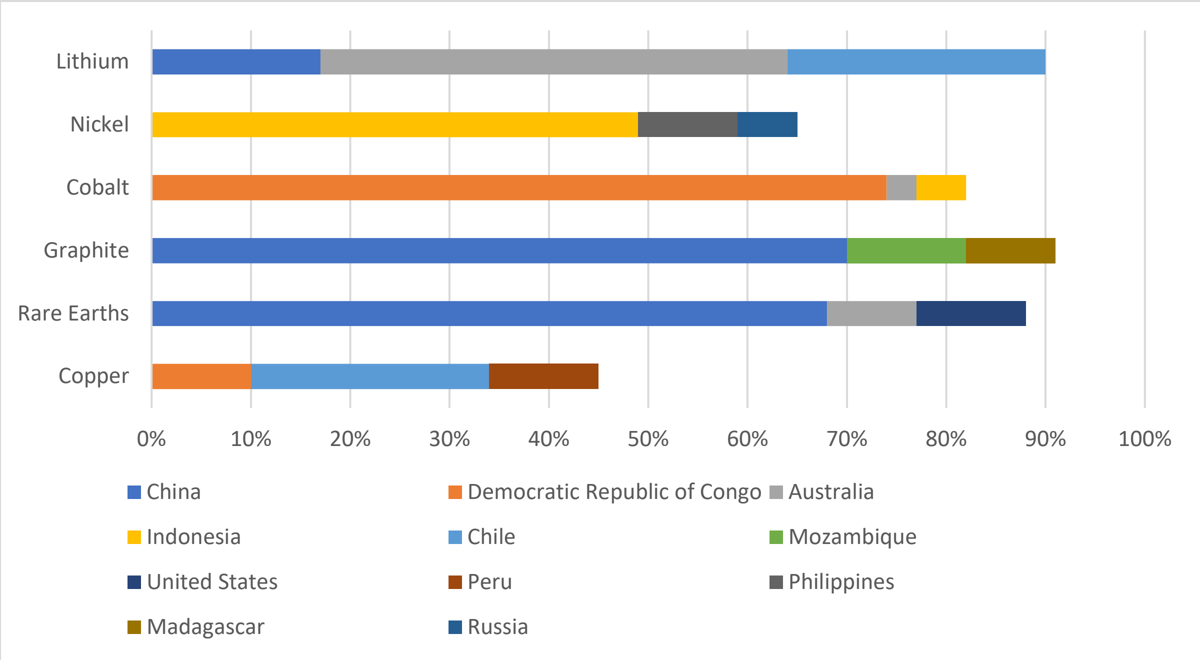
Figure 23: Mineral demand growth from new EV sales by scenario, 2020 compared to 2040



Source: IEA

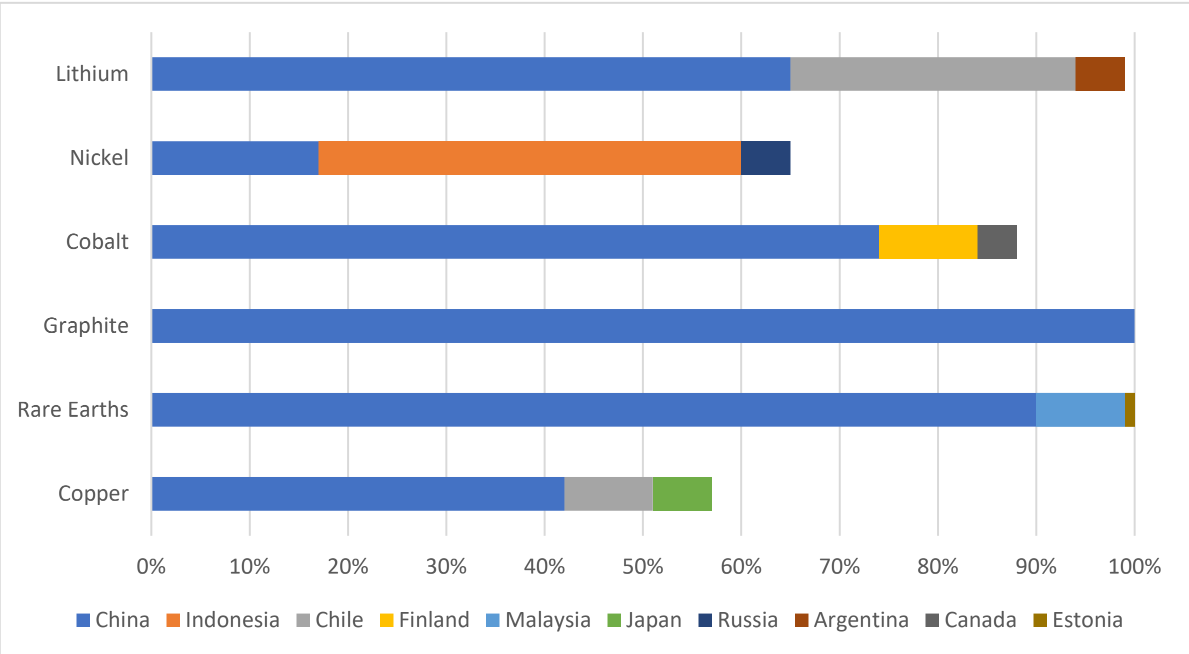
While the demand for key raw materials for EVs is expected to soar, their mining and processing are concentrated in a few countries. Australia and Chile dominate lithium mining, with China playing a key role in processing. Indonesia leads in nickel production and processing. The Democratic Republic of Congo (DRC) is a major source of cobalt, with China processing a large share of it. Graphite mining is largely concentrated in China, which also handles almost all processing. Similarly, China is the leading producer and processor of rare earth elements. Copper, essential for EV wiring and components, is mined in several countries, including Chile and Peru, with significant processing also occurring in China. (See Figure 24 and Figure 25)

Figure 24: Share of top three producing countries in mining of selected minerals, 2022



Source: IEA

Figure 25: Share of top three producing countries in processing of selected minerals, 2022

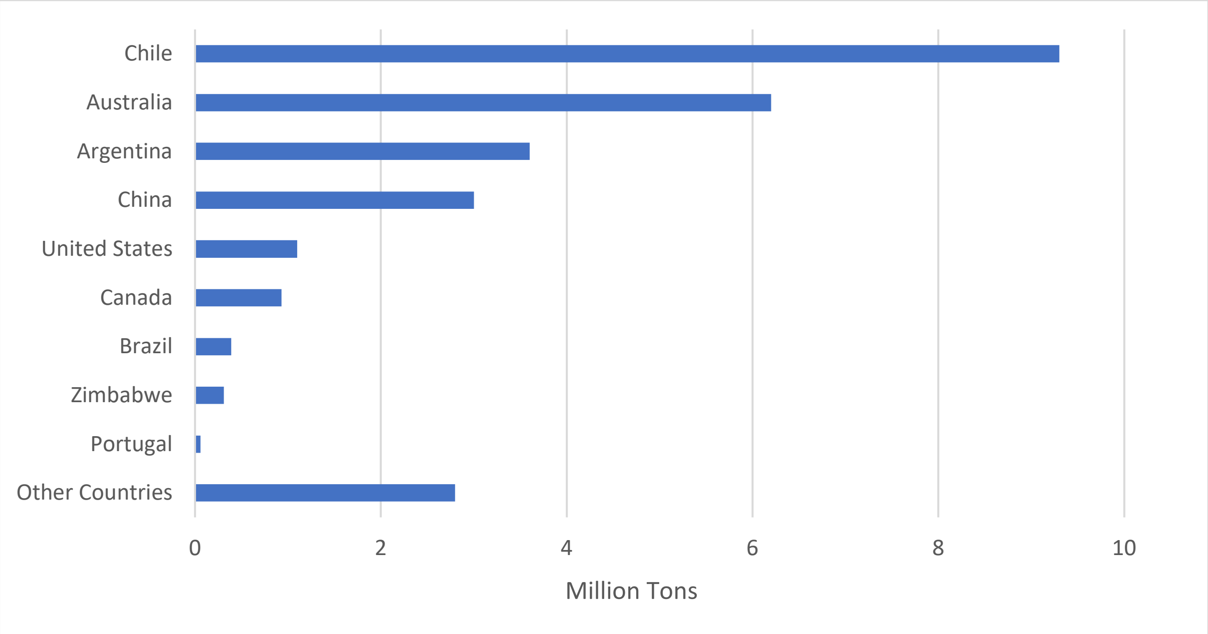


Source: IEA

Lithium

There are 105 million tons of measured and indicated lithium resources in the world, with only 28 million tons classified as reserves, which can be economically extracted or produced (See Figure 26). Lithium reserves are concentrated in the Lithium Triangle, which encompasses border regions of Chile, Argentina, Bolivia, as well as in Australia and China. Currently, Australia is leading the mining production, followed by Chile and China (See Figure 27).[40]

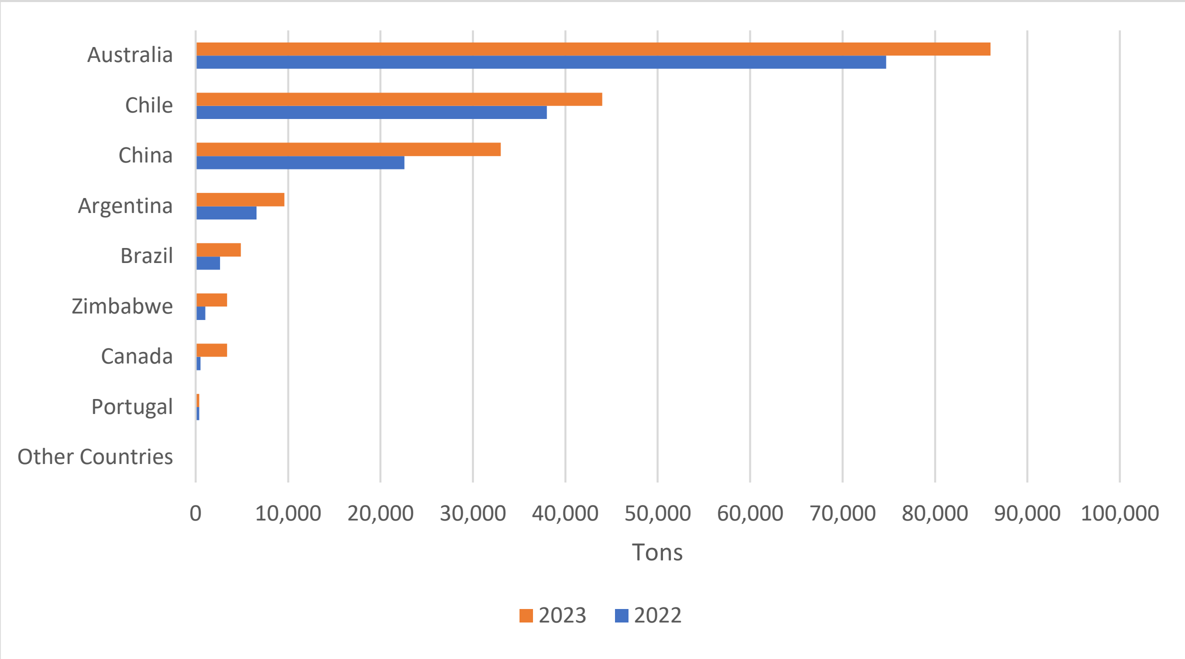
Figure 26: Countries with most lithium reserves



Source: US Geological Survey

[40] According to USGS, resource means "a concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible." It is different from reserves, which mean "that part of the reserve base that could be economically extracted or produced at the time of determination. The term 'reserves' need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials." For details, see: U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 27: Countries with most lithium production (US excluded)



Source: US Geological Survey

Leading lithium mining companies include **Sociedad Química y Minera de Chile (SQM)**, which produced 165,500 metric tons of lithium carbonate from the Salar de Atacama in Antofagasta, Chile, a premier lithium brine deposit;[41] **Talison Lithium**, a joint venture among China's Tianqi Lithium, Australia's IGO, and US's Albemarle Corp,[42] operating a major lithium mine in Greenbushes, Western Australia with a capacity of 1.34 million tons per year;[43] **Pilbara Minerals**, also based in Western Australia, which produced 620,100 tons of spodumene concentrate in 2023 from its Pilgangoora mine;[44] **Ganfeng Lithium**, the world's largest lithium metal producer with operations across the electric vehicle battery supply chain and ownership of the Pozuelos-Pastos Grandes lithium salt lake in Argentina;[45] and **Arcadium Lithium**, formed from the merger of Argentine miner Allkem and US lithium

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[41] Wealth Minerals Ltd. *Yapuckuta, Chile*. Wealth Minerals Ltd. https://wealthminerals.com/projects/yapuckuta/

[42] Talison is owned by joint venture partners Tianqi Lithium Corporation / IGO Limited JV (51%) and Albemarle Corporation (49%). While Tianqi Lithium Corporation owns 51% of the shares in the JV with IGO. (See Talison Lithium. *About Talison Lithium*. Talison Lithium. Retrieved August 30 from https://www.talisonlithium.com/about; igo. *Lithium Joint Venture*. igo. Retrieved August 30 from https://www.igo.com.au/site/operations/lithium-holdco-joint-venture)

[43] Talison Lithium. *About Talison Lithium*. Talison Lithium. Retrieved August 30 from https://www.talisonlithium.com/about

[44] Pilbara Minerals Limited. (2023, August 25). FY23 Financial Results. *Listcorp*. https://www.listcorp.com/asx/pls/pilbara-minerals-limited/news/fy23-full-year-results-2914779.html

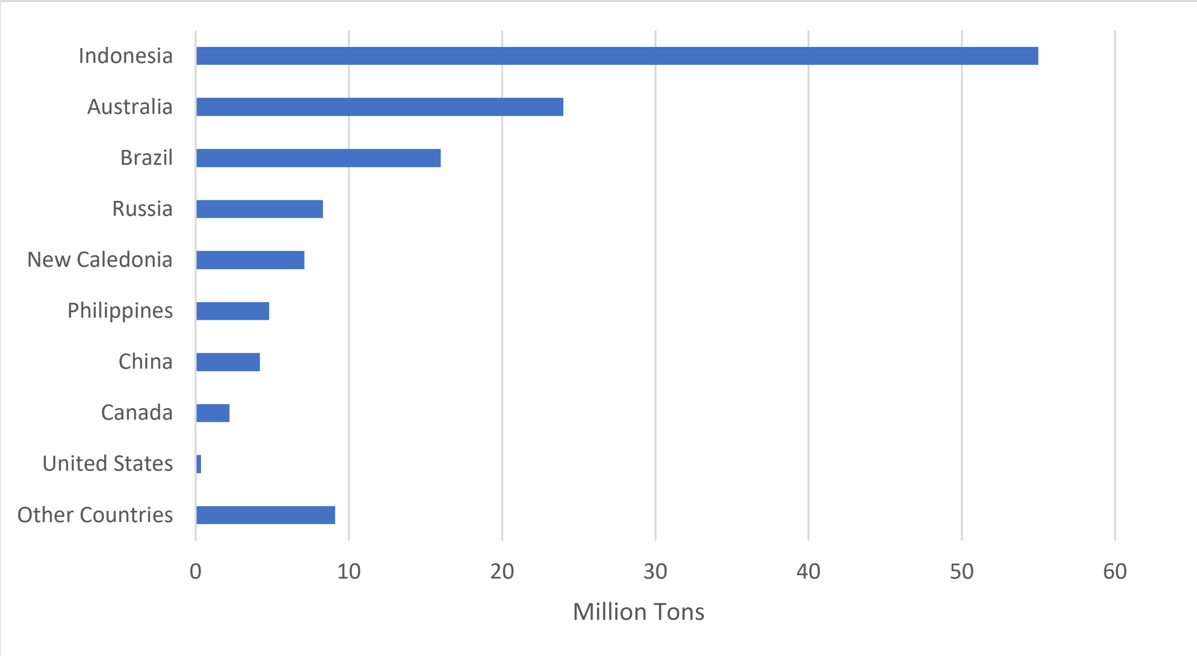
[45] Gangfeng Lithium. *Development history*. Gangfeng Lithium. Retrieved September 2 from https://www.ganfenglithium.com/about1_en.html

giant Livent, which owns the Mt Cattlin mine in Western Australia, producing 194,000 tons of spodumene concentrate in 2022.[46]

Nickel

Global nickel resources are estimated to contain over 350 million tons of nickel, including more than 130 million tons designated as reserves. Indonesia, Australia, and Brazil are the leading countries in nickel reserves, with Indonesia accounting for approximately half of global nickel mining production (See Figure 28 and Figure 29).[47]

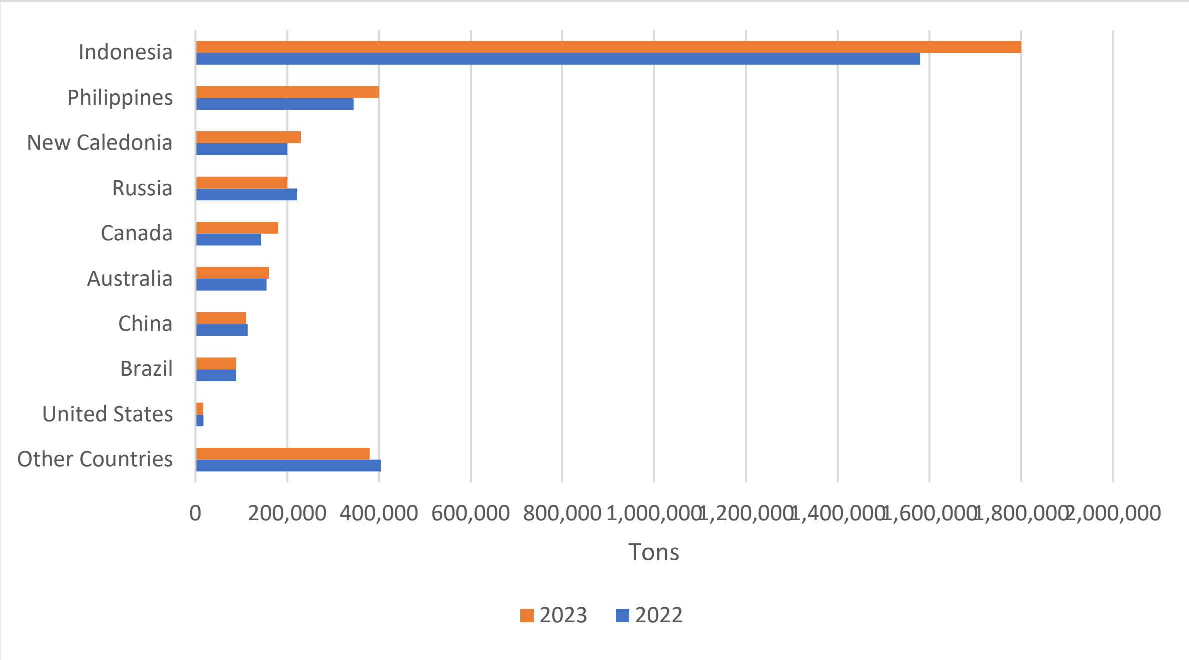
Figure 28: Countries with most nickel reserves



Source: US Geological Survey

[46] Chew, C. (2023, April 22). World's biggest lithium producers. *Reuters*. https://www.reuters.com/markets/commodities/worlds-biggest-lithium-producers-2023-04-21/
[47] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 29: Countries with most nickel production



Source: US Geological Survey

Leading nickel mining companies include the Russian mining giant **Norilsk Nickel**, the world's largest producer of refined nickel, which produced 208,577 tons in 2023 from its operations in Russia, Finland, and South Africa.[48] **Vale**, based in Brazil, is another major player in the nickel market, reporting a production of 164,900 tons in 2023 primarily from its operations in the Indonesia and Canada.[49] Swiss multinational **Glencore**, with mining operations in Canada, Australia, Norway, and New Caledonia, produced around 97,600 tons of nickel in the same year.[50] Finally, **BHP Billiton**, an Australian mining company, produced approximately 80,000 tons in 2023 from its Nickel West operations in Western Australia,[51] although the company has announced plans to suspend nickel production from October 2024 due to reduced profitability.[52]

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[48] Norilsk Nickel. *About Norilsk Nickel Group*. Norilsk Nickel. Retrieved September 2 from https://csr2018.nornickel.ru/en-US/about.html

[49] Vale. (2024). *4Q23 sales and production report*. https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/950b8306-d6c0-497c-ce27-6aa7d0f08b49

[50] Glencore. *Nickel*. Glencore. Retrieved September 2 from https://www.glencore.com/what-we-do/metals-and-minerals/nickel

[51] BHP. (2023). *BHP Annual Report 2023*. https://www.bhp.com/-/media/documents/investors/annual-reports/2023/230822_bhpannualreport2023.pdf

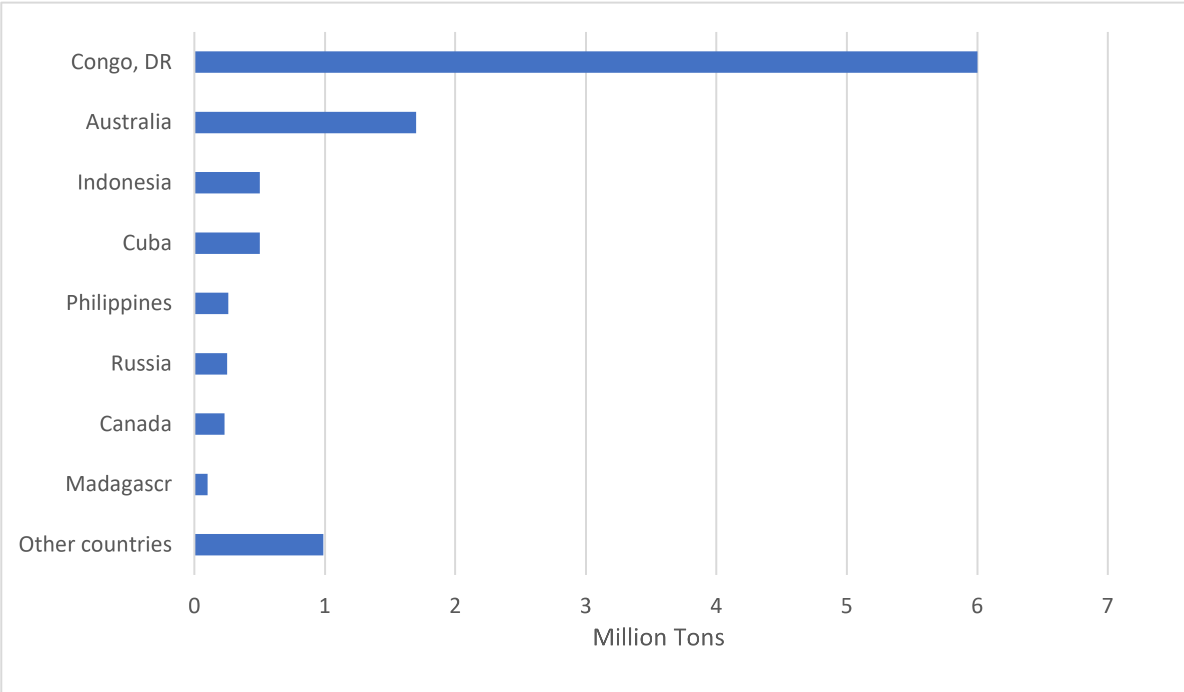
[52] BHP. (2024, July 11). Western Australia Nickel to temporarily suspend operations. *BHP*. https://www.bhp.com/news/media-centre/releases/2024/07/western-australia-nickel-to-temporarily-suspend-operations

Cobalt

Cobalt resources are intrinsically linked to copper and nickel mining, with just 2% cobalt extracted as a primary product. Approximately 60% of cobalt production comes from copper mining, while 38% is a by-product of nickel extraction.[53]

Globally, identified terrestrial cobalt resources are estimated at around 25 million tons, with approximately 11 million tons classified as reserves. The DRC and Australia hold most of these reserves (See Figure 30), with nearly three-quarters of the world's cobalt mine production originating from the DRC (See Figure 31).[54]

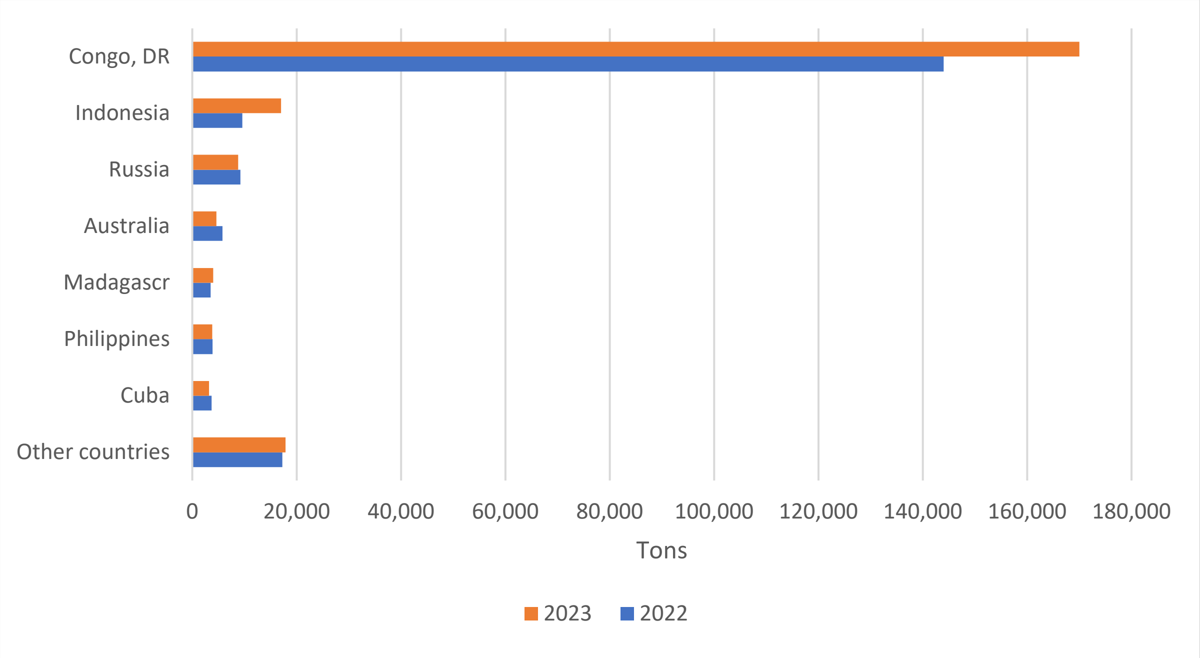
Figure 30: Countries with most cobalt reserves



Source: US Geological Survey

[53] Cobalt Institute. (2023, February). Cobalt: Powering the Green Economy. *Cobalt Institute*. https://www.cobaltinstitute.org/wp-content/uploads/2023/02/cobalt_institute_fact_sheet_2023.pdf
[54] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 31: Countries with most cobalt production



Source: US Geological Survey

About 60% of global cobalt production is concentrated in the Lualaba and Haut-Katanga provinces, located in the "Copperbelt" of southern DRC. Mineral extraction represents 90% of the DRC's exports and is a fundamental component of the Congolese economy.[55]

The global cobalt mining industry is dominated by a handful of key players, each with significant operations in the DRC. **China Molybdenum Co. (CMOC)** has risen to prominence as a top producer, leveraging its extensive mining operations in the DRC. Similarly, Swiss-based **Glencore** has established a strong presence in the country, while also maintaining cobalt mines in Australia. Within the DRC itself, the state-controlled **Gecamines** plays a crucial role in the nation's cobalt output, often partnering with international firms. Rounding out the major players is the Luxembourg-headquartered **Eurasian Resources Group (ERG)**, which, like its counterparts, has focused its cobalt mining efforts in the cobalt-rich DRC.

Cobalt is highly recyclable, making it a valuable resource in lithium-ion battery recycling. As of 2021, around 65% of recycled cobalt came from used batteries.[56]

Manganese

Manganese resources are abundant globally but unevenly distributed, with South Africa accounting for approximately 70% of the world's known manganese resources. The global manganese reserves—resources that are economically viable for extraction—are estimated

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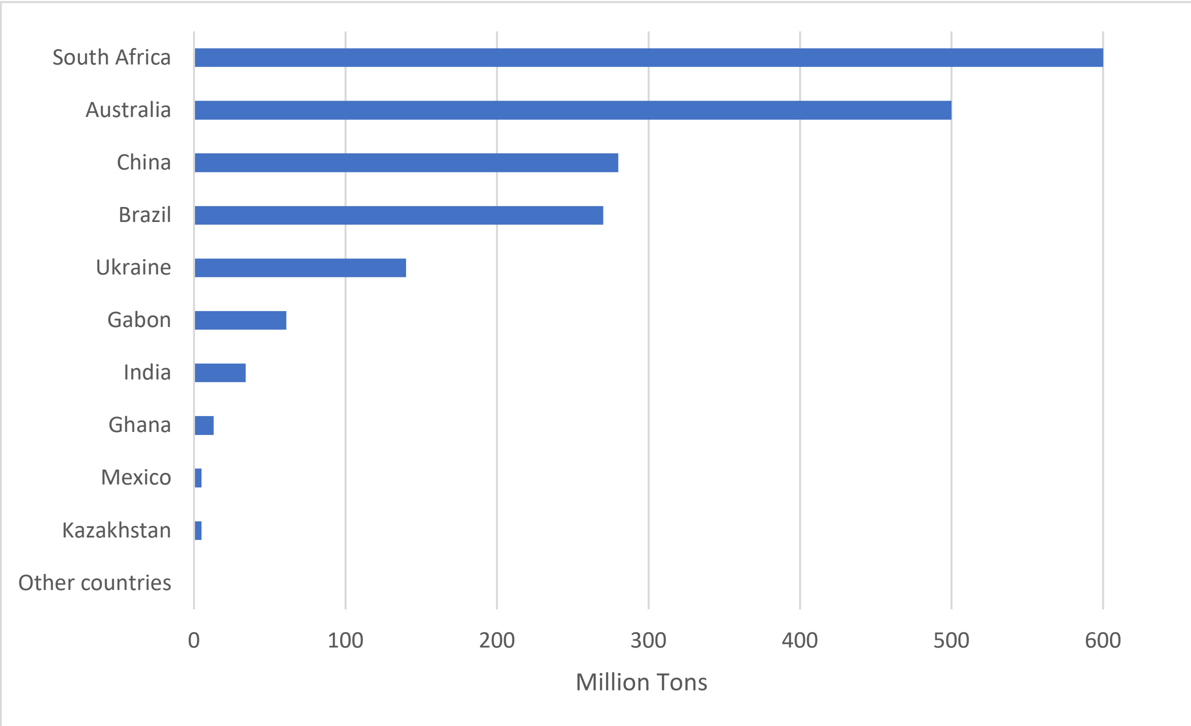
[55] Cobalt Institute. (2023, February). Cobalt: Powering the Green Economy. *Cobalt Institute*. https://www.cobaltinstitute.org/wp-content/uploads/2023/02/cobalt_institute_fact_sheet_2023.pdf

[56] Cobalt Institute. Cobalt Value Chain Mapping. *Cobalt Institute*. https://www.cobaltinstitute.org/cobalt-sourcing-responsability/cobalt-value-chain/

at around 1.9 billion tons. South Africa and Australia lead in manganese reserves, collectively possessing more than half of the world's total (See Figure 32). The primary contributors to the global supply of manganese are South Africa, Gabon, and Australia (See Figure 33).[57]

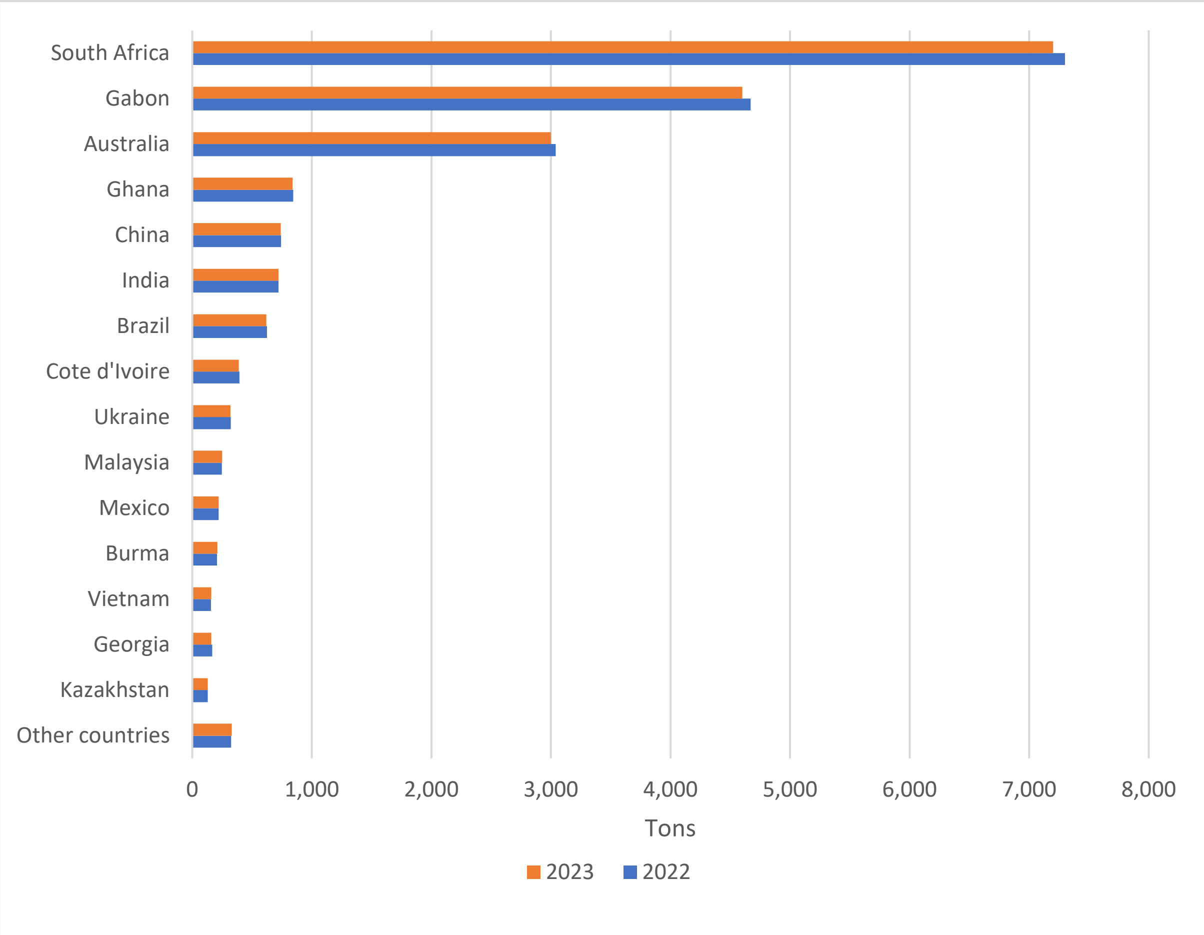
Figure 32: Countries with most manganese reserves



Source: US Geological Survey

[57] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 33: Countries with most manganese production



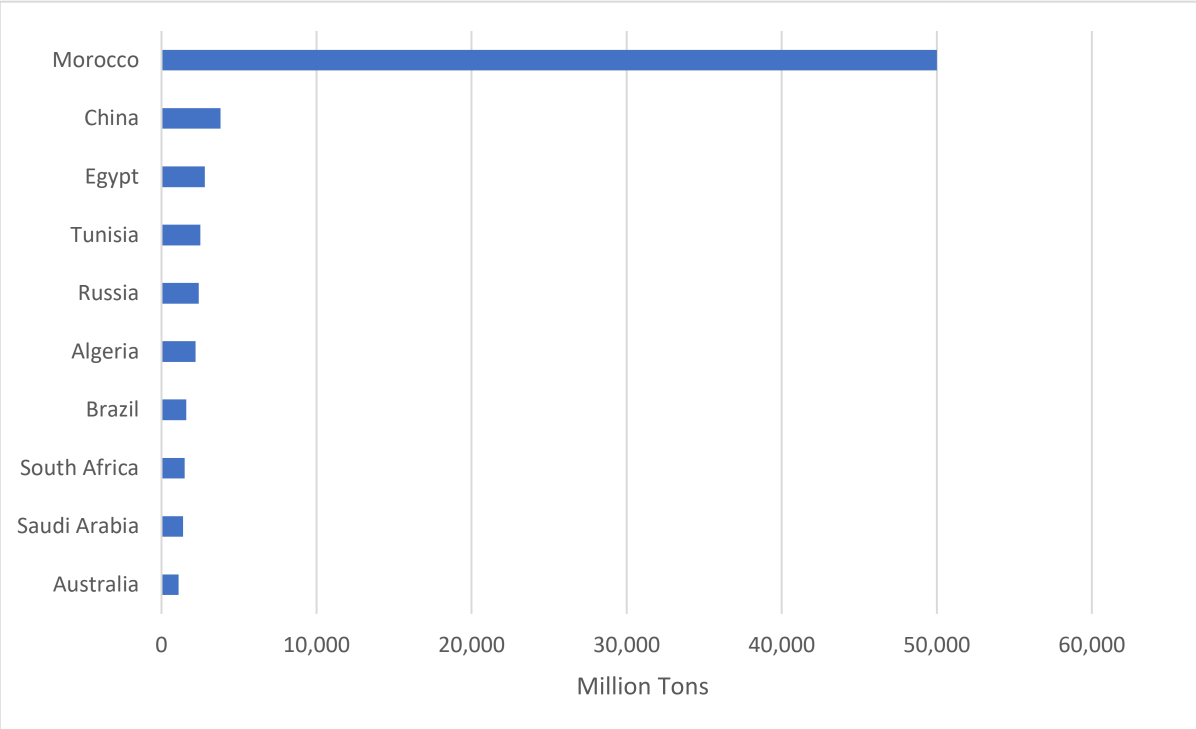
Source: US Geological Survey

South32 leads the charge as the world's largest manganese producer, with its South Africa subsidiary accounting for 36% of global manganese output. South32 is heavily involved in the South African manganese industry, managing the Mamatwan and Wessels mines alongside the Metalloys alloy smelter. Australia ranks third in global production, with South32 holding a 60% stake in the cost-efficient Gemco operations. Following closely is Gabon's **Eramet**, whose subsidiary Comilog operates the prominent Moanda mine, solidifying Gabon as the second-largest producer and Eramet as the world's second-largest supplier of high-grade manganese ore. Ghana's **Consolidated Minerals**, through its subsidiary Ghana Manganese Company, places the nation fourth in manganese production, contributing significantly to the global market. Finally, Brazil's **Vale** adds to the mix, leveraging its diversified portfolio to produce manganese via its ferrous minerals division, which includes several mines and ferroalloy plants across the country.[58,59]

Phosphate

A crucial material for LFP batteries, phosphate is primarily found in sedimentary marine phosphorites. About 60% of phosphate is used to produce phosphate fertilizers, while the material is also widely utilized in animal feed, food processing, herbicides, and crop desiccants. Only less than 6% of phosphate is converted into FLP for battery applications.[60] Global phosphate rock resources exceed 300 billion tons, with 74 billion tons classified as reserves. Most of these phosphate resources are in northern Africa, the Middle East, China, and the United States. Notably, Morocco holds nearly 70% of the world's phosphate rock reserves and ranks as the second-largest producer of phosphate, after China, which accounts for approximately 40% of global phosphate production.[61]

Figure 34: Countries with most phosphate reserves



Source: U.S. Geological Survey

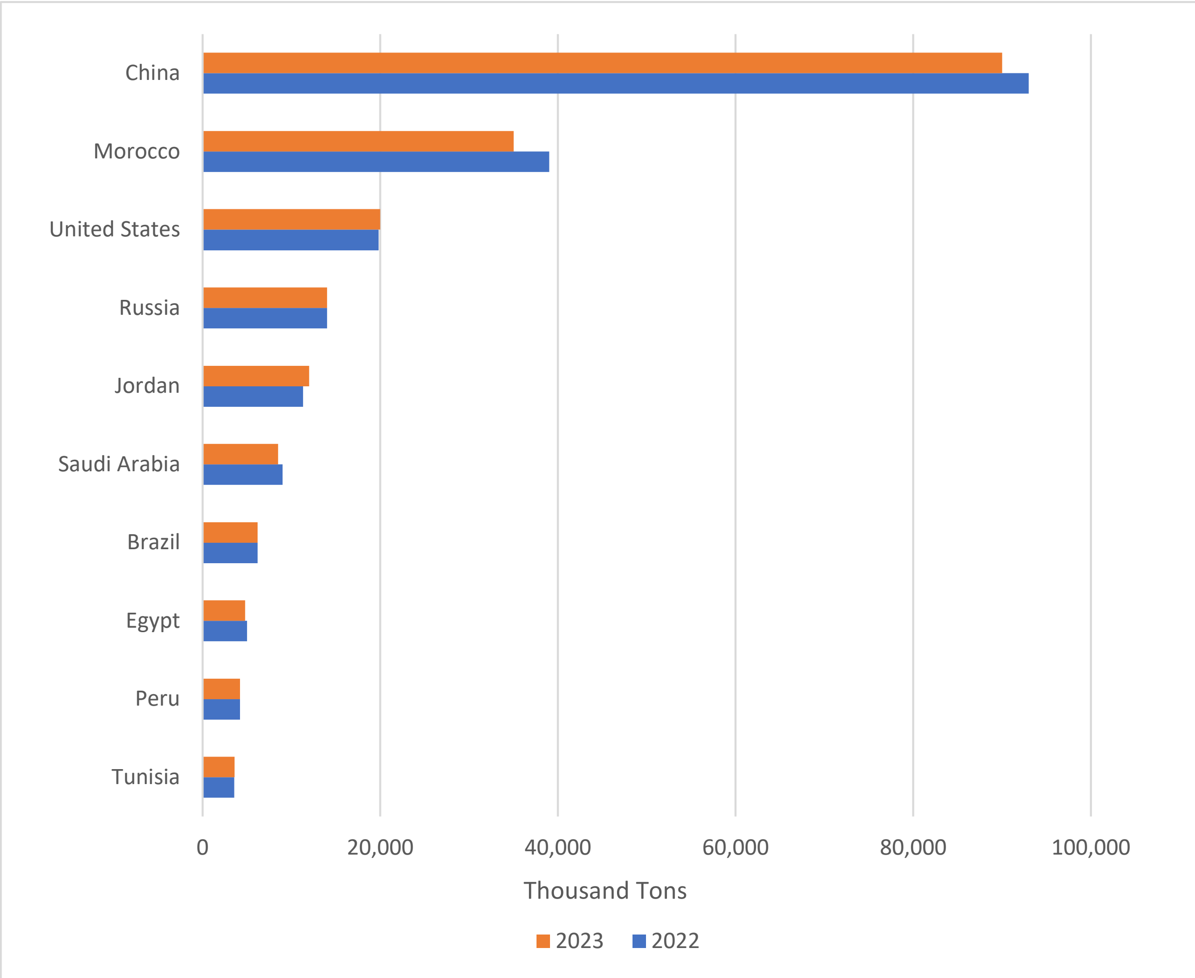
[58] Pistilli, M. (2024b, July 29). Top 10 Manganese-producing Countries. *Investing News Network*. https://investingnews.com/daily/resource-investing/battery-metals-investing/manganese-investing/top-manganese-producing-countries/

[59] Skillings. (2022, July 13). Top 5 Manganese Mining Companies & Manganese producing Countries. *Skillings*. https://skillings.net/top-5-manganese-mining-companies-manganese-producing-countries/

[60] 于泽远. (2024, May 12). 2024 年中国磷矿石行业发展现状分析，政府实行保护性开采政策，推动磷化工高效高值利用转型，提高资源利用率. *华经情报网*. https://www.huaon.com/channel/trend/984629.html

[61] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 35: Countries with most phosphate production



Source: U.S. Geological Survey

The largest phosphate mining companies include **OCP Group** from Morocco, a state-owned enterprise and the world's leading producer of phosphate and phosphate-based products; **The Mosaic Company** from the United States; **Nutrien** from Canada; **PhosAgro** from Russia; **Yara International** from Norway; **ICL Group** from Israel; **Jordan Phosphate Mines Company**; **Ma'aden** from Saudi Arabia; and **Yunnan Yuntianhua** from China.

Graphite

There are abundant natural graphite resources, totalling 800 million tons worldwide, with 280 million tons designated as reserves. China, Brazil, Mozambique, and Madagascar are the largest reserve holders.[62] While natural graphite offers higher conductivity, lower cost, and less CO_2 emission compared to synthetic graphite, it has inconsistent particle size, lower compatibility with electrolytes, and a shorter cycle life. As a result, despite its higher cost, synthetic graphite is preferred for EV batteries and other high-performance applications.[63,64,65]

In terms of weight, China produced 75% of the world's natural graphite and 74% of synthetic graphite products in 2023. Notably, China accounted for 99% of spherical graphite, which is processed natural graphite ideal for battery use, and 97% of synthetic graphite anode production.[66] Major production bases of graphite are in Heilongjiang, Inner Mongolia, Shandong, Hunan, and Jilin.[67] **BTR New Material Group**, the leading player in natural graphite mining, accounts for over 60% of the country's production. In contrast, China's synthetic graphite production is distributed among several companies, including **Shanghai Putailai (PTL)**, **Kaijin New Energy**, **Shanshan**, and **BTR**.[68]

Rare Earth Elements

Rare earth elements (REEs) are a group of 17 highly valuable metallic elements that exhibit unique magnetic, luminescent, and electrochemical properties. They are critical for EVs as their magnetic properties enable enhanced motor efficiency, power output, and torque. Key rare earth elements used in EVs are Neodymium (Nd), which provides strong magnetic fields, as well as Praseodymium (Pr), Dysprosium (Dy) and Terbium (Tb), which are added to the Nd-based materials to improve performance.

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[62] Ibid.

[63] 橙子. (2018, January 8). 天然石墨 VS 人造石墨，谁才是动力电池真正的宠儿？. *中国粉体网*. https://news.cnpowder.com.cn/44382.html

[64] 信瑞达石墨. (2022, October 21). 天然石墨和人造石墨谁更具潜力呢？. *信瑞达石墨*. https://www.xrdshimo.com/2022/10/21/%E5%A4%A9%E7%84%B6%E7%9F%B3%E5%A2%A8%E5%92%8C%E4%BA%BA%E9%80%A0%E7%9F%B3%E5%A2%A8%E8%B0%81%E6%9B%B4%E5%85%B7%E6%BD%9C%E5%8A%9B%E5%91%A2%EF%BC%9F/

[65] Benchmark Source. (2022, November 24). ESG of graphite: how do synthetic graphite and natural graphite compare?. *Benchmark Source*. https://source.benchmarkminerals.com/article/esg-of-graphite-how-do-synthetic-graphite-and-natural-graphite-compare

[66] Benchmark Source. (2024, November 7). Infographic: China controls three-quarters of graphite anode supply chain. *Benchmark Source*. https://source.benchmarkminerals.com/article/infographic-china-controls-three-quarters-of-graphite-anode-supply-chain

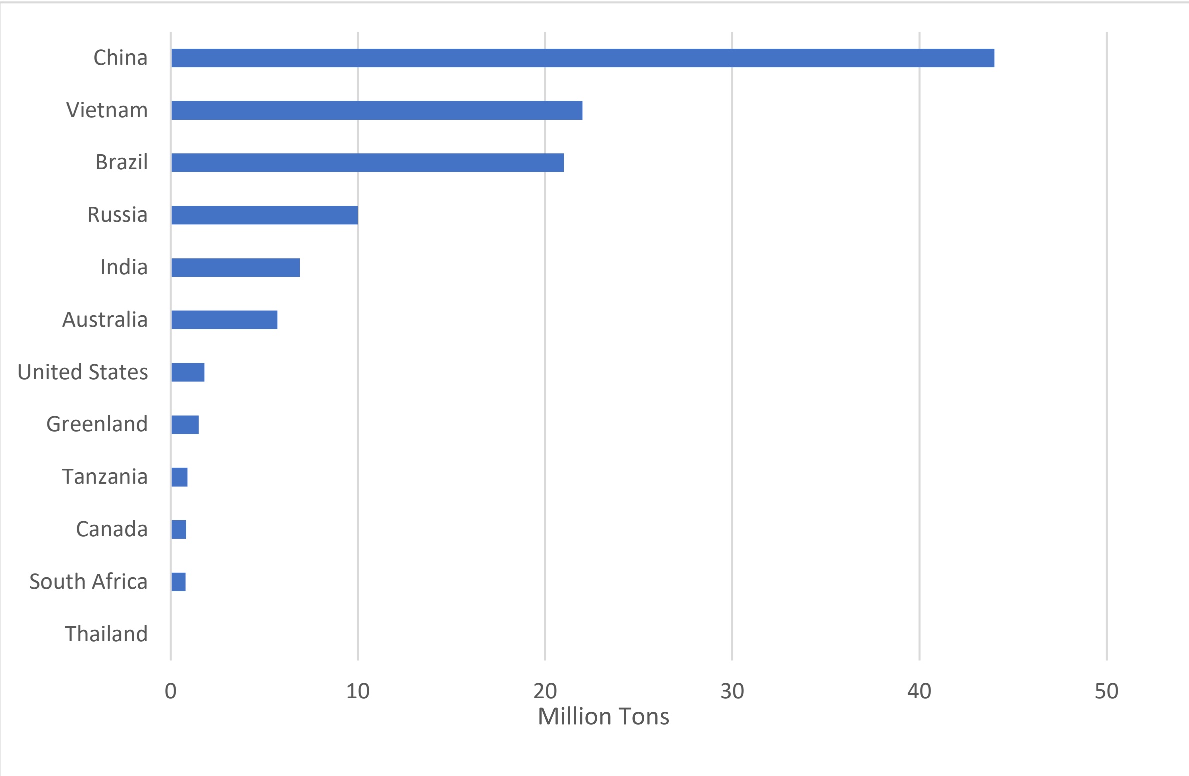
[67] 矿业界. (2023, July 4). 石墨定价受哪些因素影响. *澎湃*. https://www.thepaper.cn/newsDetail_forward_23721958

[68] 李深. (2023). *2023 年中国石墨行业竞争格局及重点企业分析：行业市场高度集中，头部企业加速推进产能项目建设*. 智研咨询. https://www.chyxx.com/industry/1140713.html

Rare earth elements, despite their name, are not particularly scarce in the Earth's crust. However, their concentrations that are economically viable for mining are much less common compared to other minerals. These elements often coexist in nature due to their similar atomic structures and chemical properties. Of the more than 250 known rare earth minerals, only about ten are suitable for industrial extraction under current processing technologies. Currently, commercially viable sources are limited to a few key minerals, including bastnäsite, monazite, and xenotime.

The global reserves of rare earth elements are estimated at around 110 million tons, with China holding approximately 40% of the total, followed by Vietnam and Brazil (See Figure 36). China holds a major share in the production and processing of rare earth elements, accounting for about 70% of global output, while the United States, Australia and Burma also play significant roles in the market (See Figure 37).[69]

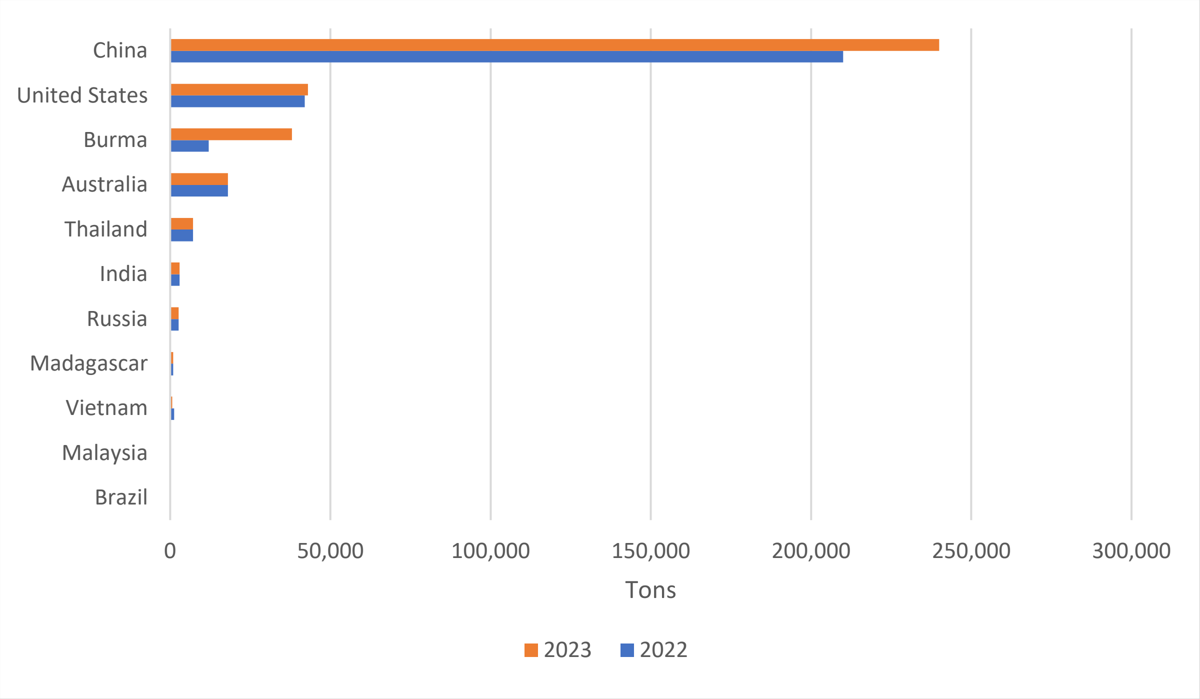
Figure 36: Countries with most rare earth reserves



Source: US Geological Survey

[69] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 37: Countries with most rare earth production



Source: US Geological Survey

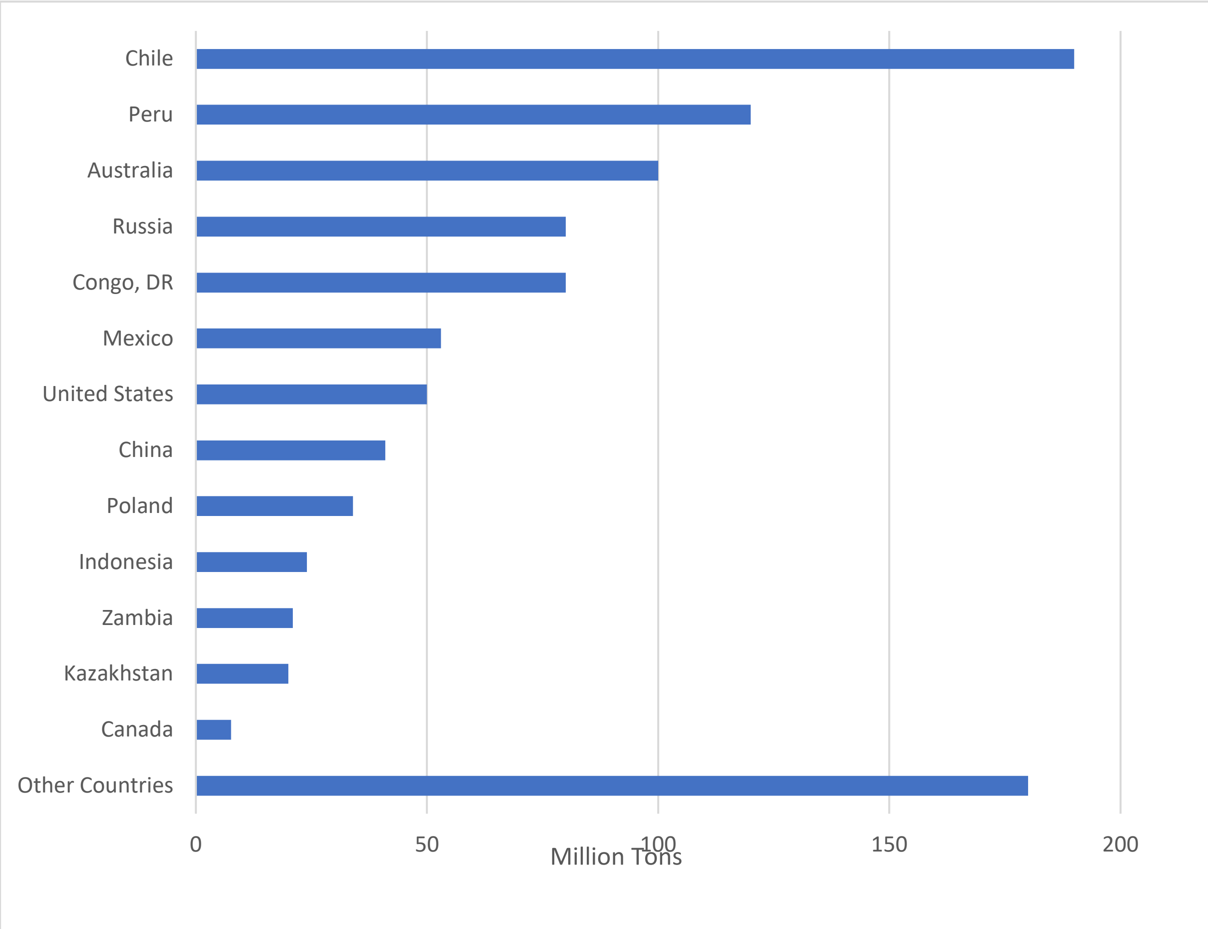
The global rare earth mining industry is prominently led by **China Northern Rare Earth High-Tech**, the largest producer by production volume, thanks to its ownership of the prolific Bayan Obo mining complex in Inner Mongolia, which contributes significantly to global rare earth output. In a strong second position is **MP Materials**, which runs the Mountain Pass mine in California, the largest rare earth mine in the United States. In 2022, MP Materials produced an impressive 42,400 metric tons of rare earth elements. Following closely is **Lynas Rare Earths**, recognized as the third-largest producer globally; this Australian company operates the Mount Weld mine in Western Australia, which is celebrated for its high-grade rare earth ore and is a major source of separated rare earth materials outside of China. **Iluka Resources** from Australia ranks fourth among the leading rare earth producers; while its core business focuses on heavy mineral sands extraction, the mining activities yield valuable monazite, a mineral rich in rare earth elements. Lastly, **Energy Fuels** is making strides in the sector through its White Mesa Mill in Utah, US, where it processes monazite ore to produce separated rare earth oxides and is positioned to become one of the largest rare earth producers outside of China.[70,71,72]

[70] Pistilli, M. (2024c, August 29). Top 11 Countries by Rare Earth Metal Production (Updated 2024). *Investing News Network*. https://www.nasdaq.com/articles/top-11-countries-rare-earth-metal-production-updated-2024
[71] I2M. (2024, March 16). *The Five Largest Rare Earth Companies in the World - 2024*. https://web.i2massociates.com/resource_detail.php?resource_id=13741
[72] Williams, G. (2024, August 7). Rare Earths Stocks: 9 Biggest Companies in 2024. *Investing News Network*. https://investingnews.com/top-rare-earth-stocks/

Copper

The world is estimated to have 5.6 billion tons of copper resources, with 1 billion tons categorized as reserves. Chile, Peru, and Australia hold the largest copper reserves (See Figure 38). Chile leads in mine production, contributing over 20% of the global total, followed by Peru and the DRC (See Figure 39).[73]

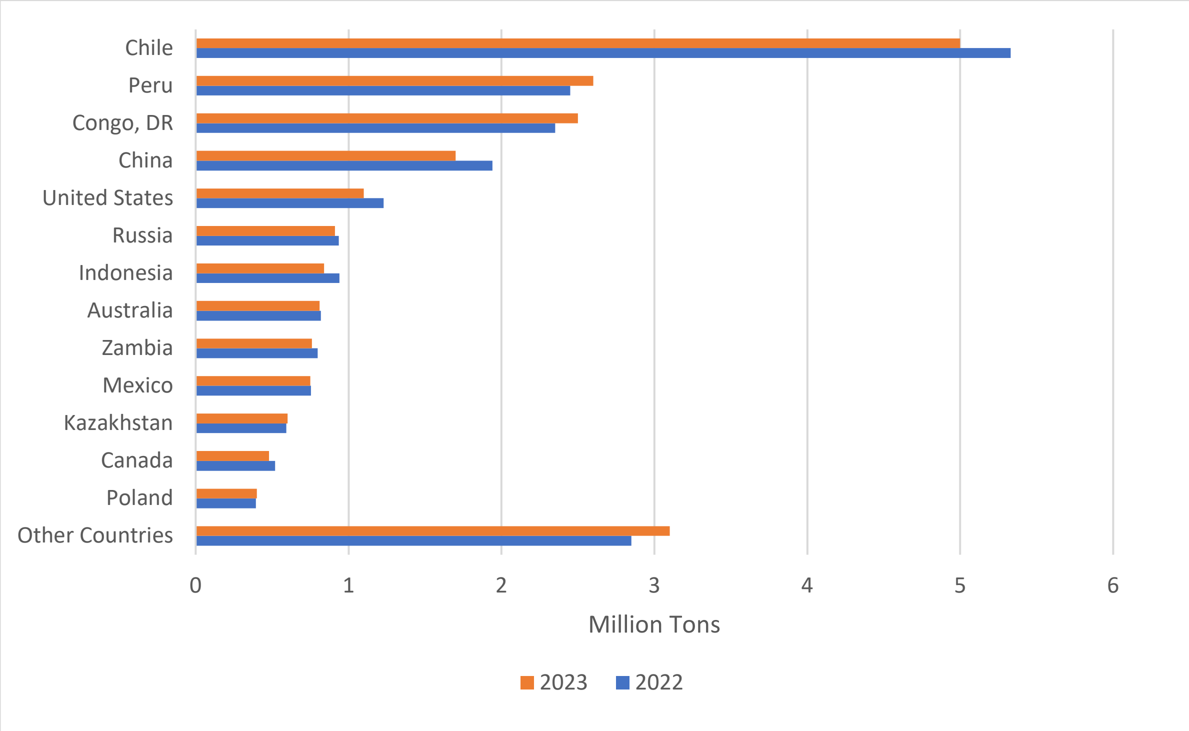
Figure 38: Countries with most copper reserves



Source: US Geological Survey

[73] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 39: Countries with most copper mine production



Source: US Geological Survey

US company **Freeport-McMoRan** leads the way of copper mine production by producing 2.05 million metric tons of copper in 2023. Following closely was **BHP**, an Australian company that generated 1.39 million metric tons, leveraging its extensive operations in Chile, Peru, and Australia. The state-owned **Codelco** from Chile, recognized as the world's third largest copper producer, contributed 1.35 million metric tons, operating prominent mines such as Chuquicamata and El Teniente. Rounding out the top five were **Anglo American** from the United Kingdom, producing 1.15 million metric tons with significant operations in Chile and Peru, and **Antofagasta**, also from Chile, which produced 714,972 metric tons from its four local mines. Lastly, Swiss-based **Glencore**, accounted for 695,750 metric tons from its diverse operations across Chile, Peru, the Democratic Republic of Congo, and Zambia.[74,75,76]

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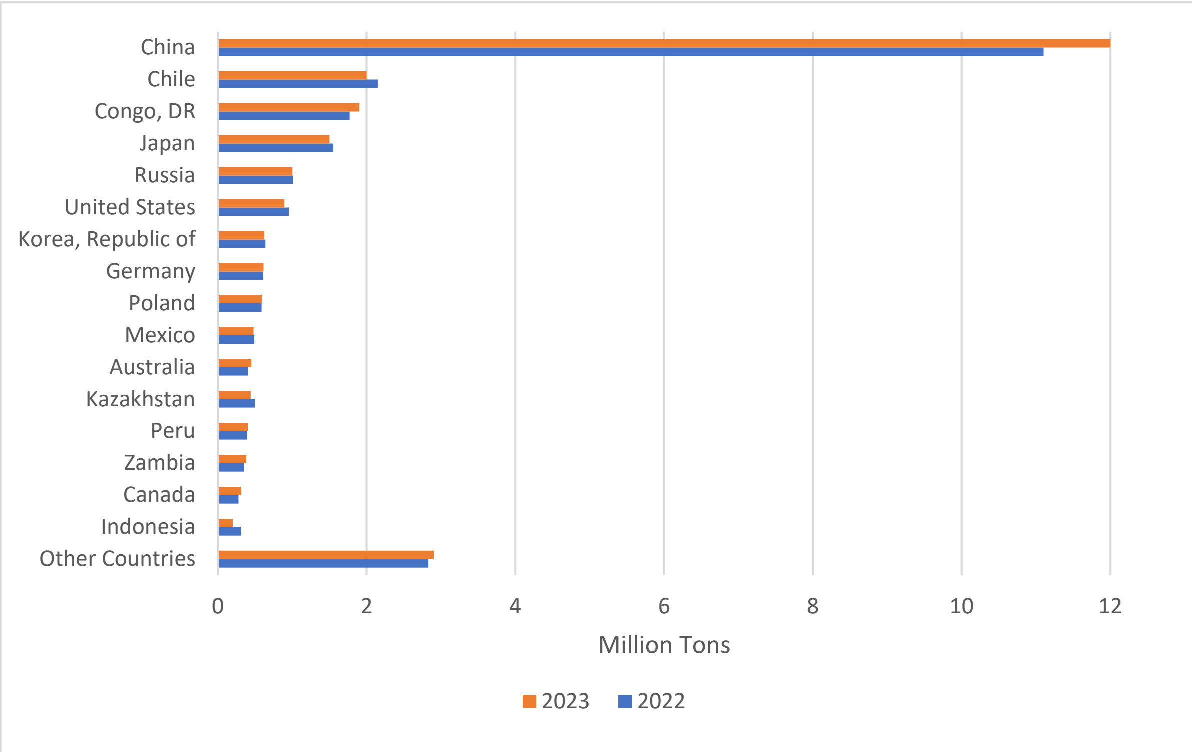
[74] Pistilli, M. (2024a, May 17). Top 10 Copper-producing Companies. *Investing News Network*. https://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/top-copper-producing-companies/

[75] Network, I. N. (2024). Leading copper mining companies worldwide in 2023, by production output (in 1,000 metric tons). In *Statista*: Investing News Network.

[76] Cryptal.global. (2023, November 16). Top 10 Copper Mining Companies. *Medium*. https://medium.com/cryptal-global/top-10-copper-mining-companies-b8ca8113e554

Figure 40: Countries with most copper refinery production



Source: US Geological Survey

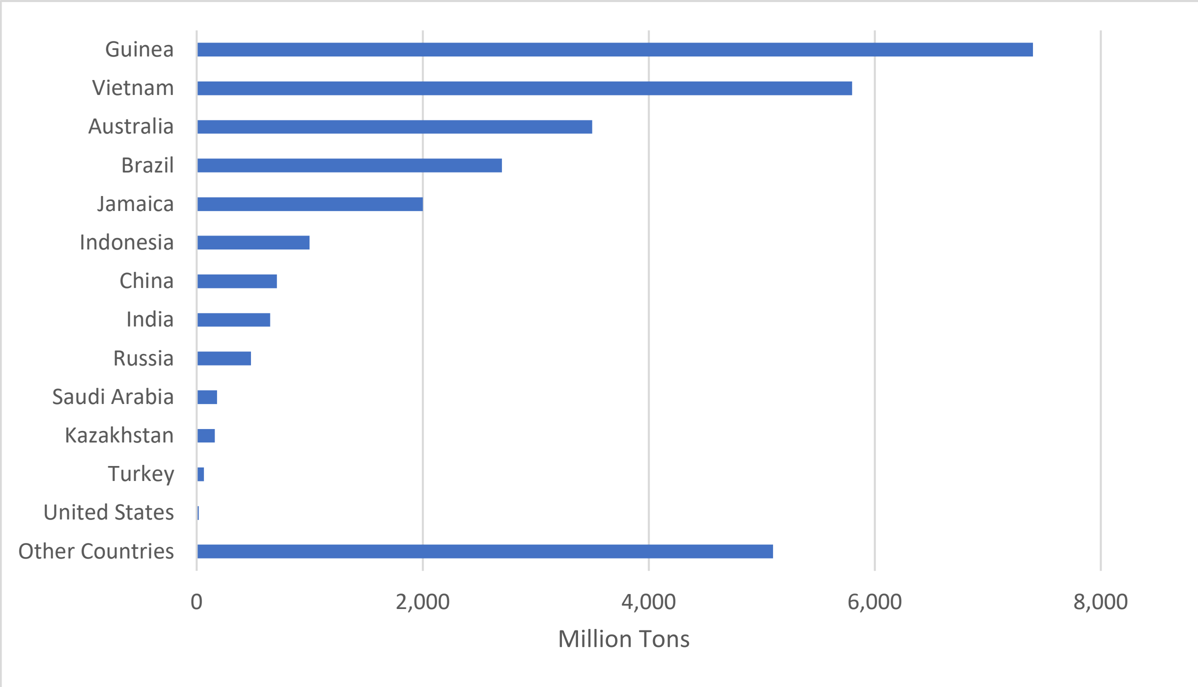
In contrast to the geographical distribution of copper mining, copper refining is heavily concentrated in China, which houses the top five refineries in the world. In 2024, these leading firms—**Guixi**, **Jinchuan Gansu, Shandong Fangyuan**, **China Daye, and Yanggu C&D**—collectively possess approximately 3.7 million metric tons of copper refining capacity. Positioned across various provinces, their smelters are located in Jiangxi, Shandong, Hubei, and Gansu.

Aluminium

There are 55 billion to 75 billion tons of bauxite resources globally, with the distribution as follows: Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and other regions (6%). Around 30 billion tons of these resources are classified as reserves, with more than half located in Guinea, Vietnam, and Australia (See Figure 41). In terms of production, Australia, Guinea, and China account for 70% of the global bauxite output (See Figure 42). China produces nearly 60% of world's alumina, followed by Australia and Brazil (See Figure 43).[77]

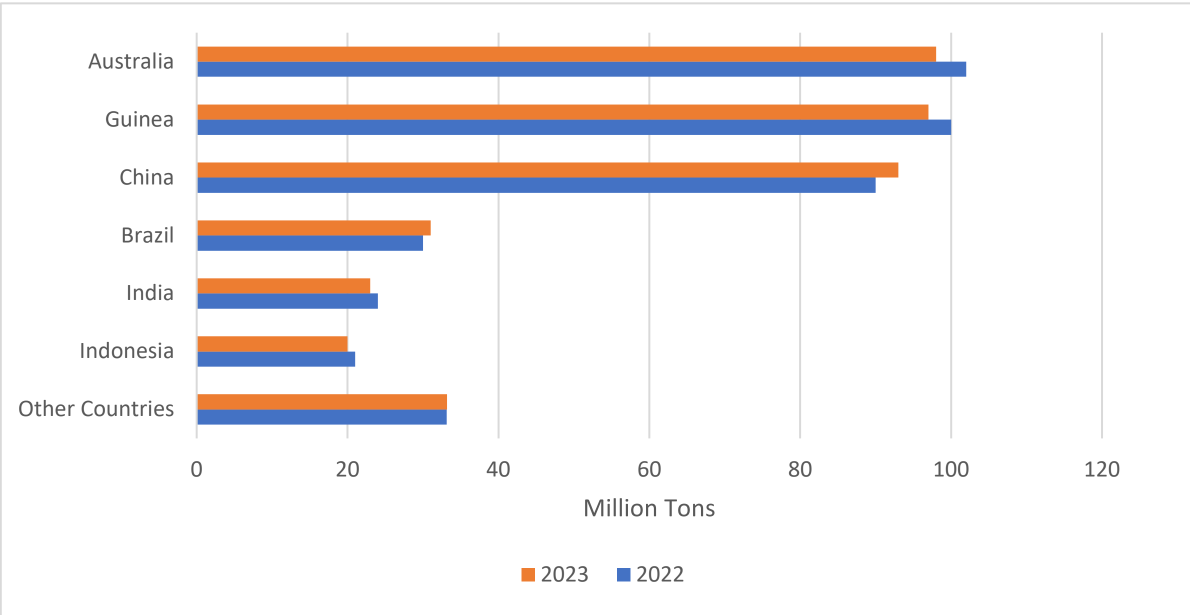
[77] U.S. Geological Survey. (2024). *Mineral Commodity Summaries 2024*. https://pubs.usgs.gov/publication/mcs2024

Figure 41: Countries with most bauxite reserves



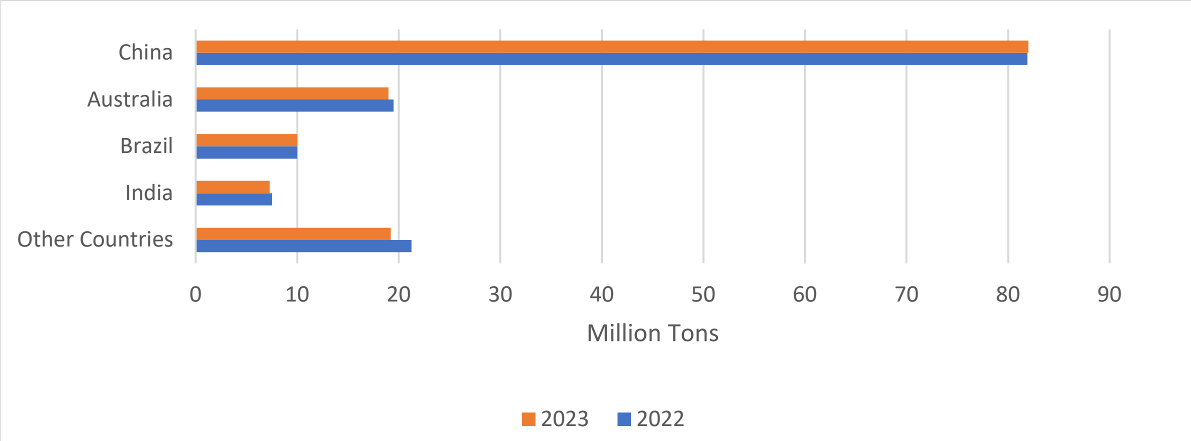
Source: US Geological Survey

Figure 42: Countries with most bauxite production (US excluded)



Source: US Geological Survey

Figure 43: Countries with most alumina production



Source: US Geological Survey

UK-based **Rio Tinto** stands out as the largest producer of bauxite, with 1.49 billion tons of bauxite reserves and 1.9 billion tons of resources in Australia's Cape York region, primarily from its Gove and Weipa mines. In 2023, Rio Tinto produced approximately 54.6 million metric tons of bauxite.[78] US-based **Alcoa** followed with a production of 41 million dry metric tons in the same year,[79] operating three of its seven active bauxite mines worldwide and holding mining rights for extensive deposits for up to 20 years. The **Aluminum Corporation of China (Chinalco)** produced 30.42 million tons of bauxite in 2023,[80] with major operations in Shanxi province. **Compagnie des Bauxites de Guinea (CBG)**, a joint venture between the Guinean State (49%) and Halco Mining (51%), operates the Sangaradi mine in Guinea, delivering 15.2 million tons of high-grade bauxite annually. Russian company **United Company RUSAL (UC RUSAL)** contributed 13.38 million tons of bauxite in 2023, mainly from its mining operations in Africa, particularly in Guinea and Jamaica.[81] **Norsk Hydro** of Norway produced 10.9 million tons of bauxite in 2023,[82] drawing from its Paragominas mine in Brazil, which has an annual capacity of nearly 10 million metric tons.[83]

[78] Rio Tinto. (2024, January 16). Rio Tinto releases fourth quarter production results. *Rio Tinto*. https://www.riotinto.com/en/news/releases/2024/rio-tinto-releases-fourth-quarter-production-results
[79] Alcoa. *Overview*. Retrieved September 3 from https://investors.alcoa.com/investor-overview/default.aspx
[80] Aluminum Corporation of China Limited. (2024). *2023 Annual Report*. https://www.chalco.com.cn/tzzgx/yjbg/ndbg/202404/P020240403370231841073.pdf
[81] RUSAL. (2024a). *Annual Results Announcement for the Year Ended 31 December 2023*. S. E. o. H. Kong. https://www1.hkexnews.hk/listedco/listconews/sehk/2024/0315/2024031500087.pdf
[82] Hydro. (2024). *Integrated annual report 2023*. Hydro. https://www.hydro.com/globalassets/06-investors/reports-and-presentations/annual-report/nhar23/integrated-annual-report-2023_eng.pdf
[83] Biswas, B. (2016, November 12). Top five bauxite mining companies in the world. *AlNews*. https://www.alcircle.com/news/top-five-bauxite-mining-companies-in-the-world-26315

Other notable players include **South32**, with its Boddington Bauxite Mine in Western Australia, and **Nalco**, the largest bauxite miner and aluminium producer in India.[84]

The global aluminium production landscape is dominated by several key players, with China leading the charge. **Chinalco** stands as the country's largest producer, generating approximately 6.8 million metric tons of primary aluminium in 2023.[85] Following closely is the **Hongqiao Group**, which reported an output of around 6.3 million tons of aluminium alloy products in the same year.[86] Another significant contributor from China is **Xinfa**, which holds a notable position in the global market. **UC RUSAL** from Russia emerges as another major player as well, focusing on the mining and production of primary aluminium and alloys, with a commitment to low-carbon processes—90% of its production is derived from renewable energy. In 2023, UC RUSAL produced about 3.9 million tons, slightly surpassing Xinfa's output of 3.6 million tons.[87] Representing India is **Hindalco Industries**, recognized as the world's largest recycler of aluminium and a leading producer of flat-rolled aluminium products through its subsidiary, Novelis. Its production of alumina in 2023 exceeded 3.5 million tons.[88] Other significant companies in the aluminium sector include **Rio Tinto**, **Emirates Global Aluminium (EGA)**, **Vedanta**, **East Hope**, and **Alcoa**.

1. **Battery Manufacturing**

China not only leads in refining battery metals but also hosts a substantial portion of battery cell manufacturing capacity, including the production of anodes, electrolytes, and other essential battery components. Battery manufacturing in China is more integrated than in other countries, largely due to its leading role in the upstream stages of the supply chain.

In 2023, the country produced 887.4 GWh of the world's lithium-ion batteries, accounting for over 70% of global supply.[89] Around 12% of EV batteries made in China are being exported, making it the largest exporter of EV batteries worldwide,[90] with the US being the primary importer of Chinese lithium batteries.[91] However, China's share in global EV battery

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84 Inven. Ranking the Top 26 Bauxite Mining Corporations. https://www.inven.ai/company-lists/top-26-bauxite-mining-companies

85 Aluminum Corporation of China Limited. (2024). *2023 Annual Report*. https://www.chalco.com.cn/tzzgx/yjbg/ndbg/202404/P020240403370231841073.pdf

86 China Hongqiao Group Limited. (2024). *2023 Annual Report*. http://en.hongqiaochina.com/Uploads/File/2024/04/20/E24010180-Hongqiao-AR23.20240420081243.pdf

87 RUSAL. (2024b). *General Information on the Company*. Stock Exchange of Hong Kong. https://www.hkexnews.hk/listedco/listconews/sehk/2024/0426/2024042604499.pdf

88 Hindalco Industries Limited. *Integrated Annual Report 2022-23*. https://www.hindalco.com/integrated-annual-report2022-23/pdf/Hindalco-Integrated-Annual-Report-2022-23.pdf

89 EVTank. (2024c, January 19). EVTank：2023 年全球锂离子电池出货量达 1202.6GWh，2030 年远期出货量预测值调低至 5000GWh. *伊维观点*. http://www.evtank.cn/DownloadDetail.aspx?ID=547

90 IEA. (2024). *Global EV Outlook 2024: Moving towards increased affordability*. https://www.iea.org/reports/global-ev-outlook-2024

91 Griffith University. (2024, 9 May). China's 'new three' exports dominate the 2023 global green transition. *News and analysis*. https://news.griffith.edu.au/2024/05/09/chinas-new-three-exports-dominate-the-2023-global-green-transition/

supply is expected to decline in the coming years as new lithium-ion battery factories in Europe and the US begin operations.[92]

China holds nearly 90% of the global production capacity for active cathode materials and more than 97% for active anode materials. The only other countries with notable shares in active cathode material production are South Korea, with 9%, and Japan, with 3%.[93]

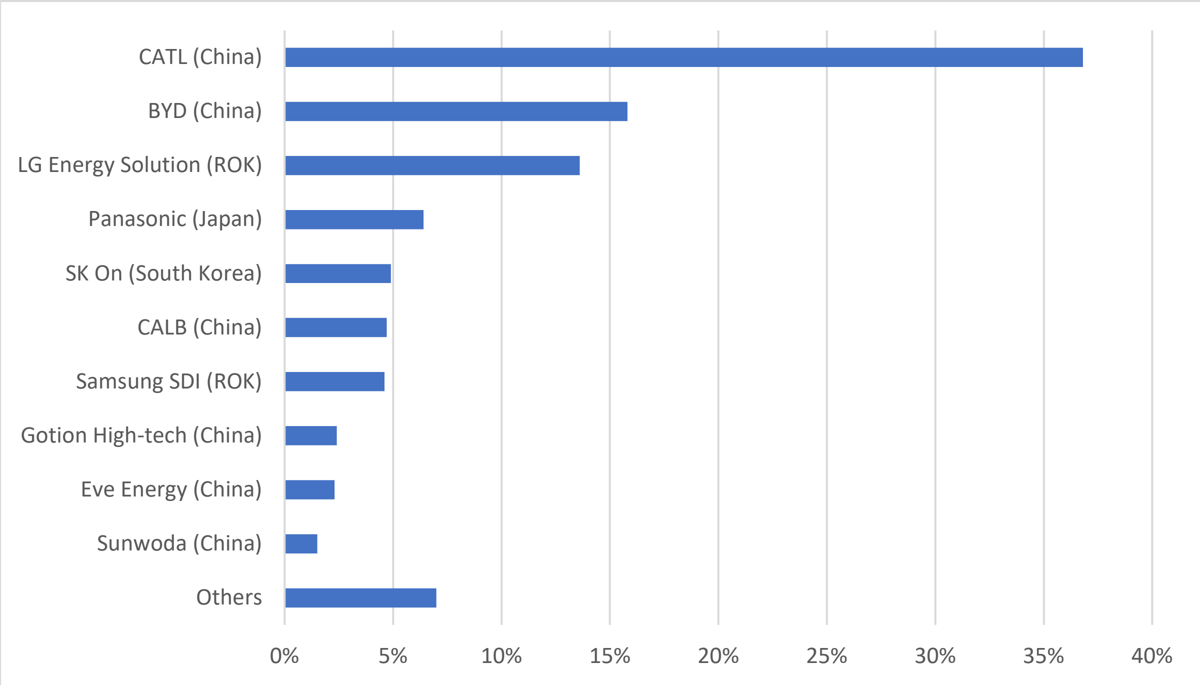
China's **Contemporary Amperex Technology Co. Limited (CATL)** is the clear leader in EV battery manufacturing in the world, with its market share reached 36.8% in 2023. The company is followed by another Chinese company, **BYD Battery**, which held a 15.8% market share in 2023.[94] BYD is known for its blade battery, a form of LFP battery that offers improved safety and range compared to traditional EV batteries.

In the January-July 2024 period, CATL's market share increased further to 37.6%, cementing its position as the dominant player in the global EV battery market. BYD also saw its market share rise to 16.1% during this period, as its EV sales rebounded.

The top three EV battery makers are rounded out by South Korea's **LG Energy Solution**, which held a 12.4% market share in the first seven months of 2024. Other notable players include **SK On**, **CALB**, **Samsung SDI**, **Panasonic**, **Eve Energy**, **Gotion High-tech**, and **Sunwoda**.[95]

[92] EVTank. (2024c, January 19). EVTank：2023 年全球锂离子电池出货量达 1202.6GWh，2030 年远期出货量预测值调低至 5000GWh. *伊维观点*. http://www.evtank.cn/DownloadDetail.aspx?ID=547
[93] Virta. The Global Electric Vehicle Market Overview in 2024. *Virta*. https://www.virta.global/global-electric-vehicle-market
[94] Kang, L. (2024a, February 7). Global EV battery market share in 2023: CATL 36.8%, BYD 15.8%. *CNEV Post*. https://cnevpost.com/2024/02/07/global-ev-battery-market-share-in-2023/
[95] Kang, L. (2024b, September 5). Global EV battery market share in Jan-Jul 2024: CATL 37.6%, BYD 16.1%. *CNEV Post*. https://cnevpost.com/2024/09/05/global-ev-battery-market-share-jan-jul-2024/

Figure 44: Market share of world's top EV battery makers (2023)



Source: CNEV Post

Cathode

The manufacturing of cathodes is notably concentrated in East Asia, with China asserting a commanding lead by accounting for nearly 90% of the world's cathode active material manufacturing capacity. This includes a significant hold on LFP production, where China holds nearly 100% of the global output, as well as over 75% of the production for nickel-based chemistries like NMC.[96] **Beijing Easpring Material Technology**, **Hunan Changyuan Lico**, **Guizhou Zhenhua E-chem**, **XTC New Energy Materials**, **Shanshan**, **Ningbo Ronbay New Energy** are among the top cathode manufacturers in China, but there is no clear dominant leader in the industry.

Following China, South Korea emerges as the second-largest producer, contributing approximately 9% to the global supply. Major South Korean companies, such as **LG Chem** and **Samsung SDI**, are actively enhancing their production capabilities both within their home country and through strategic expansions abroad. Japan's contribution to the cathode manufacturing landscape is relatively modest, at about 3%, but companies like **Panasonic** are also extending their production reach internationally.[97]

Geopolitical tensions coupled with a growing emphasis on supply chain diversification have spurred significant investment and partnerships outside China. South Korean firms are

[96] IEA. (2024). *Global EV Outlook 2024: Moving towards increased affordability*. https://www.iea.org/reports/global-ev-outlook-2024
[97] Ibid.

proactively expanding their cathode production facilities and forming joint ventures in the US and Europe to better cater to their respective markets. Concurrently, battery manufacturers are keenly exploring collaborations with mining companies in resource-rich countries such as Indonesia, Australia, Argentina, and South Africa, aiming to bolster their supply of essential cathode materials.

Anode

China dominates the global anode materials market, producing over 97% of the world's anode active material manufacturing capacity.[98] The remaining production is primarily split between Japan and South Korea. However, there is a growing trend of diversification of anode to reduce reliance of a single source.

Among the major players, China's **BTR New Material Group** stands out as a leading company, holding approximately 22% of the global market share in 2023. **Shanshan**, another Chinese firm, is the largest producer of synthetic graphite and is expanding internationally with plans to invest up to 1.28 billion euros in a Finnish production facility.[99]

Japanese and South Korean companies are also significant in this space. **Resonac Holdings Corporation** (formerly Showa Denko) from Japan and **POSCO FUTURE M** from South Korea are key players with global operations. POSCO FUTURE M is particularly notable as the sole synthetic graphite producer in South Korea.

Separator

The separator is a crucial component in the lithium-ion battery supply chain, marked by significant technological barriers. China began producing separators only after 2010, making it the last of the four main materials to be domestically manufactured. By 2019, the share of domestically produced battery separators in China surpassed 92%, with these materials now supplied to nearly all major battery manufacturers worldwide.[100]

In 2023, China accounts for over 83% of global lithium battery separator shipment. The Chinese lithium-ion battery separator industry is dominated by five key players – **Semcorp**, **Senior**, **Sinoma**, **Gellec and ZIMT** - accounting for about three-quarters of the market share in China. Notably, Semcorp alone comprises one-third of the country's market share in this sector.[101]

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[98] Ibid.

[99] 森宁. (2024, January 10). 去年全球电池负极产量中国占比超 97%：杉杉人造石墨第一，贝瑞特总量第一. *澎湃*. https://www.thepaper.cn/newsDetail_forward_25950805

[100] 赵汉斌. (2022, May 12). 锂电池隔膜，不止一片“塑料”那么简单. *中国科技网*. http://stdaily.com/index/kejixinwen/202205/edb885b2b1e94ff0b55ed881d2417c6e.shtml

[101] EVTank. (2024b, January 10). 2023 年中国锂电池隔膜出货量 176.9 亿㎡ 干法隔膜占比首次回升. *电池网*. https://www.itdcw.com/news/hangyebaogao/011013920H024.html

However, the industry is seeing a shift towards diversifying the supply chain, with companies expanding their production capacities in other regions. These investments in North America and other regions outside of Asia-Pacific are driven by the need to establish local supply chains to meet the growing demand for electric vehicles and energy storage systems, as well as to comply with domestic content requirements, such as those set by the Inflation Reduction Act (IRA) in the United States.

Asahi Kasei, a leading battery separator manufacturer from Japan, announced plans to construct an integrated plant for base film manufacturing and coating of lithium-ion battery separators in Ontario, Canada. This plant is expected to have a production capacity of approximately 700 million square meters per year and is scheduled to start operations in 2027. Asahi Kasei has also reached a basic agreement with Honda to potentially establish a joint venture to manufacture separators for the North American EV market.[102]

US's **Entek**, another major battery separator manufacturer, received a $1.2 billion conditional loan from the US Department of Energy to build a lithium-ion battery separator manufacturing facility in Terre Haute, Indiana. This facility is expected to have an annual production capacity of 1.72 billion square meters, supporting the production of up to 1.9 million mid-size or 1.3 million full-size electric vehicles.[103]

Electrolyte

China produced 86.7% of the world's lithium battery electrolyte in 2023.[104] The remaining production was distributed among Japan, South Korea, and a small percentage in Europe and North America.

Tinci is the clear leader in China's lithium battery electrolyte market, accounting for 34.7% of the total market share in China in 2023. It was followed by **BYD** and **Capchem**, which represented 16.7% and 11.6% of the total market share respectively.[105]

3. Motors

The EV motor supply chain is a complex network of materials, technology, and global partnerships.

Japan and Germany excel in producing top-tier NdFeB permanent magnets and silicon steel. The world's leading EV manufacturer, China, while less advanced in these materials, can

[102] Asahi Kasei Corp. (2024, April 25). Asahi Kasei to Construct a Lithium-ion Battery Separator Plant in Canada. *Asahi Kasei*. https://www.asahi-kasei.com/news/2024/e240425.html
[103] Anselmo, J. (2024, July 10). Entek receives $1.2B DOE conditional loan for Indiana battery separator facility. *UntilityDive*. https://www.utilitydive.com/news/entek-1-billion-doe-loan-terre-haute-indiana-battery-separator-facility/720980/
[104] EVTank. (2024a, January 5). 2023 年中国电解液出货量达 113.8 万吨 前十企业排名变化明显. *电池网*. https://www.itdcw.com/news/hangyebaogao/01051391322024.html
[105] Ibid.

largely substitute silicon steel domestically. The country also benefits from abundant rare earth resources.

In the realm of bearings manufacturing, particularly high-speed bearings, Japan is one of the global leaders, supported by renowned companies such as **NSK**, **Koyo**, **NTN**, and **NACHI**. Additionally, the US's **Timken** and **TORRINGTON**, Sweden's **SKF**, and Germany's **FAG** and **INA** also contribute significantly to this specialized area.

The production of top-tier insulation materials is led by companies from the United States and Europe. Notable leaders include **Du Pont** from the US, **Von Roll** from Switzerland, **BASF** from Germany, and **Saint-Gobain** from France.

Design capabilities also play a crucial role in the EV motor landscape. Leading firms across various countries, including US, Japan, Germany and China, are capable of producing innovative solutions that enhance motor performance. However, the challenge lies in effectively integrating materials, design, and manufacturing processes, which requires collaboration and expertise across disciplines.[106]

In terms of manufacturing processes, countries like Germany, Japan, and Canada have developed sophisticated technologies and practices that set the standard for quality and efficiency. While other regions, including China and the US, are rapidly improving their manufacturing capabilities, the established expertise in Europe and Japan remains a benchmark. These countries combine high-quality equipment with a skilled workforce, enabling them to maintain a competitive edge in the global supply chain.[107] **Bosch** and **Siemens** from Germany, **Nidec**, **Denso**, **Hitachi**, and **Mitsubishi** from Japan, and **Magna** from Canada are among global leaders in this sector.

4. Power Electronics

Chips are an indispensable element of power electronics, with chip manufacturers from the United States, Europe, Japan, and Korea at the forefront of the global market.

The automotive chip industry exhibits a distinct division of labour across different geographical regions. The United States primarily focuses on chip design and manufacturing, leveraging cutting-edge technologies to push the boundaries of innovation. Meanwhile, Japan and Europe lead in the production of critical equipment and semiconductor materials essential for chip fabrication. In the Chinese mainland, the spotlight is on developing smaller chips that cater to specific regional market needs, while Taiwan is recognized for its expertise in advanced processes, contributing significantly to cutting-edge semiconductor technologies.

[106] 中国通信院. (2024). *电动化、网联化、智能化时代新能源汽车产业链全要素生产率报告（2023 年）*. http://www.caict.ac.cn/kxyj/qwfb/ztbg/202401/P020240130561587956295.pdf
[107] Ibid.

Automotive chips are required to endure extreme conditions, which presents several challenges, including high vibrations and electromagnetic interference. Consequently, the design of these chips must adhere to rigorous reliability standards due to safety concerns, requiring a lifespan of 15 years or 200,000 kilometres before replacement, alongside stringent certification processes.[108]

MCUs and IGBTs represent the highest barriers in the automotive chip sector.[109]

Key manufacturers of MCUs dominate the global market, with the top five suppliers accounting for around 80% of sales: **NXP Semiconductors** from the Netherlands, **Microchip Technology** from the US, **Renesas Electronics** from Japan, French-Italian company **STMicroelectronics**, and Germany firm **Infineon Technologies**.[110] In the IGBT market, major players include renowned global suppliers such as Germany's **Infineon Technologies**, Switzerland's **ABB**, and several leading Japanese firms like **Mitsubishi**, **Fuji Electric**, **Hitachi**, **Toshiba Corporation**, and **ROHM**, as well as Chinese entities like **BYD** and **StarPower**.

While China has emerged as the leading global producer of EV, over 90% of the chips utilized in these vehicles are either imported or manufactured by foreign-owned local firms. While alternatives produced in China are available, their reliability and durability still require thorough validation over time.

5. EV Platforms

The chassis of an EV is closely integrated with battery packs, electric motor, and other essential components, forming the vehicle's underlying architecture, known as the "platform". Unlike traditional chassis, where components are connected via mechanical linkages, the EV platform increasingly relies on electronic signals for control. This shift allows for the elimination of bulky, imprecise parts, resulting in a more compact structure with improved controllability and faster response times. As autonomous driving technology advances, "X-by-wire" or "by-wire" systems, a technology originally developed for aircraft, have become essential to the EV platform, as they physically execute autonomous driving.

Key components of by-wire systems include throttle-by-wire, steer-by-wire, brake-by-wire, and wire-controlled suspension. Germany leads the world in all these areas.

Throttle-by-wire is the most mature technology and is prevalently used in the automotive industry. Leading companies in this sector include **ZF**, **Bosch**, and **Continental** from

108 ATC 汽车技术平台. (2023, July 28). 造一辆车需要多少芯片？（附国内急需的汽车芯片替代清单）. *搜狐汽车*. https://www.sohu.com/a/707097352_100109629
109 Ibid.
110 Insights, I. (2024, June 14). The Five Biggest MCU Suppliers Accounted for 82% of 2021 Sales. *IC Insights*. https://www.icinsights.com/news/bulletins/the-five-biggest-mcu-suppliers-accounted-for-82-of-2021-sales/

Germany; **Nexteer** from the US; **Danfoss** from Denmark; **Ficosa** from Spain; **Curtiss-Wright** from the US; **Nissan** and **Hitachi** from Japan; and **Kongsberg Automotive** from Norway.

Wire-controlled suspension technology is also well-developed, but due to high costs, it is primarily found in high-end vehicles, with its use gradually expanding into the mid-to-high-end market in recent years. Germany and the United States leads in the production of wire-controlled suspension systems, creating a near-monopoly, with key players including **WABCO**, **AMK**, and **Continental** from Germany, as well as **BWI** Group, a US-based company acquired by China's Beijing West Smart Mobility Zhangjiakou Automotive Electronics.

Brake-by-wire and steer-by-wire technologies present significant barriers to entry. Germany holds a significant advantage in this area, followed by Japan, with South Korea also demonstrating notable strengths. Major manufacturers include Germany's **Bosch**, **Continental**, **ZF**, **Schaeffler**, which collectively hold a lion's share of the market, as well as Japan's **Advics**, South Korea's **HL Mando**, and China's **Bethel**, **NASN**, and **Trinova**. In steer-by-wire technology, Germany leads significantly, while Japan, South Korea, and China constitute the second tier, with China lagging slightly behind the other two. Leading manufacturers in this sector include Germany's **Bosch** and **ZF**, Japan's **Kayaba**, **JTEKT**, and **NSK**; South Korea's **HL Mando** and **Hyundai Mobis**, and **Nexteer**, a US-based company with Chinese ownership. However, mass production remains a challenge for steer-by-wire systems.

Chinese manufacturers are increasingly entering these fields. In ICEVs, braking and steering power sources are mechanical, dominated by countries with established automotive industries. In contrast, EVs utilize electricity for these functions, creating opportunities for China to compete. With advancements in technology and the entry of more Chinese companies into the competition, the cost of wire-controlled chassis systems is expected to decrease.[111]

6. Interior and Exterior Components

Compared to other parts of a car, the interior and exterior components sector encompasses a broader array of items, such as wiring harnesses, connectors, lighting systems, coatings, tires, passive safety systems (like seat belts and airbags), and seats. This diversity necessitates a high degree of specialization. As in many other automotive sectors, the US, Europe, Japan, and South Korea have also established themselves as leaders in this field due to their technological advancements and manufacturing capabilities.

[111] 中国通信院. (2024). *电动化、网联化、智能化时代新能源汽车产业链全要素生产率报告（2023 年）*. http://www.caict.ac.cn/kxyj/qwfb/ztbg/202401/P020240130561587956295.pdf

The market for automotive wiring harnesses is dominated by the United States, Japan, and Germany. Leading companies in this sector include **Aptiv** from the United States, **Yazaki Corporation** and **Sumitomo Electric** from Japan, **Leoni AG** from Germany, and **Nexans Autoelectric** from France.

Similarly, the United States holds a significant advantage in the production of automotive connectors, with companies like **TE Connectivity** and **Amphenol Corporation** leading the way. Japan also plays a crucial role, with **Yazaki Corporation, Hirose,** and **JAE** being the leaders. Europe is well-represented by firms such as **Aptiv**. These companies have established international benchmarks for quality and innovation in automotive connectors. Meanwhile, China is rapidly enhancing its competitiveness and presence in the market, with companies like **Luxshare Precision** making significant strides.

European and Japanese companies dominate the global market for automotive lighting, with France and Germany leading the way. **Valeo**, a French company, holds a significant market share due to its innovative lighting solutions and extensive product range. Germany is represented by **Osram** and **Hella**. Osram is renowned for its high-performance LED and laser lighting systems, which are used in premium and electric vehicles. Hella is known for its innovative lighting systems that offer optimal road illumination and unique design features. Japanese companies such as **Koito Manufacturing** and **Stanley Electric** are also key players. Koito Manufacturing is a leader in LED headlamps and Adaptive Driving Beam (ADB) technologies. Stanley Electric excels in optical design and light distribution technology.

The coatings market Is led by major companies from the United States and Europe. The United States is represented by **PPG Industries, Axalta Coating Systems,** and **Sherwin-Williams**. Notable leaders in Europe include **BASF** from Germany and **Sika AG** from Switzerland. Japan also has strong players in this sector, such as **Nippon Paint**. In contrast, China lags behind in comparison, although it is making efforts to enhance its competitiveness in the global market.

The global tire market is led by companies from France, Japan, and the United States. Italy, South Korea, and China also have advanced tire manufacturing capabilities. Industry giants include France-based **Michelin**, celebrated for its high-performance and durable tires. **Bridgestone** from Japan is the world's largest tire manufacturer, renowned for its extensive range of tires for various vehicles. The United States is represented by **Goodyear**, a major player known for its advanced tire technologies and strong market presence. Italy's **Pirelli** is famous for its premium tires, especially in the high-performance and luxury segments. South Korea's **Hankook** and **Kumho** are also significant contributors, recognized for their competitive pricing and quality. China is rapidly advancing with companies like **Zhongce Rubber** and **Maxxis**, which are expanding their global footprint.

In the field of passive safety systems, such as seat belts and airbags, the United States company **Autoliv** is the leader, known for its innovative safety technologies. Germany follows closely with companies like **ZF** and **Continental**. China is rapidly advancing in this sector, with companies like **Joyson Safety Systems** making great headway. **Korea** is represented by **Hyundai Mobis**, while **Japan** has strong players like **Toyoda Gosei** and **Denso**.

The market for automotive seats is dominated by companies from the United States, Canada, France, and Japan. **Adient**, based in the United States, is a leading global provider of automotive seating solutions, renowned for its advanced designs and comfort features. **Lear Corporation**, also from the United States, excels in integrating cutting-edge technology into their seats, enhancing the overall driving experience. **Magna International** from Canada is another key player, known for its high-quality and durable seating systems. France's **Faurecia** is celebrated for its innovative and sustainable seating solutions, contributing significantly to the EV market. Japan's **Toyota Boshoku**, **TS Tech**, and **TACHI-S** are recognized for their ergonomic designs and advanced manufacturing techniques. China is also rapidly emerging as a significant player in this sector, with companies like **Yanfeng** making notable advancements.

7. Vehicle Manufacturing

The world's automotive assembly capacity is primarily concentrated along the east coast of the Chinese mainland, the eastern US (from the Rust Belt down to Mississippi and Alabama), the west coast of India, the east coast of South America, and a corridor in Europe stretching from the Netherlands and Belgium to Romania and Serbia. Significant capacity is also found on the west coast of Taiwan, the west coast of South Korea, the southern coast of Japan, southern Thailand, and along the Malacca Strait and in Jakarta.

Of the 1,219 vehicle production facilities worldwide, China is home to over 400, nearly five times the number in the US, which ranks second (See Figure 45). When it comes to EV plants, China has 350 out of 806 EV production facilities globally, while the US has a total of 64 (See Figure 46).[112,113]

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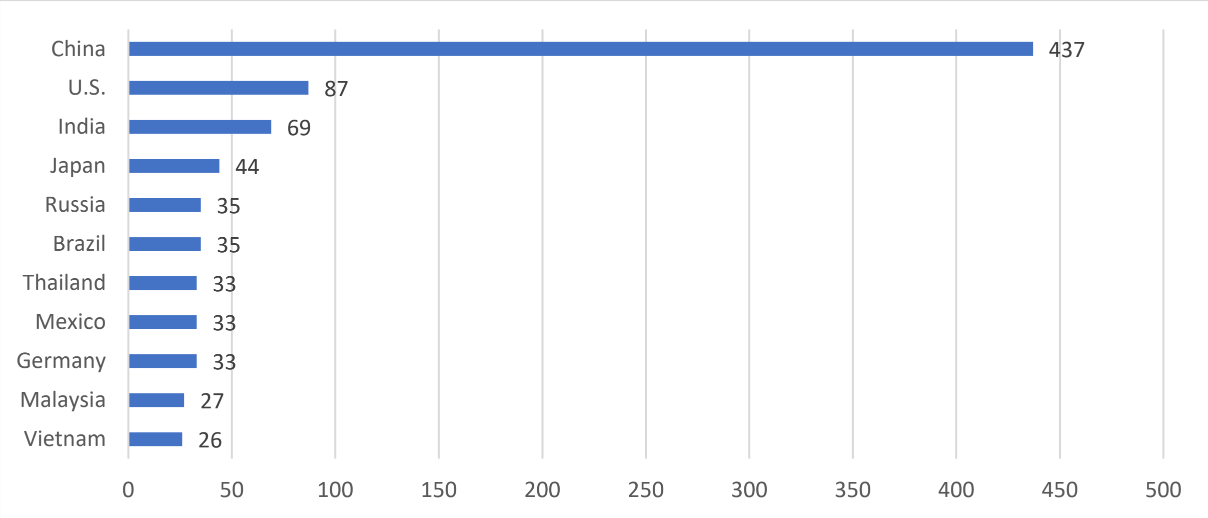
[112] MarkLines. (2024b). *OEM Plants Search*. MarkLines. Retrieved October 9 from https://www.marklines.com/en/global/search

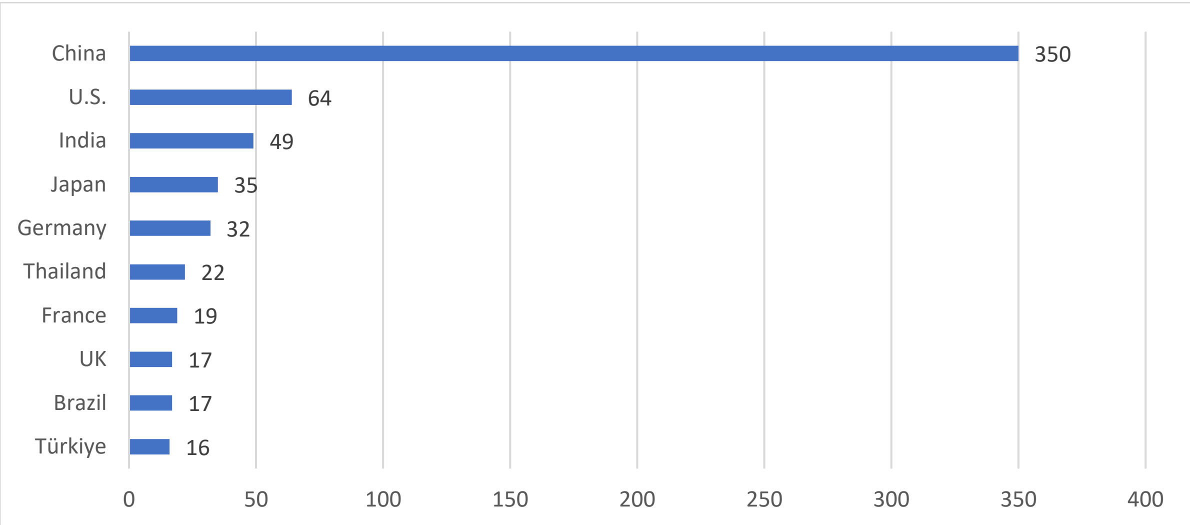
[113] Marklines. (2024a). *OEM Plants Interactive Map (2,392 listed locations as of end of September)*. Marklines. https://www.marklines.com/en/global/index

Figure 45: Countries with most vehicle production facilities (2023)



Source: MarkLines

Figure 46: Countries with most EV production facilities (2023)



Source: MarkLines

Chinese carmakers produce more than half of all electric cars sold worldwide. In 2022, China accounted for 64% of the world's total EV production in 2022.[114] In 2023, 9.3 million EVs were manufactured in China, representing 65% of global EV sales.[115] China exported 1.2 million Evs in 2023, a year-on-year increase of 77.6%.[116]

[114] Ellerbeck, S. (2023, May 11). Electric vehicle sales leapt 55% in 2022 - here's where that growth was strongest. *World Economic Forum*. https://www.weforum.org/agenda/2023/05/electric-vehicles-ev-sales-growth-2022/

[115] Irle, R. (2024, January 22). Global EV Sales for 2023. *EV Volumes*. https://ev-volumes.com/news/ev/global-ev-sales-for-2023/

[116] Songbo, W. (2024, April 11). Chinese EVs can overcome headwinds in global markets. *China Daily*. https://www.chinadaily.com.cn/a/202404/11/WS661717a4a31082fc043c147a.html

8. EV Supply Chain Management

The traditional automotive supply chain is characterized by a hierarchical structure, where Tier-1 suppliers support OEMs, and Tier-2 and Tier-3 suppliers support Tier-1 suppliers. This tree-shaped tiered approach often results in long information transmission chains, which can lead to delays and inefficiencies. These issues became particularly evident during the recent chip shortage, where the extended supply chain exacerbated the problem, causing significant delays and misinformation.

In contrast, EV companies are adopting a flatter and more flexible supply chain model. This new approach allows for faster product iteration and better adaptation to market changes. Notably, Tier-2 and Tier-3 suppliers can now directly supply new car manufacturers, bypassing the traditional Tier-1 companies. This shift has facilitated the rapid integration of specialized component manufacturers into the automotive sector, enhancing the industry's ability to innovate and respond to market demands.

The EV supply chain is also seeing increased involvement from technology companies. Giants like Baidu, Tencent, Alibaba, Huawei, and Xiaomi are entering the EV market, contributing significantly to the development of new energy vehicles and intelligent driving systems. This trend is transforming the automotive industry from a manufacturing-assembly focus to a technology-intensive industry, integrating advanced technologies into vehicle production and operation.

The chip shortage in recent years has highlighted the weaknesses of the traditional supply chain structure. The long information transmission chains led to significant delays and misinformation, prompting OEMs to establish direct communication with chip manufacturers. This direct interaction improves efficiency and gives OEMs better control over critical components, ensuring a more reliable supply chain.

Furthermore, the traditional dominance of OEMs in the supply chain is being challenged. Leading component manufacturers are becoming key players in the intelligent vehicle sector, driving technological innovation and gaining influence over the supply chain. Companies like Huawei are not only providing technology but also actively participating in the research and development, manufacturing, and marketing processes of EVs. This involvement is reshaping the supply chain dynamics, with technology companies playing a more central role in the automotive industry.

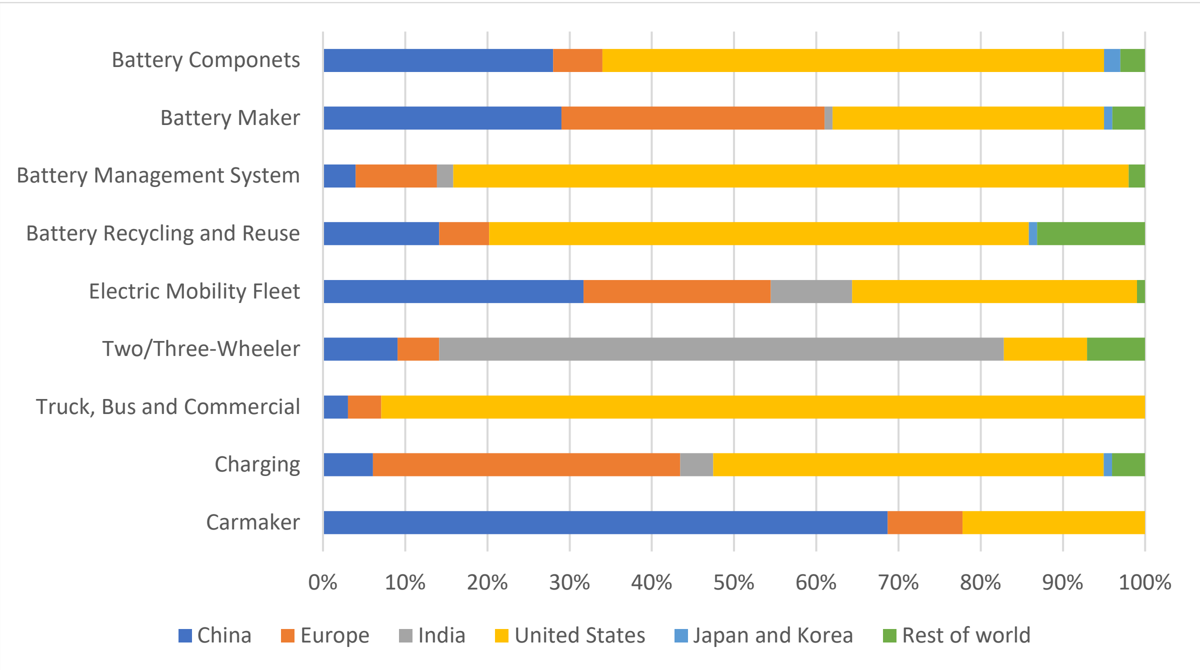
These changes reflect a broader transformation in the automotive industry, driven by the need for greater flexibility, faster innovation, and closer integration of technology and manufacturing.

9. Research and Development

The R&D landscape of the EV industry has fundamentally transformed the competitive dynamics of the automotive sector. Unlike traditional ICEVs, EVs do not require complex engines or transmissions, significantly lowering the barriers to entry and reducing the long development cycles associated with these components. This shift has weakened the decades-long advantages held by traditional automakers in engine and transmission technology. In the era of electrification and smart mobility, the core competitive factors in the automotive industry have shifted dramatically. Traditional component giants no longer have the extensive lead they once did, placing domestic and international companies on a more level playing field. In some areas, new entrants are even leading the industry. This has opened opportunities for new companies to rapidly innovate and deploy advanced technologies, potentially outpacing established global competitors in certain aspects of EV development and smart mobility.

Between 2018 and 2023, global venture capital investment in electric mobility technology has shown distinct trends across various countries and regions. The United States leads the way in almost all fields, capturing a significant share of investments. China and Europe also demonstrate strong engagement. India is emerging as a key player, particularly in two/three-wheeler investments, highlighting its growing focus on electric mobility. Japan and Korea are also active, though their investments are more concentrated in specific sectors like battery and charging technologies. (See Figure 47)

Figure 47: Share of total cumulative venture capital investment in electric mobility technology areas by country or region, 2018-2023



Source: IEA

V. Forces Shaping the Future Global Supply Chain Landscape

1. Geopolitical Competition[117]

Geopolitical competition is reshaping the global EV sector, with countries like China, the United States, and those in Europe striving to establish self-reliant EV ecosystems. This competition is driven by techno-nationalism, where technological capabilities are linked to national security, economic prosperity, and socio-political stability. Control over critical supply chains, such as those for rare earth materials and lithium batteries, provides significant economic and security advantages.

China has positioned itself as a leading player in the EV market through decades of strategic planning and investment. The country is the provider of a substantial portion of the global supply of rare earth materials, lithium, cobalt, and graphite, which are essential for EV batteries. In response, other countries are taking measures to secure their own supply chains. The United States, Europe, and Japan are investing in reshoring and ring-fencing their supply chains to reduce dependence on China. This involves developing local sources of raw materials, as well as establishing partnerships and alliances to ensure a stable supply of these critical components.

In 2020, the US has reopened the Mountain Pass mine in California and is collaborating with Australia on rare earth extraction and processing.[118] The US Inflation Reduction Act (IRA) of 2022 offers tax credits for plug-in electric drive motor vehicles that have their final assembly in North America. To qualify, these vehicles must also meet specific requirements regarding the percentage of critical minerals that are extracted, processed, or recycled in the US or its Free Trade Agreement (FTA) partners.[119] China is most affected by this measure, as it holds the largest market share in EV manufacturing and critical mineral processing, often at more affordable prices. Japan, which was not an FTA partner with the US and, along with China and South Korea, is one of the top three EV battery suppliers, reached a deal with the US in March 2023 to exempt duties on critical minerals.[120]

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[117] Capri, A. (2021). *The geopolitics of electric vehicles: techno-nationalism reshapes the automotive industry*. https://research.hinrichfoundation.com/hubfs/White%20Paper%20PDFs/The%20geopolitics%20of%20electric%20vehicles%20(Alex%20Capri)/The%20geopolitics%20of%20electric%20vehicles%20-%20Hinrich%20Foundation%20-%20Alex%20Capri%20-%20November%202021.pdf

[118] Scheyder, E. (2020, July 16). US rare earths miner MP Materials to go public in $1.47 billion deal. *Reuters*. https://www.reuters.com/article/us-mp-materials-ipo/u-s-rare-earthsminer-mp-materials-to-go-public-in-1-47-billion-deal-idUSKCN24G1WT

[119] EY. (2022, August 18). IRS issues guidance on which vehicles qualify for EV credits under the Inflation Reduction Act. *EY*. https://taxnews.ey.com/news/2022-1262-irs-issues-guidance-on-which-vehicles-qualify-for-ev-credits-under-the-inflation-reduction-act

[120] Office of the United States Trade Representative. (2023). *FACT SHEET: Agreement Between the Government of the United States of America and the Government of Japan on Strengthening Electric Vehicle Battery Critical Minerals Supply Chains*. Retrieved from https://ustr.gov/about-us/policy-offices/press-office/fact-sheets/2023/march/fact-sheet-agreement-between-government-united-states-america-and-government-japan-strengthening

With Donald Trump starting his second term as US President, US EV policies are undergoing a big shift as he signed the executive order of ‘Unleashing American Energy’. The document ordered to revoke the so-called ‘electric vehicle mandate’ and other Biden-era policies aimed at promoting EV adoption. This includes halting federal funding for EV charging infrastructure and possible rolling back the US $7,500 tax credit for new EV purchases under the IRA. Additionally, Trump has vowed to withdraw the US from the Paris Climate Agreement once again.

The European Union’s (EU) Critical Raw Materials Act entered into force in May 2024 aims to bolster the EU’s self-sufficiency in critical raw materials by 2030. The Act mandates that 10% of the EU’s annual consumption for extraction, 40% for processing, and 15% for recycling of critical raw materials be sourced domestically. In October 2024, the EU voted to impose tariffs on Chinese-made electric vehicles. These tariffs could be as high as 45.3%, including the existing 10% tariff on imported vehicles, until the EU and China reach an agreement on this matter.

2. Domestic Development Policies

Government policies and incentives play a crucial role in shaping the EV supply chain. China released the “New Energy Vehicle Industry Development Plan (2021-2035)” in November 2020, emphasizing the need to accelerate the research, development, and industrialization of solid-state batteries. In June 2023, China introduced a significant tax incentive package worth RMB 520 billion (US$72.3 billion) over four years. This package includes tax breaks for EVs and environmentally friendly vehicles, offering a complete exemption from purchase tax for new energy vehicles (NEVs) purchased in 2024 and 2025 and halved exemption from 2026 to 2027. Various regions in China have also implemented local initiatives to support the NEV industry. Additionally, China has employed various tools to promote the EV sector, including regulatory changes like the “dual-credit system,” which encourages automakers to increase the share of their fleets that are electrified.

In the US, the Biden administration has introduced a comprehensive set of policies under the IRA to promote EV adoption and domestic production. The IRA includes substantial subsidies and tax credits for both consumers and manufacturers. For consumers, the act offers up to US$7,500 in tax credits for purchasing new EVs, provided the vehicles meet specific criteria regarding battery sourcing and assembly within North America. For manufacturers, the IRA provides significant incentives to build and expand EV production facilities in the US, including grants and loans aimed at boosting domestic battery manufacturing and supply chain resilience. Additionally, the administration has committed to investing US$7.5 billion in a national network of 500,000 EV charging stations by 2030, addressing one of the key barriers to EV adoption. The US Department of Energy (DOE) is also actively supporting research and development in advanced battery technologies and sustainable manufacturing practices. These initiatives are complemented by state-level policies, such as California's mandate to phase out the sale of new gasoline-powered cars by 2035, which further drive the transition to electric mobility.

Similarly, the EU's Green Deal aims to make Europe carbon neutral by 2050, with significant investments in EV manufacturing and supply chains. This includes the development of the Alternative Fuels Infrastructure Regulation (AFIR), which mandates the installation of fast charge points every 60 km along the Trans-European Transport Network (TEN-T). Additionally, in the UK, the Public Charge Point Regulations focus on improving the customer experience at public charge points.

India launched the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME), a key initiative under the National Electric Mobility Mission Plan (NEMMP), in 2015, to promote the adoption of electric and hybrid vehicles in the country. In 2020, the country introduced the Production-Linked Incentive (PLI) scheme, aiming to boost domestic manufacturing across various sectors, including EVs, by providing financial incentives to companies based on their incremental sales and production.

3. Supply of Raw Materials and Critical Components

The supply of raw materials and critical components plays a crucial role in the EV supply chain, significantly impacting production costs, technological advancements, and market stability. The IEA estimates that the soaring EV sector will require 50 new lithium projects, 60 nickel mines, and 17 cobalt developments by 2030.[121]

EVs have become the largest single source of demand for lithium, contributing 58% of total lithium demand in 2021, a figure expected to rise to 76% by 2032. Despite this growing demand, Europe and the US are projected to contribute only a small fraction of the global lithium supply, with Australia currently producing most of the lithium, which is then predominantly refined in China.[122]

This concentration of supply can lead to dramatic price fluctuations and potential disruptions, affecting the cost and availability of EVs, therefore, poses significant challenges.

The price of lithium skyrocketed during the COVID-19 pandemic due to a significant supply deficit. The long-term agreement-based supply model also contributed to the situation, as these arrangements lock in supply quantities and prices for extended periods, limiting flexibility in responding to sudden increases in demand. The price of lithium in April 2022 was more than seven times of that in July 2020 (See Figure 48). Between November 16,

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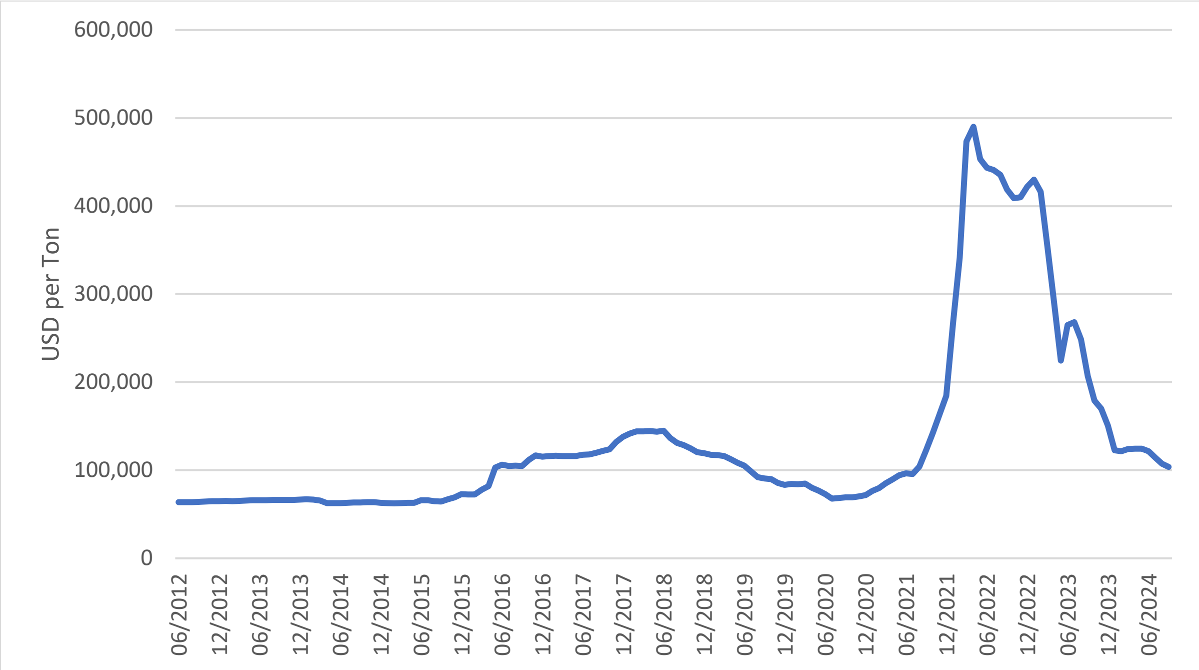
[121] Roberts, G. (2022a, December 28). Cost of minerals vital for electric vehicle batteries soars. *FleetNews*. https://www.fleetnews.co.uk/news/latest-fleet-news/electric-fleet-news/2022/12/28/cost-of-minerals-vital-for-electric-vehicle-batteries-soars
[122] Ibid.

2020 and November 14, 2022, the price of lithium carbonate, a key material for lithium-ion batteries, increased 14 times.[123] This price volatility has driven Chinese car and battery manufacturers to seek alternative battery technologies, such as sodium-ion batteries, which are cheaper and suitable for mass production. Despite of this, lithium-ion batteries are likely to remain the dominant technology in the near future and expected to see rapid technological advancements in the coming years.

Figure 48: Prices of lithium

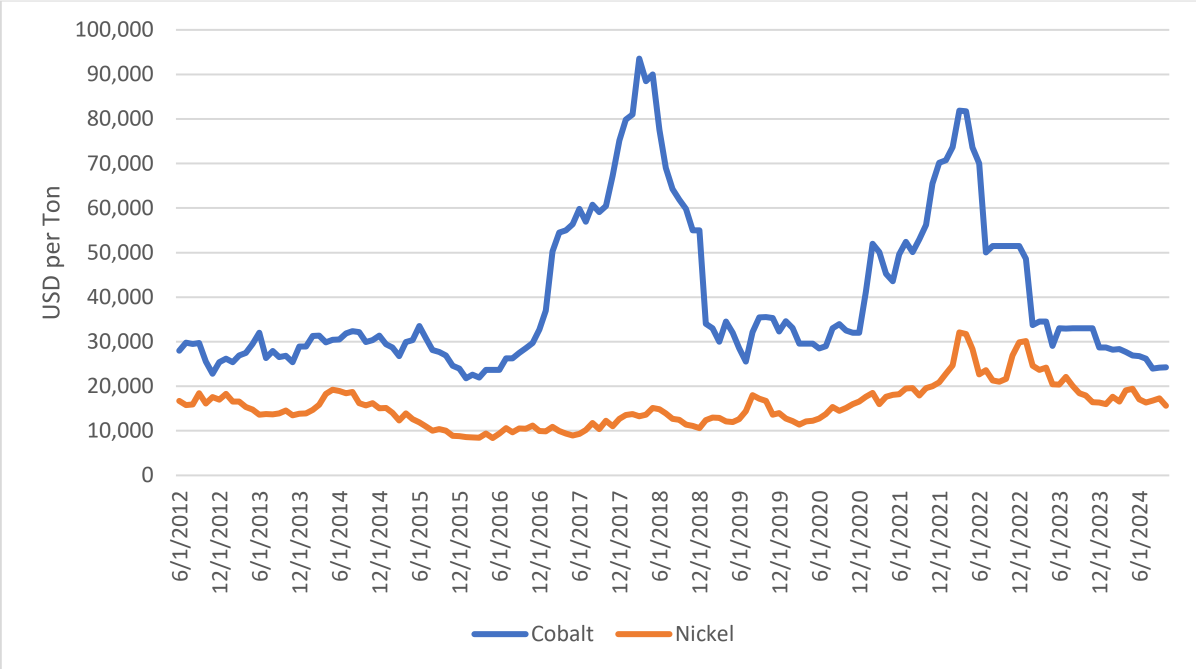


Source: CEIC

As discussed above, the concentration of supply also exists in other critical materials for EVs. The Ukraine war started in late February 2022 put pressure on the supply of nickel, a critical material for EV batteries, as Russia is a major player in nickel refining. The price of Nickel in March 2022 was more than two times four months ago in December 2021. Cobalt prices have experienced significant volatility since 2016, largely driven by shifting expectations around EV demand and unstable supply from the DRC. (See Figure 49)

[123] Trading Economics. Price of Lithium Carbonate. In: Trading Economics.

Figure 49: Prices of cobalt and nickel



Source: S&P Capital IQ

The COVID-19 pandemic not only exacerbated the price fluctuation of critical minerals but also exposed the fragility of the automotive chips supply chain. Factory shutdowns and port closures disrupted production and logistics, while a sudden shift in demand complicated the situation. Initially, auto sales plummeted, but the rapid recovery caught semiconductor manufacturers off guard. The automotive industry's reliance on just-in-time manufacturing practices left little buffer to absorb these shocks, resulting in immediate production halts. Although the chip shortage has eased as the pandemic wanes, the supply chain remains vulnerable to geopolitical factors such as trade tensions and economic sanctions. This experience underscored the need for greater resilience and flexibility in the supply chain, prompting automakers and semiconductor manufacturers to reevaluate their strategies.

4. Costs and Capacity of Production

The cost of labour plays a crucial role in the production of EVs. Traditional automakers have already laid off thousands of highly paid workers to transition towards EV production. Furthermore, they have spent billions to address skill gaps, which raises production costs.[124] New automakers also face recruitment challenges. For instance, when Tesla opened its Gigafactory in Berlin, it encountered a shortage of qualified workers. Tesla's attempt to offer higher wages backfired due to Germany's heavily unionized auto sector, which prevents new

[124] Charette, R. N. (2023, January 17). How EVs Are Reshaping Labor Markets. *IEEE Spectrum*. https://spectrum.ieee.org/the-ev-transition-explained-2658797703

employees from earning more than long-term employees with similar qualifications. Ultimately, Tesla resolved this by giving all employees a 6% pay raise.[125]

Logistics are another critical factor affecting EV supply chains. The COVID-19 pandemic caused significant disruptions in global logistics, leading to delays in the delivery of essential components such as semiconductors and batteries. These delays impacted the production schedules of many EV manufacturers. General Motors and Ford both experienced significant production slowdowns due to semiconductor shortages exacerbated by the pandemic.[126,127]

China's EV production benefits from a 20% cost advantage over Western manufacturers, primarily due to a streamlined supply chain that reduces expenses in logistics, labour, and land.[128] This efficiency, combined with lower labour costs and high performance, contributes to China's leadership in the global EV market.

5. Technology

The integration of automation and robotics in manufacturing processes enables EV makers to relocate production to regions with higher labour costs, allowing them to be closer to end markets. This shift not only facilitates the production of complex components with greater precision but also helps companies optimize production efficiency and maintain high-quality standards.

The adoption of advanced materials,"such'as lightweight, high-strength steel and aluminium, combined with integrated casting technology, especially gigacasting, is driving the lightweighting of EVs. These materials reduce overall vehicle weight without compromising strength or safety, enhancing efficiency and extending range. Integrated casting allows for the creation of larger, single-piece components, simplifying vehicle design and reducing the number of parts. This streamlining not only simplifies the manufacturing process but also minimizes supply chain complexity and lowers production costs by decreasing the need for extensive welding and painting.

A notable example is Tesla's gigacasting for the Model Y's rear floor assembly, which reduced the number of parts from 70 to just one and cut welding points from 700-800 to about 50,

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[125] Jackson, J. (2022, December 5). Tesla's Berlin Hub Can't Hire Enough People, or Keep Them. *WIRED*. https://www.wired.com/story/tesla-vacancies-staff-shortage-berlin/

[126] Maynard, C. (2021, April 9). GM and Ford stop production at more factories due to semiconductor chip shortage. *Consumer Affairs*. https://www.consumeraffairs.com/news/gm-and-ford-stop-production-at-more-factories-due-to-semiconductor-chip-shortage-040921.html

[127] Klayman, B., & Nellis, S. (2023, February 4). Focus: Ford's pain underscores uneven impact of two-year auto chip shortage. *Reuters*. https://www.reuters.com/business/autos-transportation/fords-pain-underscores-uneven-impact-two-year-auto-chip-shortage-2023-02-03/

[128] Sito, P., Ren, D., & Xue, Y. (2023, April 22). Electric vehicles: why the West needs China's battery prowess as it moves to build supply-chain capacity. *South China Morning Post*. https://www.scmp.com/business/china-business/article/3217855/electric-vehicles-why-west-needs-chinas-battery-prowess-it-moves-build-supply-chain-capacity

compared to the Model 3. This innovation resulted in a 30% weight reduction in the lower body assembly and a 40% decrease in manufacturing costs. Additionally, Tesla estimates that this method can save battery costs by reducing vehicle weight by 10%, increase range by 14%, and improve material utilization from 60-70% to over 95%. The high level of automation in this process also reduces labour needs and factory space, cutting land use by 30%.[129,130]

Despite the high initial costs—due to the complexity of manufacturing the machines needed for gigacasting and the required factory floor revamps—Chinese OEM manufacturers are increasingly adopting this technology, viewing it as the future of the industry.

6. Environmental Factors

The EU is most aggressive in environmental policy. The EU has implemented stringent environmental regulations to protect local industries and promote sustainability. For instance, the EU's Batteries Regulation, effective from August 2023, mandates that batteries sold in the European Economic Area must have carbon footprint declarations, labels, and digital battery passports. It also sets requirements for the recycling rates of critical raw materials. These regulations increase compliance costs for battery manufacturers and can act as a "green trade barrier," making it challenging for non-compliant companies to export to Europe. Additionally, the EU's Carbon Border Adjustment Mechanism (CBAM), which started in October 2023, imposes carbon tariffs on imports based on their carbon footprint, further influencing the location of production facilities.

Mining operations for critical minerals like lithium, cobalt, and nickel can have significant environmental impacts, including soil erosion, habitat disruption, and biodiversity loss. The EV industry, a major user of these minerals, is under pressure to source materials sustainably. Regulations like the EU's Battery Regulation push companies to reduce their carbon footprint and pursue sustainable production practices. This has led to a shift towards sourcing materials from regions with stringent environmental standards and robust regulatory frameworks.

As the industry recognizes the importance of transitioning from reliance on scarce and potentially toxic materials towards the adoption of non-toxic and widely available materials, there is a strong impetus to pivot towards more sustainable and environmentally-friendly battery chemistries and raw materials. Gotion High-Tech, a Chinese battery manufacturer, partnered with Volkswagen to industrialize battery cell production in Germany. However, Gotion faced significant challenges due to its high carbon emissions, which were reportedly

[129] 黄秀瑜. (2022, October 31). 汽车一体压铸专题分析：一体压铸方兴未艾，推动车身制造变革. *腾讯网*. https://news.qq.com/rain/a/20221031A0632600

[130] Lambert, F. (2021, Janurary 11). Tesla starts production of Model Y with massive single-piece rear casting. *Electrek*. https://electrek.co/2021/01/11/tesla-starts-production-model-y-massive-single-piece-rear-casting/

twice the industry average. Volkswagen required Gotion to use green energy throughout the production process, which significantly increased costs.[131]

7. Consumer Preferences

Consumers are increasingly turning to electric cars due to a combination of factors, including comparable performance to traditional vehicles, more affordable pricing, lower operating costs, environmental benefits, and the growing availability of charging infrastructure. On top of that, policies to phase out internal combustion engine vehicles have also been pushing consumers towards EVs and other zero-emission vehicles.

The steady improvements in battery technology, motor performance, and charging capabilities have made electric cars a viable and attractive option for a wider range of consumers. Additionally, the rising concerns about emissions and the push for more sustainable transportation options have further bolstered the demand for electronic vehicles. As charging networks continue to expand, range anxiety among potential buyers has also diminished, making electric cars a more practical choice for daily use and long-distance travel. These advancements and compelling attributes have driven a significant surge in consumer adoption of electronic cars in recent years.

VI. Forecasts

The EV supply chain is poised to become more localized, technologically advanced, and sustainable. Companies will prioritize in-house production, diversify their sources of raw materials, expand charging infrastructure, and forge strategic partnerships to adapt to the evolving regulatory landscape and meet increasing consumer demand.

1. In-House Production and Onshoring Becoming Popular

Manufacturers are increasingly bringing the production of critical components, such as battery and EV chips, in-house. For leading EV brands from the largest markets and automotive manufacturing bases, this often leads to onshoring of manufacturing. A notable example is Tesla’s production of its self-developed 4680 battery cells in Texas. Similarly, China’s BYD, already competitive in battery manufacturing, is enhancing its self-sufficiency in electric motors and EV chips. By making production in-house, companies can reduce reliance on external suppliers, gain greater control over production costs and quality, and mitigate risks associated with supply chain disruptions. This shift is likely to continue as companies seek to enhance supply chain resilience.

[131] 方诗意. (2024, February 14). 锂电出海，逆流而上. *36 氪出海*. https://mp.weixin.qq.com/s/Aa9MgErIAMLT8RTsTYuj9w

2. Increased Localization

European and US EV brands are increasingly adopting localization strategies. Volvo established their first US factory in South Carolina soon after the US-China trade war started in 2018. Companies like BMW and Volkswagen have expanded their manufacturing capabilities in the US, with significant facilities in South Carolina and Tennessee, respectively. Conversely, Tesla has established a Gigafactory in Berlin, Germany, to serve the European market. Nio from China has set up an R&D centre in Germany, and CATL has built a battery plant in Thuringia, Germany, to supply local automakers. To enhance their presence in the Southeast Asian market, companies such as BYD and Great Wall Motors have established production facilities in Thailand, while SAIC-GM-Wuling produces EVs in Indonesia. These moves not only reduce logistical costs and tariffs but also align with regional regulatory requirements and consumer preferences, ensuring a more robust and responsive supply chain.

3. Nearshoring as Lower-Cost Alternative

While localization offers numerous benefits, it can be expensive, especially since the largest EV markets often have higher manufacturing costs. To effectively approach target markets while remaining cost-competitive, EV manufacturers, especially Chinese ones are trying to nearshore their operations to key regions like North America, East Europe, and Central Asia.

In North America, Tesla is building a new gigafactory in Nuevo León, Mexico, to complement its existing facilities in the US and better serve the North American market. Additionally, BYD is exploring factory sites in Mexico, and JAC Motors has set up production facilities there. These strategic moves reflect a broader effort to leverage regional advantages, comply with local regulations, and meet growing demand for electric vehicles in these markets.

Countries near major EV markets are striving to attract more of the EV supply chain. Turkey is actively courting Chinese EV manufacturers, including BYD, Chery, SAIC, and Great Wall Motors, to establish operations aimed at selling their EVs in the European market.[132] Eastern European countries have emerged as popular destinations for nearshoring EV production, targeting other parts of Europe. Poland has successfully welcomed LG Energy Solution, which has set up its primary production base for global EV battery manufacturing in Wroclaw. Hungary has drawn significant investments from Chinese and other international companies, including BYD, BMW, and their suppliers. Notably, BYD operates an electric bus manufacturing plant in Komárom and is constructing its first European electric car factory in Szeged. Additionally, CATL is building a €7.3 billion battery plant in Debrecen, which will supply batteries to major automakers like Mercedes-Benz, BMW, and Audi. BMW is likewise

[132] Anderson, B. (2024, May 20). Turkey Talking With BYD And Chery About Potential EV Factories. *Carscoops*. https://www.carscoops.com/2024/05/turkey-talking-with-byd-and-chery-about-potential-ev-factories/

investing in Hungary with a new EV factory in Debrecen, which will collaborate with EVE Energy Co. Ltd., a Chinese firm, to provide on-site battery supply.

4. Technological Advancements in Battery Technology

Advancements in battery technology, including the development of solid-state batteries and improvements in lithium-sulphur batteries, are expected to drive down costs and improve the performance of EVs. These innovations will make Evs more affordable and extend their driving range, further boosting consumer adoption. Additionally, the integration of thermal management systems, as seen in Tesla's Cybertruck, will enhance battery efficiency and longevity.

5. Sustainability and ESG Compliance

Environmental, social, and governance (ESG) factors are becoming increasingly important in the EV supply chain. Regulations such as the EU's Battery Regulation and the CBAM are pushing companies to reduce their carbon footprint and pursue sustainable production practices. This trend will likely lead to more localized production and increased investment in green technologies and renewable energy sources.

6. Diversification of Raw Material Sources

The need for critical minerals like lithium, cobalt, and nickel will drive efforts to diversify supply sources. Companies are seeking to reduce dependency on single regions, particularly those with geopolitical risks. This diversification will involve securing supply agreements with multiple countries and investing in sustainable mining practices. The EU's Critical Raw Materials Act is an example of regulatory efforts to ensure a stable and sustainable supply of essential materials.

7. Expansion of Charging Infrastructure

The expansion of charging infrastructure is crucial for the widespread adoption of EVs. Governments and private companies are investing heavily in building more charging stations, both fast-charging and wireless options. This expansion will make Evs more convenient for consumers and support the growth of the EV market. For instance, the US National Electric Vehicle Infrastructure (NEVI) program and the EU's Regulation for the Deployment of Alternative Fuels Infrastructure are key initiatives driving this trend.

8. Market Consolidation and Strategic Partnerships

As the EV market matures, we can expect increased consolidation and strategic partnerships among automakers, battery manufacturers, and technology providers. These collaborations will help companies scale production, share technological advancements, and reduce costs. For example, partnerships between OEMs and suppliers for the development of integrated e-Axles and other components are becoming more common.

9. Impact of Regulatory Changes

Regulatory changes, such as President Trump's revert of EV-related policies under President Biden's administration, will continue to shape the EV supply chain. While last administration's IRA provided incentives for US local production and sourcing, driving further localization and investment in domestic supply chains, Trump's policy shifts are expected to slow the growth of the EV market in the US, potentially reducing demand for critical minerals like lithium and cobalt. However, the global demand for EVs remains strong, driven by continued investments and policies in Europe and Asia. Meanwhile, the US may see a fragmented regulatory landscape, with states like California continuing to push for stricter emissions standards despite federal rollbacks.

10. China's Leadership and Export Growth

China will continue to lead the global EV supply chain, leveraging its established manufacturing capabilities and extensive raw material resources. China is expected to maintain this leadership position in global EV sales, driven by its strong manufacturing capabilities, continuous development of a comprehensive supply chain, and increasing domestic acceptance and demand for EVs. Chinese companies are also expanding their export markets, with significant growth in EV exports to Europe and Asia-Pacific regions. This trend is supported by China's strategic investments in battery technology and production capacity, positioning it as a key player in the global EV market.

VII. Conclusion

The EV industry is characterized by high risk, uncertainty, and fragility, arising from its extensive global supply chain, the uneven distribution of critical raw materials, and significant barriers in technology and manufacturing. These factors are likely to drive greater vertical integration within the industry, both at the enterprise level and among countries. Looking ahead, the sector is expected to grow rapidly as demand for electric vehicles increases, prompting further investment in technology and infrastructure. However, achieving stability will require addressing supply chain vulnerabilities and fostering international cooperation.

Our Global Supply Chain Analysis by Industry

Electric Vehicle

Charged Up: The Rise of Electric Vehicles and the Race for Critical Minerals and Components

View

Solar PV

Chasing the Sun: Will the Global Solar Supply Chain Find New Horizons?

View

Apparel

Beyond Borders: The Global Landscape of Apparel Supply Chains and China's Evolving Role

View

Medical Device

Embracing Multipolarity: Post-COVID Evolution of Global Medical Device Supply Chain

View

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