Global Supply Chain Report

Summary
Electric Vehicle
Solar PV
Apparel
Medical Device

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HKUST LI & FUNG
SUPPLY CHAIN INSTITUTE

Expansion and Diversification: Securing EV Supply Chains Amid Global Fragmentation

Executive Summary

Electric vehicle (EV) adoption has accelerated globally between 2023 and 2025, with EV sales reaching about 17 million in 2024, accounting for over 20% of new car sales worldwide. The total EV fleet on the road grew to around 58 million by the end of 2024, more than triple the stock just three years prior. This surge has been led by China, Europe, and the US, which together made up 95% of 2024 EV sales. Major emerging markets like Southeast Asia and Latin America are witnessing even more rapid growth—for example, Thailand's EV sales share surged to 13% in 2024, up from just 2% two years prior, while Brazil's EV sales more than doubled to around 125,000 units, capturing about 6% of its market. Despite this progress, EVs still represent only around 4.5% of the 1.6 billion vehicles on the road globally in 2024, leaving substantial room for growth.

EV supply chains have expanded and evolved in response to this demand. **Batteries remain the costliest component of EVs, though their share of total vehicle cost has fallen** to around 30–40% in most mainstream models and is expected to decline further. **Critical minerals are unevenly distributed**: Australia, China and Chile provide over three-quarters of lithium; the Democratic Republic of Congo (DRC) supplies nearly 70% of cobalt; and Indonesia has become the dominant producer and processor of nickel for battery use. China, meanwhile, plays a central role in refining—processing around 60% of lithium, 70% of cobalt, and up to 90% of rare earth elements—as well as producing most battery-grade graphite. **Ensuring stable mineral supply has therefore become a strategic priority**, with governments and companies pursuing diversification through new mining projects and investing in alternatives such as lithium-iron-phosphate (LFP) and sodium-ion batteries to reduce reliance on scarce materials.

At the same time, **geopolitical tensions and trade barriers are reshaping supply chains**. The intensification of the US-China rivalry, European trade investigations into Chinese EV imports, and new export controls on minerals such as graphite, gallium, and germanium have heightened disruption risks. In response, automakers and battery producers are shifting towards **localization of production**, **'friend-shoring'**, and **vertical integration**. These strategies aim to reduce exposure to geopolitical shocks, diversify supply, and strengthen resilience, even if they sometimes raise costs or duplicate capacity.

Leading manufacturers have also expanded their global production footprints, but China remains the manufacturing powerhouse. In 2024, it produced around 12.9 million EVs—over 70% of global output—and sold nearly the same number domestically, accounting for about 60-75% of global EV sales depending on definitions. Chinese firms dominate: BYD sold more than 4.27 million EVs in 2024, topping the global ranking, while CATL supplied about 38% of the world's EV batteries, with BYD ranking second at 17.2%. The world's second-largest EV seller, Tesla, delivered 1.79 million units in 2024, retaining its lead in battery-electric vehicles (BEVs). European manufacturers such as Volkswagen continued to expand EV sales, particularly in Europe, though global growth remains more modest compared with China's rapid scale-up. A landmark came in 2023 when the Tesla Model Y became the world's top-selling car of any type, with over 1.2 million units sold worldwide, signalling EVs' entry into the automotive mainstream.

Looking forward, policy and technology will be decisive in shaping the next phase of the EV supply chain. In the US, the *Inflation Reduction Act* (IRA), enacted in 2022 to incentivize local EV and battery production, is under review by the new administration in 2025, creating uncertainty over the future of tax credits and domestic content rules. Europe has moved ahead with stringent sustainability measures: the EU Batteries Regulation (enacted in 2023, phased in from 2024) mandates carbon footprint disclosure and recycled content, while the *Carbon Border Adjustment Mechanism* (CBAM) entered a transitional reporting phase in 2023-2025 and will apply carbon costs to imports such as steel and aluminium from 2026. China is pressing ahead with its *New Energy Vehicle Industry Development Plan (2021-2035)* and, in mid-2023, extended purchase tax exemptions for EVs through 2027 to sustain domestic demand. India, meanwhile, is strengthening its EV ecosystem—especially for two- and three-wheelers.

Against this backdrop, **three plausible mid-term scenarios emerge for the late 2020s**. In a **Fragmented Blocs** world, US-China decoupling leads to distinct regional supply spheres; in a **Resilient Diversification** outcome, supply chains remain global but with broader sourcing and less dependence on any one country; while in an **ESG-Driven Localization** pathway, sustainability and ethical requirements force greater localization, recycling, and reshaped material sourcing. Each carries different implications for cost, innovation, and resilience. To thrive, businesses will need agility—investing in next-generation technologies such as solid-state batteries and AI-driven manufacturing, while forging strategic partnerships. Policymakers, in turn, must balance industrial competitiveness with international cooperation to keep the EV transition on track with climate goals while securing supply chain integrity.

Contents

I. Introduction

Between 2023 and 2025, the electric vehicle (EV)[1] sector has advanced notably, shaped by rising sales, important policy developments, and intensifying competition in the EV supply chain. Global EV sales rose by around 35% yoy in 2023 and by a further 25% yoy in 2024,[2] even as overall auto markets grew by less than 10% yoy in 2023 during their post-pandemic rebound, followed by only 2.5% yoy growth in 2024.[3] By 2024, EVs accounted for more than 20% of all new car sales worldwide, up from about 14% in 2022.[4] This shift signalled that electric mobility had moved beyond a niche product and entered the mass market in many regions. The rapid uptake has been fuelled by government incentives, broader model availability, and greater consumer acceptance of benefits such as lower running costs and zero tailpipe emissions. The number of EV models available globally reached 785 in 2024, representing an increase of about 15% compared with the previous year, and providing consumers with a wider range of choices across vehicle segments.[5]

Governments have intensified efforts to achieve electrification targets and strengthen supply chain security. In China, the world's largest EV market, direct purchase subsidies ended in December 2022. However, the government offset this by extending the New Energy Vehicle (NEV) purchase tax exemption until 2027, with an estimated value of RMB520 billion, ensuring continued demand. In the EU, the Fit for 55 package moved forward with the EU Batteries Regulation, which entered into force in August 2023 and introduced stringent sustainability and traceability requirements. At the same time, the EU launched the *Carbon Border Adjustment Mechanism* (CBAM) in October 2023. The scheme entered a transitional phase with reporting obligations already in place and will ultimately apply carbon costs to imports.

In the US, the *Inflation Reduction Act*'s (IRA) manufacturing tax credits began to influence investment decisions from early 2023. However, following the 2025 change of administration, the legislation is under review. President Trump's second term has introduced proposals to reduce or alter EV-related incentives, creating uncertainty for

[1] Unless otherwise stated, "EVs" in this report refers specifically to battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) in the passenger car and light-duty vehicle (LDV) segments. Two- and three-wheelers, buses, and trucks are mentioned only in special cases but are not included in the core global statistics. See *Annex A* for a detailed taxonomy of EV categories by powertrain and vehicle type.

[2] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*, International Energy Agency, (Paris, 2025), https://www.iea.org/reports/global-ev-outlook-2025; Virta Ltd, *The global electric vehicle market overview in 2025*, Virta (Virta, 2025), https://www.virta.global/global-electric-vehicle-market.

[3] European Automobile Manufacturers' Association, "Economic and Market Report: Global and EU auto industry – Full year 2023," *ACEA*, March 8, 2024, https://www.acea.auto/publication/economic-and-market-report-global-and-eu-auto-industry-full-year-2023/; European Automobile Manufacturers' Association, "Economic and Market Report: Global and EU auto industry – Full year 2024," *ACEA*, March 13, 2025, https://www.acea.auto/publication/economic-and-market-report-global-and-eu-auto-industry-full-year-2024/.

[4] Virta Ltd, *The global electric vehicle market overview in 2025*.

[5] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

automakers and prompting some firms to accelerate projects to qualify under existing rules, while others scaled back or delayed EV production plans. At the same time, some state-level mandates remain in place. California's *Advanced Clean Cars II* regulation, for example, requires 100% of new car sales to be zero-emission by 2035, helping to sustain momentum despite federal reversals.

Geopolitical developments have also strongly shaped the EV supply chain. Tensions between the West and China escalated over technology and trade. In September 2023, the European Commission launched an anti-subsidy investigation into Chinese EV imports, citing concerns that Chinese state-supported manufacturers were undercutting European producers. In December 2023, China imposed export controls on graphite, a material critical for EV battery anodes and one in which it accounts for more than 90% of global supply. Exporters must now obtain permits for refined graphite products. This move, akin to earlier Chinese curbs on semiconductor metals like gallium and germanium, is widely interpreted as retaliation for Western technology restrictions and an assertion of China's leverage over battery materials. In May 2025, the Chinese government launched a nationwide campaign to crack down on the smuggling of strategic minerals, further emphasising its determination to retain control of these resources.

Elsewhere, resource nationalism also gathered pace. Indonesia, the world's largest producer of nickel, has enforced an export ban on unprocessed nickel ore since 2020 to attract downstream investment in refining and battery production. The government broadened this approach by banning bauxite exports in June 2023 and, through subsequent updates to the list of prohibited commodities, extended restrictions to additional minerals. To curb widespread artisanal extraction and smuggling, the Zimbabwean government in late 2022 prohibited the export of raw lithium ore, allowing only processed materials such as concentrates to leave the country. Namibia followed a comparable path in June 2023 by prohibiting exports of unprocessed lithium and rare earth ores in order to promote local refining. This move came after the country signed a critical minerals partnership with the EU in November 2022, illustrating how resource-rich nations are seeking greater value capture and strategic alliances.

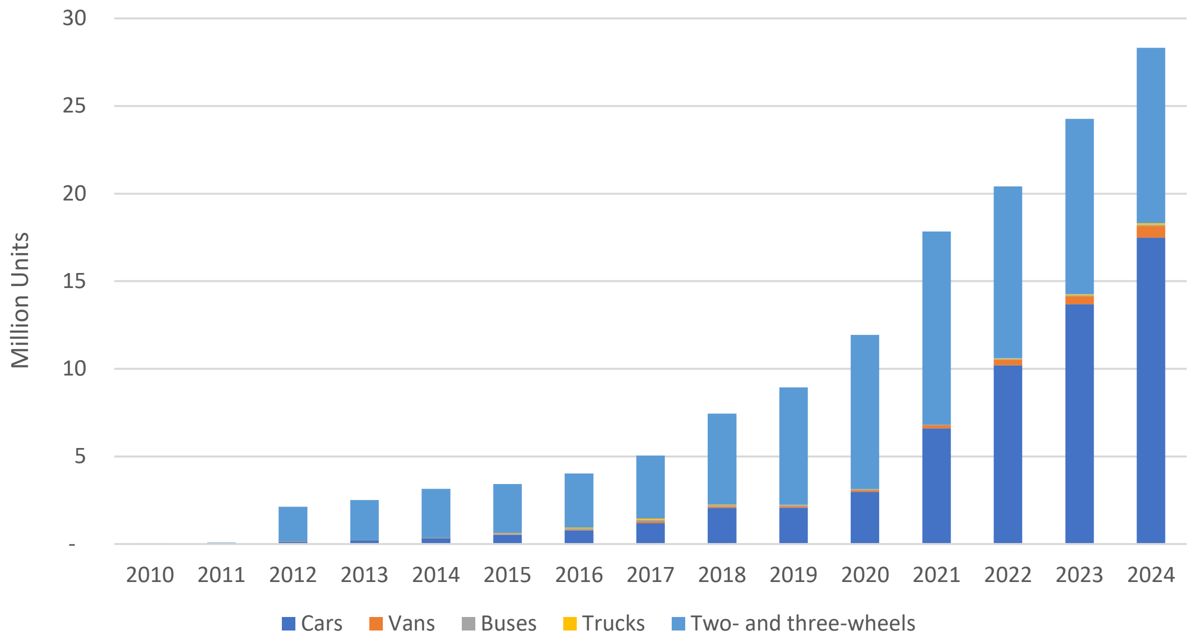
These developments underscore a defining theme of 2023-2025: the global race to establish secure, resilient, and sustainable EV supply chains. This report provides an updated overview of the EV market and examines each stage of the value chain, from raw materials to final assembly and recycling. It identifies the leading companies and emerging regional clusters and analyses the geopolitical undercurrents influencing investment and trade. Particular attention is devoted to technological innovation, including advances in battery chemistry and AI-driven manufacturing, as well as to evolving (environmental, social, governance) standards that increasingly shape industry practice through ethical sourcing requirements and carbon footprint rules. The report also offers comparative insights across regions, contrasting the strategies of China, the US, Europe, and other key markets to assess competitive positioning and policy lessons. Finally, it presents forward-looking scenarios—fragmentation, diversification, and localization—that explore how the supply chain may evolve under different global conditions. The aim is to inform business leaders and policymakers of the current landscape and emerging trends, supporting informed decision-making in this fast-changing sector.

II. An Overview of the EV Consumer Market

1. Global adoption

Electric vehicles have maintained a steep adoption trajectory. Global electric car sales rose from just over 10 million units in 2022 to about 14 million in 2023, representing around 21% of new auto sales, and exceeded 17 million in 2024, accounting for nearly 26%.[6] Momentum has continued into 2025: in the first quarter alone, more than 4 million EVs were sold worldwide, 35% higher than in the same period of 2024, putting the market on course to approach or exceed 20 million sales this year. That would be equivalent to roughly one in every four new cars.[7]

Figure 1: Global electric vehicle sales by type, 2010-2024



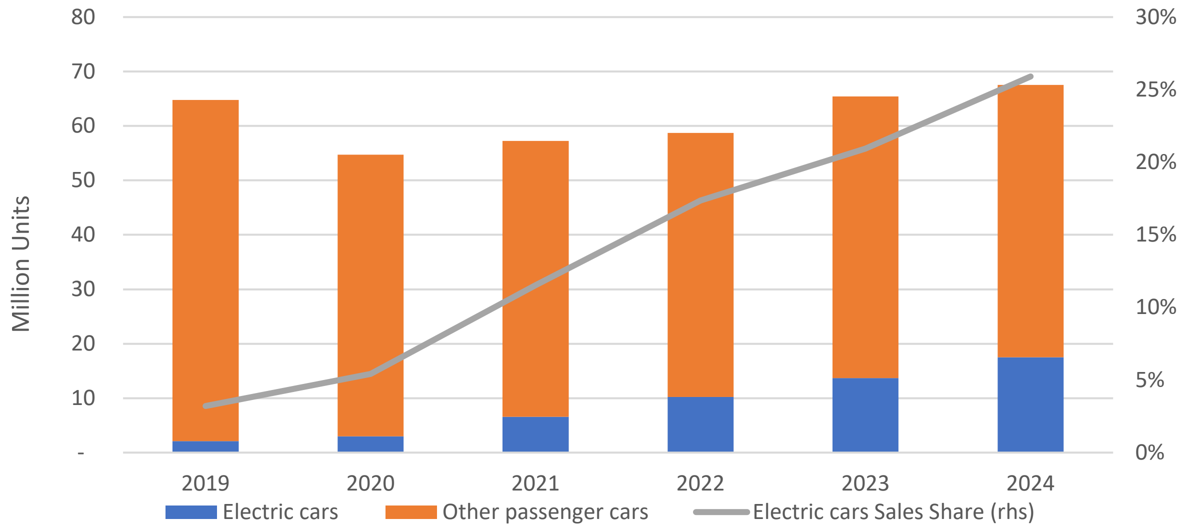
Source: IEA, compiled by HKUST Li & Fung Supply Chain Institute (LFSCI)

[6] OICA, Global Sales Statistics, International Organization of Motor Vehicle Manufacturers, 2025, accessed September 19, 2025, https://www.oica.net/category/sales-statistics/; IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[7] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

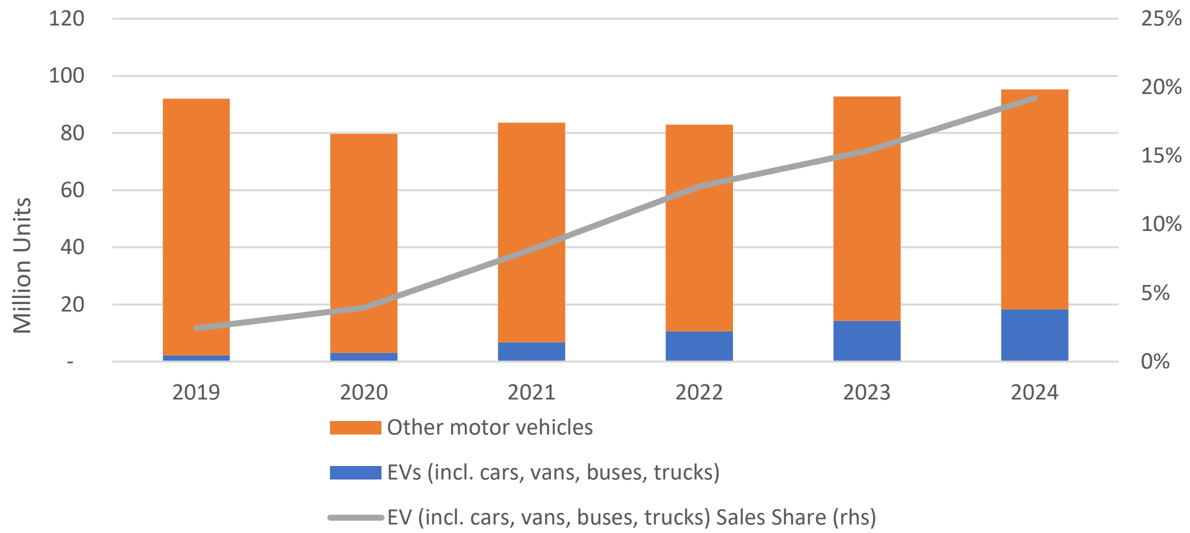
This surge has rapidly expanded the global electric car fleet. Having surpassed 40 million vehicles in 2023, the stock reached about 58 million in 2024—more than three times the total recorded in 2021. Even so, electric cars still represented only around 4% of all passenger cars in operation at the end of 2024. When considering the broader category of electrified road transport, which includes commercial vehicles such as vans, buses and trucks as well as two- and three-wheelers, the adoption rate was higher, accounting for approximately 20.4% of total vehicle sales in 2024.[8]

Figure 2: Global passenger cars sales, 2019-2024



Source: OICA and IEA, compiled by LFSCI

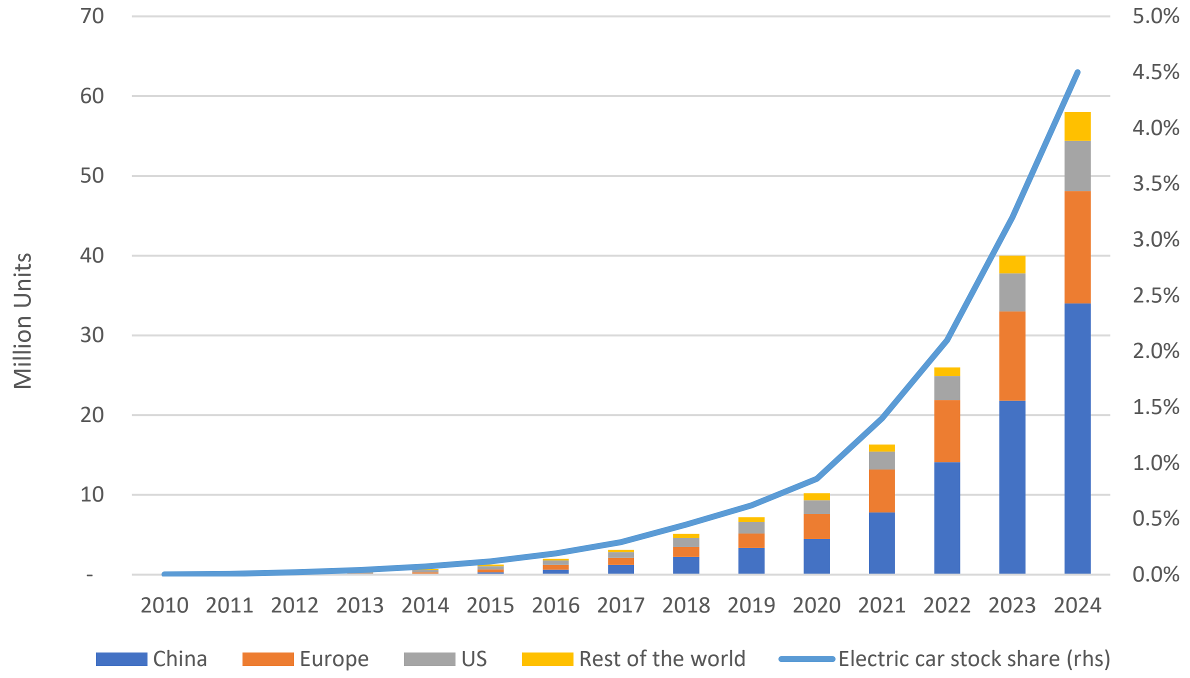
Figure 3: Global auto sales, 2019-2024



Source: OICA and IEA, compiled by LFSCI

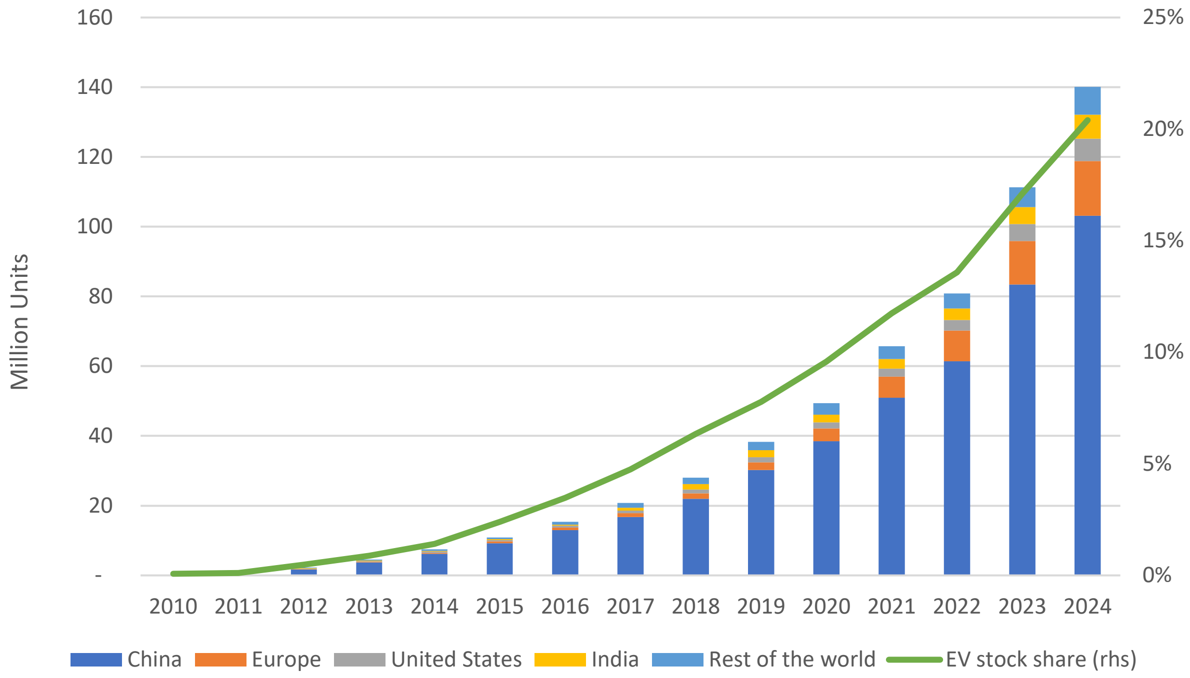
[8] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

Figure 4: Global electric car stock, 2010-2024



Source: IEA, compiled by LFSCI

Figure 5: Global EV stock, 2010-2024



Note: Including electric cars, vans, buses, trucks, two-and three-wheels.
Source: IEA, compiled by LFSCI

Battery electric vehicles (BEVs) continue to dominate the global EV market, accounting for about 67% of EV sales in 2024.[9] Their share, however, varies widely by region: BEVs represented more than 99% of EV sales in India, about 80% in the US, 68% in Europe, and 60% in China. Plug-in hybrid electric vehicles (PHEV) remain a niche segment in India but have greater traction in Europe and China. Across all markets, demand for battery-electric sport utility vehicles (SUVs) and multi-purpose vehicles (MPVs) rose strongly in 2023-2024, reflecting both automaker supply strategies and consumer preference shifts towards larger vehicle segments.[10]

A parallel surge has taken place in **charging infrastructure**, which is essential for sustaining EV growth. By 2024, the global stock of public charging points reached about 5.4 million connectors, roughly double the number in 2022. China accounted for the largest share, with around 3.58 million, followed by Europe at 1.03 million and the US at 200,000.[11] Deployment of high-power charging is accelerating. Europe had about 71,000 ultra-fast public chargers (≥150 kW) in 2024—an increase of around 50% from the previous year.[12] China, meanwhile, had more than 1.64 million public DC fast charging outlets (≥60 kW) by the end of 2024 and has set a goal of adding over 100,000 ultra-fast chargers by 2027.[13] The EU, aiming to sustain this pace, has set corridor coverage requirements equivalent to fast chargers every 60 km along key highways by the mid-2020s.[14]

[9] Ilma Fadhil and Chang Shen, "Global EV market monitor for LDV in key markets 2024," *ICCT, The International Council On Clean Transportation*, June 10, 2025, https://theicct.org/publication/global-ev-market-monitor-for-ldv-in-key-markets-2024-jun25/.

[10] Fadhil and Shen Global EV market monitor for LDV in key markets 2024; IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

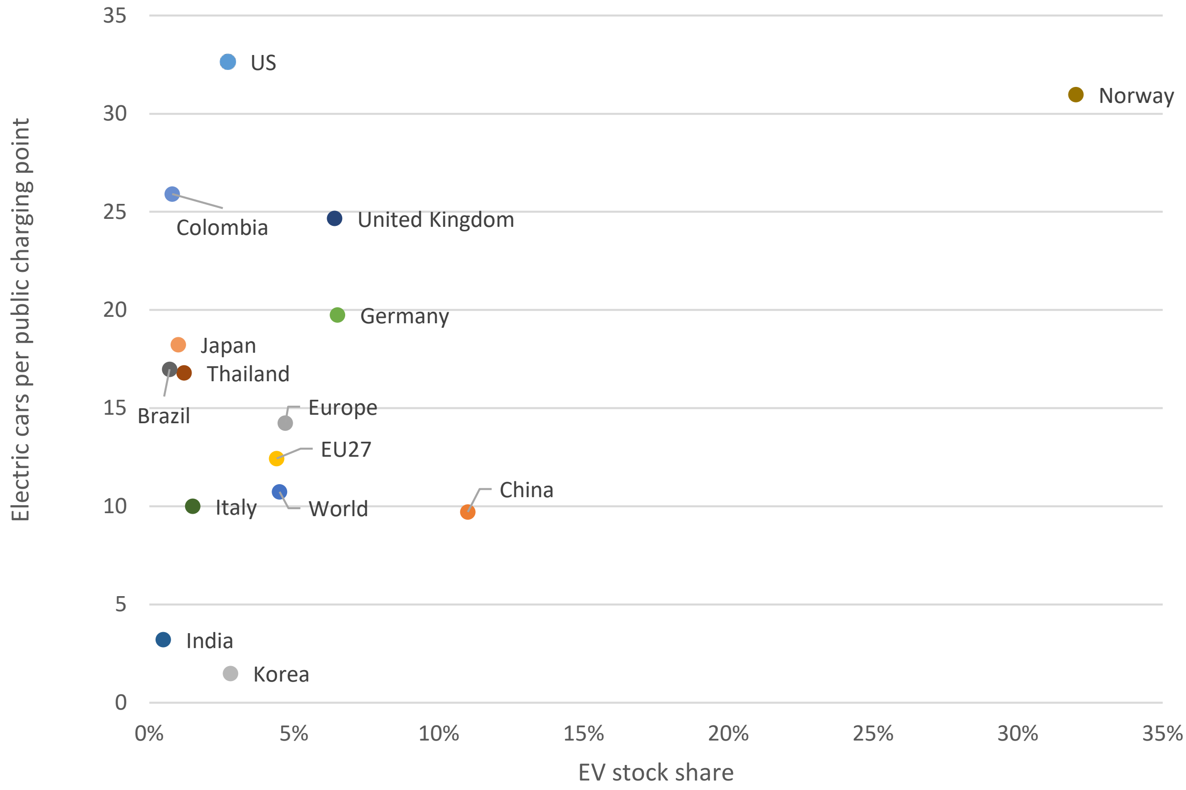
[11] IEA, *Global EV outlook 2025 — Electric vehicle charging*, International Energy Agency (Paris, 2025), https://www.iea.org/reports/global-ev-outlook-2025/electric-vehicle-charging.

[12] Virta Ltd, *The global electric vehicle market overview in 2025*.

[13] Michelle Lewis, "China overhauls EV charging: 100,000 ultra-fast public stations by 2027," *Electrek*, July 8, 2025, https://electrek.co/2025/07/08/china-overhauls-ev-charging-100000-ultra-fast-public-stations-by-2027/; EVCIPA, "2024 年全国电动汽车充换电基础设施运行情况," *China Electric Vehicle Charging Infrastructure Promotion Alliance*, January 23, 2025, https://www.evcipa.org.cn/newsinfo/8137834.html; National Development and Reform Commission of the People's Republic of China, "关于促进大功率充电设施科学规划建设的通知," in *发改办能源〔2025〕632 号*, ed. National Development and Reform Commission of the People's Republic of China (July 7, 2025 2025). https://www.ndrc.gov.cn/xwdt/tzgg/202507/t20250707_1399031.html; Xinhua, "China to promote construction of high-power charging facilities," *The State Council of the People's Republic of China*, July 7, 2025, https://english.www.gov.cn/news/202507/07/content_WS686b8b25c6d0868f4e8f3ea1.html.

[14] European Parliament, "Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure (AFIR)," in *Regulation (EU) 2023/1804* (April 14 2025). http://data.europa.eu/eli/reg/2023/1804/oj.

Figure 6: Electric cars per public charging point compared to EV stock share in selected regions, 2024



Source: IEA, compiled by LFSCI

Most charging still occurs at home or at workplaces, with private chargers outnumbering public ones globally by an estimated 10 to 1.[15] In the US and Europe, more than 80% of EV drivers have access to home charging,[16] but this option is far less common in dense Chinese and Japanese cities, where reliance on public networks is much higher.[17] This divide shapes both infrastructure demand and consumer behaviour: in markets with widespread home charging, public networks mainly need to support long-distance travel, whereas in urban markets the availability and reliability of public chargers are critical for mainstream adoption.

[15] Dominic Shales, "EV charging races ahead globally, but gaps remain," *EV Life*, July 10, 2025, https://evlife.world/news/ev-charging-races-ahead-globally-but-gaps-remain/.

[16] National Car Charging, "EV Adoption Is Surging—and Multifamily Properties Can't Afford to Wait," *National Car Charging*, April 17, 2025, https://www.nationalcarcharging.com/blog/ev-adoption-is-surgingand-multifamily-properties-cant-afford-to-wait; Javiera Altamirano, "81% of European EV users charge at home—which countries rely most on public charging?," *Mobility Portal*, September 26, 2025, https://mobilityportal.eu/ev-users-charge-home/.

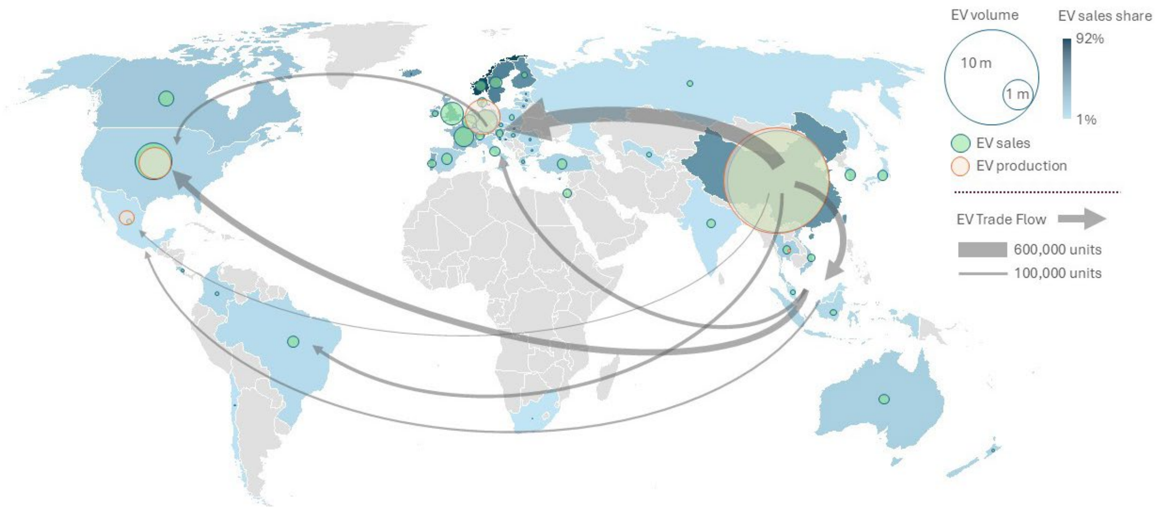
[17] ENECHANGE, "ENECHANGE launches EV Charging flat-rate subscriptionplan "ENECHANGE Passport", backed by solar power and targeting reduced EV running costs," news release, May 16, 2024, https://enechange.co.jp/en/news/press/evcharge-flatrateplan/; Suki, "EV Charging Index 2025: 99% of China EV Owners Would Stick with Electric," *ChinaEVHome*, October 30, 2025, https://chinaevhome.com/2025/10/30/ev-charging-index-2025-99-of-china-ev-owners-would-stick-with-electric/.

In emerging economies, the central challenge is not only infrastructure scale but also accessibility and trust. In India, the lack of home-charging options makes reliable public points vital for taxis, ride-hailing fleets, and early private buyers. In Southeast Asia, charging at malls, offices, and workplaces is often the first exposure for new EV users, helping to familiarize consumers with the technology. In the Middle East, highway corridors are being developed to support long-distance driving and tourism, but cheap petrol and entrenched consumer habits still limit uptake. These cases underline that charging networks are as much a social enabler of EV adoption as they are a technical backbone.

2. Regional trends

In 2024, **the majority of EV production in major markets continued to serve domestic demand.** Roughly 91% of China's NEV production was sold domestically, while the shares were 84% in Europe, 83% in the US, and as high as 99% in India. China not only remained the world's largest EV producer—accounting for about 71% of global output—but also consolidated its position as the leading exporter, with volumes far exceeding those from Europe, the US, or other markets. This dual role highlights China's dominance both as a consumer and a supplier in the global EV market.[18]

Figure 7: Global EV trade flows



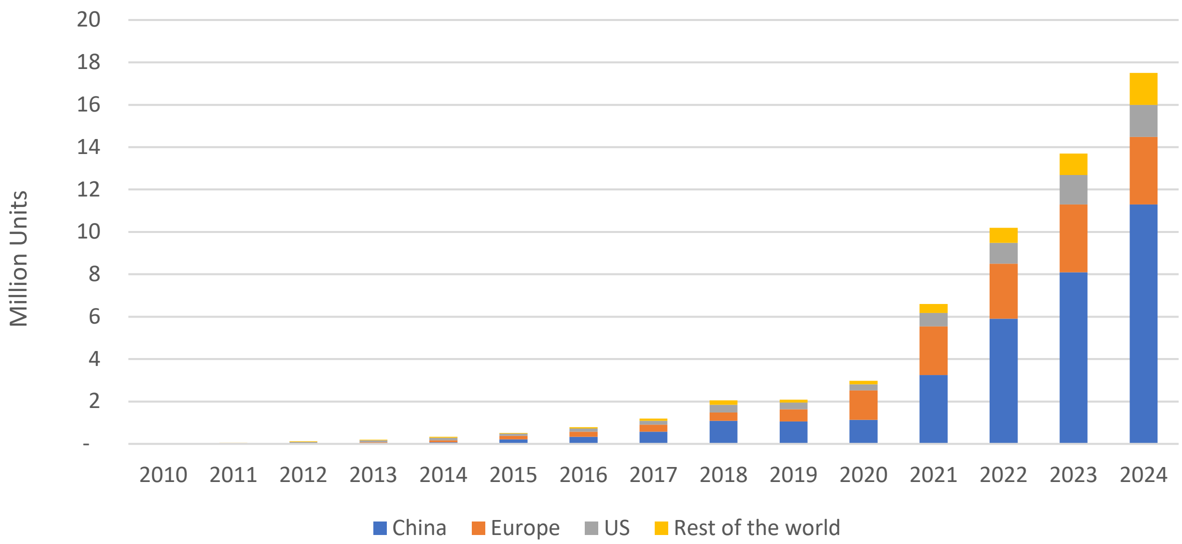
Note: 'EV sales share' here refers to the proportion of domestic BEV and PHEV passenger car sales (by units) relative to total passenger car sales.
Source: IEA, GMK, Mexico Business News, Shanghai Metal Market, compiled by LFSCI

[18] Ilma Fadhil and 申畅, "2024 年主流电动汽车市场情况追踪," *ICCT China*, *国际清洁交通委员会*, June 10, 2025, https://www.theicct.org.cn/2025/06/10/global-ev-market-monitor-for-ldv-in-key-markets-2024.

China remained as an undisputed leader in EV production and sales in 2024. Nearly 60% of all EVs worldwide were on Chinese roads by year-end, amounting to around 36 million vehicles.[19] According to official industry statistics, China produced 12.89 million NEVs[20] in 2024, representing 41.2% of total automobile production, while domestic NEV sales reached 12.87 million units (40.9% of total auto sales).[21] This accounted for roughly 70% of global EV sales.[22] Using the narrower IEA definition of passenger electric cars, China sold around 11.3 million units, equivalent to about 64.6% of global EV sales.[23]

This dominance reflects the strength of domestic brands, long-standing state support, and consumer enthusiasm for technologically advanced vehicles. Notably, Chinese manufacturers have prioritized affordability and adopted lithium iron phosphate (LFP) battery technology at scale. By the end of 2024, almost 75% of EVs produced in China were equipped with LFP batteries,[24] marking a decisive shift towards cost-effective chemistries that avoid the use of cobalt and nickel.

Figure 8: Global EV sales by region, 2010-2024



Source: IEA, compiled by LFSCI

[19] According to the dataset accompanying the IEA's *Global EV Outlook 2025*, global stock of BEVs, PHEVs, and FCEVs — covering cars, vans, buses, and trucks — reached 61.2 million units in 2024.

[20] In Chinese industry statistics, "New Energy Vehicles (NEVs)" include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs, including extended-range EVs/EREVs), and fuel cell electric vehicles (FCEVs). The category covers both passenger and commercial vehicles, but excludes two-wheelers.

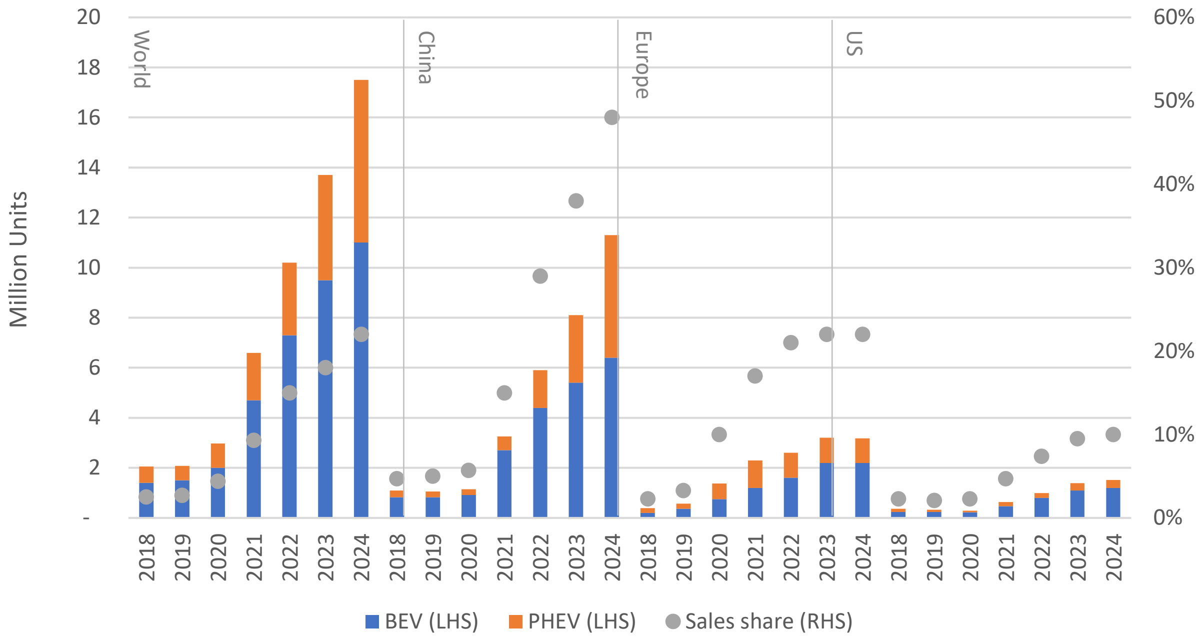
[21] 新华社, "2024 年我国新能源汽车产销量均超 1200 万辆," January 13, 2025, https://www.gov.cn/yaowen/liebiao/202501/content_6998270.htm.

[22] According to the dataset accompanying the IEA's *Global EV Outlook 2025*, global sales of BEVs, PHEVs, and FCEVs—covering cars, vans, buses, and trucks—reached 18.3 million units in 2024.

[23] According to the dataset accompanying the IEA's *Global EV Outlook 2025*, global sales of battery electric cars (BEVs) and plug-in hybrid cars (PHEVs) reached 17.5 million units in 2024.

[24] 刘家殷, "中国汽车动力电池产业创新联盟：2024 年我国动力和其他电池累计产量为 1096.8GWh 累计同比增长 41.0%," *中国能源产业发展网*, January 13, 2025, https://www.ccedia.com/storage_detail/12532.html.

Figure 9: EV sales by region, 2018-2024



Source: IEA, compiled by LFSCI

Europe collectively remains the world's second-largest EV market. Sales plateaued in 2024 at around a 22% market share, broadly similar to 2023. The slowdown in growth reflected, in part, the withdrawal of purchase incentives in key markets, most notably Germany. Even so, Europe registered more than 3.2 million EVs in 2024 (about 18% of global sales) and continues to exhibit very high penetration in some countries—for example, about 92% of new cars in Norway were electric in 2024, with Sweden close behind at around 58%. By contrast, markets such as Italy and much of Eastern Europe remained in the single digits.[25]

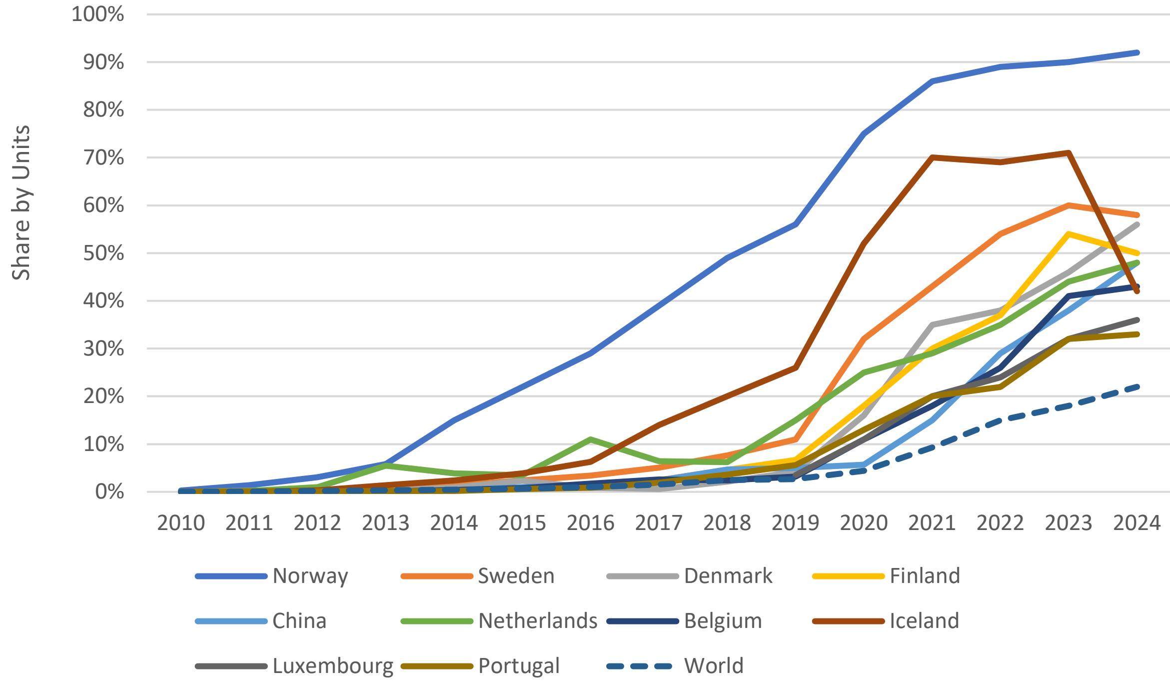
Looking ahead, Europe's regulatory framework—including binding CO_2 emissions standards and the legislated 2035 phase-out of new internal combustion engine (ICE) car sales—is expected to trigger a new wave of adoption. Projections indicate that Europe's EV share could rise to around 25% in 2025 and approach 60% by 2030.[26] Infrastructure deployment is also advancing rapidly: the stock of public charging points exceeded 1 million in 2024, a year-on-year increase of 35%, which has helped bolster consumer confidence. Germany, France, and the UK remain the continent's largest EV markets in absolute terms, though smaller countries are now catching up in percentage growth.[27]

[25] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[26] European Parliament, "EU ban on the sale of new petrol and diesel cars from 2035 explained," November 3, 2022, https://www.europarl.europa.eu/topics/en/article/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained.

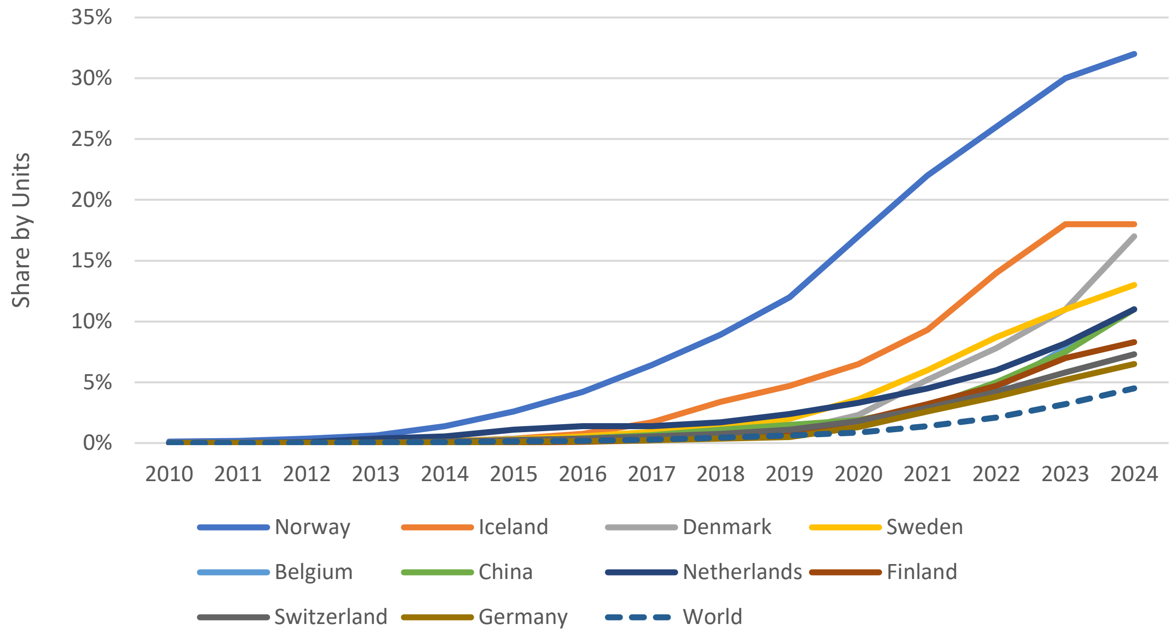
[27] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

Figure 10: Top 10 countries in EV sales share in 2024



Source: IEA, compiled by LFSCI

Figure 11: Top 10 countries in EV stock share in 2024



Source: IEA, compiled by LFSCI

In the **US**, EV adoption has accelerated but still trails Europe and China in percentage terms. In 2024, more than 1.5 million electric cars were sold in the US, representing about 8.7% of global EV sales and lifting the domestic market share to around 10% of new light-duty vehicle sales.[28] By the end of the year, the national electric car fleet had surpassed 6.3 million vehicles, equivalent to roughly 6.5% of the country's total passenger vehicle stock.[29]

The market remains highly uneven. California recorded EV (or zero-emission vehicle, ZEV) sales shares of around 25% in 2023, and accounted for about 35% of the nation's cumulative light-duty EV registrations, followed by Florida at about 7%.[30] In Q1 2025, California (23.7%) and the District of Columbia (20.6%) led the country in EV registrations, while several other coastal or progressive states reported double-digit shares. By contrast, much of the interior continues to see only single-digit adoption.[31]

The IRA, enacted in 2022, introduced clean-vehicle tax credits of up to US$7,500 from January 2023, contingent on final assembly in North America and compliant battery sourcing. This policy clearly advantaged US brands such as Tesla, GM, and Ford, while disadvantaging Korean and European imports until local production ramps up. American consumers have shown strong demand for Tesla's vehicles, which accounted for about 55% of US EV sales in 2023 before easing to just under 50% in 2024. Domestic models also gained traction—for example, Ford's F-150 Lightning and Mustang Mach-E recorded significant year-on-year growth in 2024.

Nevertheless, affordability and charging infrastructure remain challenges, particularly in the US heartland. Due to the strong policy push and new model launches, US EV sales grew by over 40% yoy in 2023. Growth slowed sharply to about 9% yoy in 2024, largely because of the phase-out of federal and state purchase incentives, higher interest rates that raised financing costs, and lingering consumer concerns about charging availability.[32] However, with domestic EV manufacturing continuing to expand and several more affordable models in the pipeline, medium-term prospects for EV adoption remain positive. Yet, recent policy reversals under the Trump administration—including pauses to IRA funding and weaker regulatory standards—have introduced uncertainty that could slow the pace of uptake in the

[28] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[29] The 6.5% estimate is based on combining IEA's stock data for electric cars with US Federal Highway Administration statistics on vehicles in use. According to the FHWA, there were 96.9 million automobiles registered in 2023. (FHWA, "State Motor-Vehicle Registrations - 2023," Highway Statistics Series, Federal Highway Administration, updated November, 2024, https://www.fhwa.dot.gov/policyinformation/statistics/2023/mv1.cfm; IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.)

[30] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy,, "Electric Vehicle Registrations by State (as of December 31, 2023)," (Alternative Fuels Data Center, 2024). https://afdc.energy.gov/data/10962.

[31] Alliance for Automotive Innovation, "Alliance for Automotive Innovation Reports New U.S. Electric Vehicle Data," news release, June 24, 2025, https://www.autosinnovate.org/posts/press-release/2025-q1-get-connected-press-release.

[32] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

near term. Under current policy settings, the IEA projects the US EV share to reach around 11% of new car sales in 2025.[33]

As fourth-largest automotive market, **Japan** has historically moved slowly towards BEVs, favouring hybrids instead. Hybrid electric vehicles have shown steady growth, rising from 21.7% of new passenger car sales in 2019 to 35.6% in 2024, largely dominated by domestic brands such as Toyota and Honda. By contrast, BEV adoption remains limited: at its peak in 2023, BEVs accounted for just 2.2% of new sales, before slipping to 1.6% in 2024 (compared with only 0.5% in 2019). The number of BEV models available has expanded substantially, from just 10 models in 2019 to 61 by 2025, yet only 10 were from Japanese automakers while the remaining 51 models were imports, underscoring the stark contrast with the hybrid segment where Japanese firms remain dominant.[34] The government's fiscal year 2035 target requires all new passenger cars to be 'electrified'—a category that includes BEVs, PHEVs, HEVs, and FCEVs. By adopting this broad categorization, policymakers have effectively allowed hybrids to remain at the centre of Japan's decarbonization strategy, reinforcing their market dominance even as BEVs gain traction elsewhere.

South Korea's EV adoption has shown mixed momentum. After strong growth earlier in the decade, EV sales in 2024 fell by nearly 4% yoy, with about 99,000 units sold and a market share of just 6.1%. This slowdown reflected the phase-down of subsidies, uneven charging infrastructure, and broader weakness in the national car market. While Hyundai and Kia remain central to the domestic EV industry, their EV sales performance in 2024 was muted. By contrast, Tesla strengthened its position, leading among imported EVs and gaining share at the expense of some local brands.[35] Early data for 2025 points to a recovery, with EVs approaching 10% of new sales by mid-year, supported by new model launches such as Kia's EV3 and price-competitive strategies.[36]

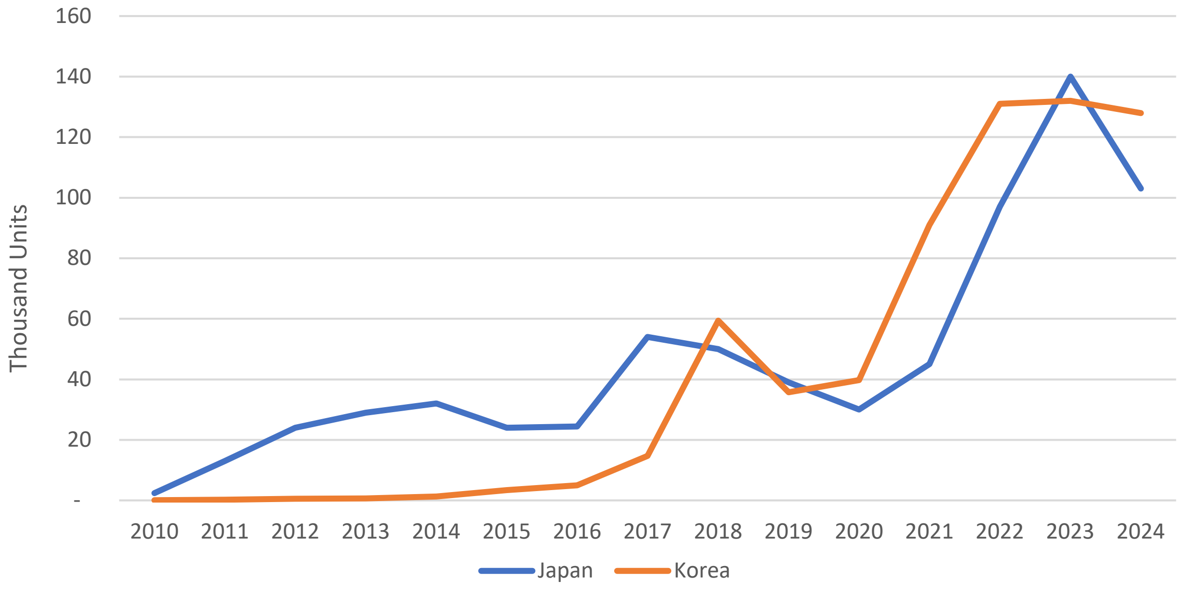
[33] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[34] GlobalData, "Japan's vehicle market: current BEV sales trends," *JustAuto*, October 21, 2024, https://www.just-auto.com/analyst-comment/japans-vehicle-market-current-bev-sales-trends/.

[35] Focus2move, "South Korea 2024. EV Market, Led By Tesla, Outpaces Broader Downturn," *Focus2move*, January 18, 2025, https://www.focus2move.com/korean-vehicles-market-2024-2.

[36] Yukie Tomoshige, "Japan's Automotive Electrification Trends (2025 H1)," *JATO*, September 19, 2025, https://www.jato.com/resources/news-and-insights/japans-automotive-electrification-trends-2025-h1.

Figure 12: EV sales in Japan and South Korea, 2010-2024



Source: IEA, compiled by LFSCI

Emerging markets such as **India, Thailand, Vietnam, and Brazil** are beginning to scale up adoption. In **India**, EV penetration in passenger cars remains modest, with EVs (BEV + PHEV) reaching about 2% of new sales in 2024. By contrast, adoption has been far stronger in two- and three-wheelers: in 2024, India sold 7.2 million electric two- and three-wheelers, ranking second globally after China (9.7 million).[37] Within this segment, India has become the world's largest market for electric three-wheelers, with sales surpassing 580,000 units in 2023 and rising by nearly 20% yoy in 2024 to around 700,000 units.[38] Policy incentives have been central to this growth. The government's *Faster Adoption and Manufacturing of Electric Vehicles* (FAME II) programme, launched in 2019, ran until March 2024, supporting millions of two- and three-wheeler sales. It was followed by the *Electric Mobility Promotion Scheme* (EMPS-2024), a four-month bridge programme that continued incentives for two- and three-wheelers, before being superseded by the broader PM E-DRIVE scheme in October 2024. Together with the *Production-Linked Incentive* (PLI) scheme for advanced batteries and automotive manufacturing, these measures have underpinned EV adoption despite affordability and infrastructure challenges. Looking ahead, India has set a national target of achieving 30% EV penetration across total vehicle sales by 2030, a definition that covers passenger cars as well as two- and three-wheelers, buses, and trucks.

[37] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[38] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*; IEA, *Global EV Outlook 2024: Moving towards increased affordability*, International Energy Agency (Paris, April 23 2024), https://www.iea.org/reports/global-ev-outlook-2024.

In **Southeast Asia**, EV adoption accelerated sharply even as the overall automotive market contracted. Light-vehicle sales across the ASEAN-6 declined by about 5.4% yoy in 2024, yet electric passenger-car sales still grew by nearly 56% yoy, raising EVs' share to around 13% of new passenger-car sales in the region.[39]

Thailand remained a strong performer with around 71,000 passenger-EV sales in 2024, down from 77,000 units in 2023, yet EVs still accounted for 13% of the total car sales, compared with 11% in 2023.[40] The Thai market continues to benefit from purchase incentives and large-scale investment by Chinese automakers such as BYD, Neta, and Great Wall Motors.[41]

Vietnam has rapidly emerged as a new regional leader in electric-vehicle adoption. Total passenger-EV sales reached approximately 69,000 units in 2024, up from 32,000 in 2023, lifting their share of total car sales from 10% to 17%.[42] This acceleration reflects both the expansion of VinFast as a national brand and the government's policy support for electrification and localization through reduced registration fees, lower special-consumption tax rates, and preferential credit facilities for EV projects.

Indonesia and **Malaysia** also recorded robust growth, with EV sales tripling in 2024; yet, penetration remains below Thailand's, at around 7% and 4% of new-car sales respectively.[43] Indonesia's momentum has been underpinned by the government's *EV Ecosystem Roadmap 2023-2035*, which offers luxury-tax cuts, import-duty exemptions on batteries and components, and value-added-tax (VAT) reductions of up to 10 percentage points for domestically produced electric vehicles.[44] Malaysia's progress has been supported by tax exemptions and its *Low Carbon Mobility Blueprint* (LCMB), aimed at raising EVs' share of total industry volume (TIV) to 15% by 2030 and 80% by 2050.[45] The **Philippines** saw an increase from near zero to around 3,000 EV and HEV units sold in 2024, supported by fiscal incentives and zero-tariff imports under the *Electric Vehicle Industry Development Act* (EVIDA).[46]

[39] PwC Vietnam, *ASEAN automotive market 2025: Key trends and outlook*, PwC (February 2025), https://www.pwc.com/vn/en/publications/2025/asean-automative-market.pdf.

[40] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[41] Kajornkiat Kiatsunthorn, "How Chinese Automakers are Taking the Thai Automotive Market by Storm," *Kadence*, 2024, https://kadence.com/en-us/knowledge/how-chinese-automakers-are-taking-the-thai-automotive-market-by-storm/.

[42] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[43] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[44] Adli Azayaka Huda, Richard Bridle, and Anissa Suharsono, "Indonesian Electric Vehicle Boom: A temporary trend or a long-term vision?," *International Institute for Sustainability Development*, February 7, 2025, https://www.iisd.org/articles/deep-dive/indonesian-electric-vehicle-boom-temporary-trend-or-long-term-vision.

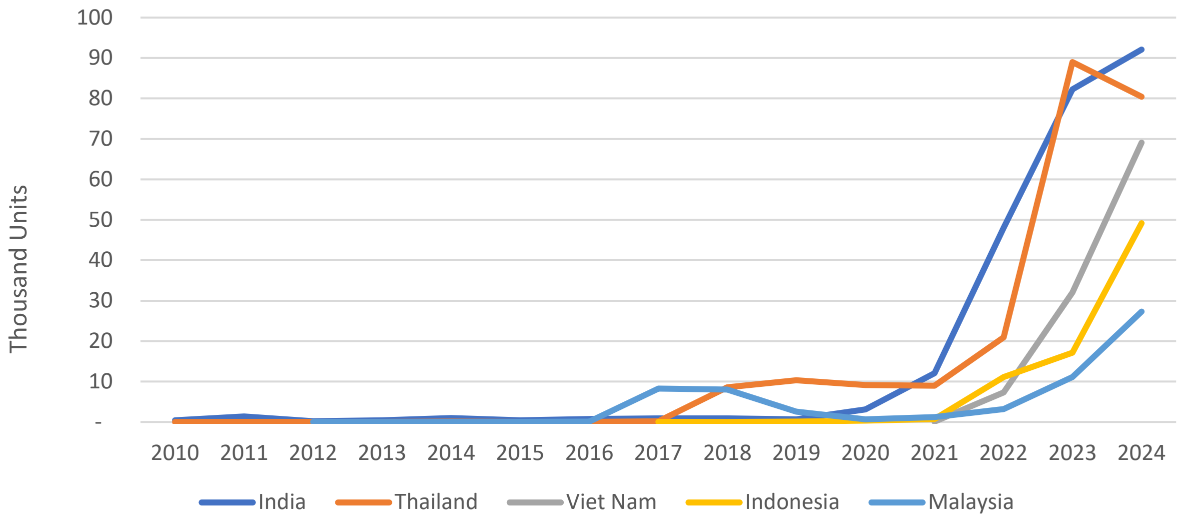
[45] MIDA, "Malaysia on track for EV revolution," *Malaysian Investment Development Authority (MIDA)*, April 29, 2024, https://www.mida.gov.my/mida-news/malaysia-on-track-for-ev-revolution/.

[46] PwC Vietnam, *ASEAN automotive market 2025: Key trends and outlook*; Raymond Tribdino, "Philippine EV Market Continues to Accelerate, Says Local EV Experts," *Clean Technica*, October 20, 2025, https://cleantechnica.com/2025/10/20/philippine-ev-market-continues-to-accelerate-says-local-ev-experts/.

Singapore, by contrast, remains a small market in absolute terms but continues to enforce one of the region's most stringent policy frameworks: high internal-combustion-engine taxes, Certificate of Entitlement (COE) quotas, and the Land Transport Authority's target of 60,000 public charging points by 2030 together create strong policy momentum despite limited scale.

Despite these advances, several challenges persist. Charging infrastructure deployment remains uneven across the region, with dense urban coverage but limited availability in secondary cities and along intercity corridors. High upfront purchase costs—particularly for imported models—continue to constrain mass-market adoption, even where fiscal incentives are in place. Nevertheless, consumer sentiment is shifting rapidly: surveys show that around 29% of consumers in Indonesia and Malaysia, and 24% in Thailand, express a preference for EV—markedly higher than the global average of 18%.[47] This suggests substantial latent demand that could be unlocked through improved affordability, wider model availability, and accelerated charging-network expansion.

Figure 13: EV sales in selected emerging markets in Asia, 2010-2024



Source: IEA, compiled by LFSCI

The EV market in **Latin America** is expanding rapidly from a low base. By the end of 2024, the EV fleet in Latin America and the Caribbean reached about 444,000 units, up nearly 187% from 2023. In **Brazil**—the region's largest auto market—EV sales more than doubled in 2024 to approximately 125,000 units**,** achieving a new-car sales share of about 6.4%. Other countries also saw sizable growth: **Costa Rica** reached 15% EV share of new car sales, **Uruguay** 13%, and **Colombia** 7.5%. While Brazil leads in absolute volume, smaller countries are pushing high penetration rates thanks to incentives and rising availability of models. Still,

[47] David Zhang and Aiste Kriauciunaite, "Four key consumer insights shaping Southeast Asia's electric vehicle market," *Euromonitor International*, July 31, 2024, https://www.euromonitor.com/article/four-key-consumer-insights-shaping-southeast-asias-electric-vehicle-market.

high upfront costs, charging infrastructure gaps, and modest model variety outside major cities remain key barriers.

Figure 14: EV sales in selected emerging markets in Latin America, 2010-2024

Source: IEA, compiled by LFSCI

EV adoption in the **Middle East** remains limited overall, but momentum is beginning to build in a few markets. **United Arab Emirates (UAE)** has emerged as a regional leader, with EVs accounting for around 3% of new car sales in 2024, supported by zero import duties, registration fee exemptions, and investment in charging corridors. Dubai aims for 25% of all transport to be autonomous and 50% of its fleet powered by clean energy by 2050. **Saudi Arabia**, though with only 0.1% of EV sales penetration in 2024, has placed EVs at the centre of its *Vision 2030* industrial diversification strategy: the Public Investment Fund (PIF) holds a majority stake in Lucid Motors, which began assembling EVs at its new Jeddah plant in 2023, while the domestic brand Ceer (a joint venture with Foxconn) is preparing to launch its first models by 2025. Both Saudi Arabia and the UAE are rolling out nationwide charging networks, though coverage remains uneven outside major cities. Other Gulf states, including **Qatar** and **Oman**, have announced pilot EV fleets and charging corridor projects, but adoption volumes remain very small. Across most of the region, fuel subsidies, limited charging infrastructure, and a strong consumer preference for large ICE vehicles continue to restrain uptake, keeping EV penetration well below 1% in many markets.[48]

[48] Abdul Latif Jameel, "Are EVs winning the race in the Middle East?," *Abdul Latif Jameel*, 2024, https://alj.com/en/perspective/are-evs-winning-the-race-in-the-middle-east/.

3. Leading brands and models

The global EV market in 2024 was led by a handful of large players, with Chinese and US firms at the forefront, while European, Korean, Japanese, and new entrants scaled up but remained behind the leaders.

BYD consolidated its lead as the world's largest EV manufacturer when counting both BEVs and PHEVs. In 2024 it sold 4.27 million NEVs, including about 1.76 million BEVs and the remainder PHEVs, up 41% yoy.[49] This gave BYD an 18% share of global EV sales**,** surpassing Tesla in combined volumes but just trailing in BEVs alone.[50] Its diverse lineup—from entry-level Seagull to premium Han sedan—underpinned this success. Exports surged to 242,765 units in 2023 and grew further to 417,204 units in 2024, with Europe, Southeast Asia, and Latin America as key destinations.[51] Bestsellers included the Song Plus DM-i and Qin Plus DM-i (PHEVs) and the Dolphin and Seagull (BEVs). BYD overtook Volkswagen as the top-selling brand (all fuel types) in China in 2023, marking a structural shift in the world's largest car market.[52]

Tesla remained the world's largest pure BEV maker in 2024, delivering 1.79 million BEVs, down about 1% from 2023's record 1.81 million.[53] The Model Y was again the world's best-selling vehicle of any powertrain, with 1.09 million units sold globally in 2024.[54] Tesla's global BEV market share slipped to around 19% in 2023, from 20% in 2021, as BYD and Chinese startups gained ground.[55] Manufacturing footprint expanded with Gigafactory Berlin scaling up for Europe and a new Gigafactory announced in Mexico. Production of the Cybertruck began in late 2023, with volume deliveries throughout 2024, and Tesla previewed a next-generation platform designed for mass-market affordable EVs.[56]

Volkswagen Group remained the top European legacy automaker in EV volumes but faced headwinds. It sold 744,800 BEVs in 2024, a 3.4% decline from 771,100 in 2023, equivalent to 7% of global BEV sales. Europe remained its main EV market, with China contributing around

[49] Tridens, "BYD Sales by Model and Country Statistics (Feb 2025)," *Tridens Technology*, February, 2025, https://tridenstechnology.com/byd-sales-statistics/.

[50] Gloria Li, "China's electric-vehicle leader BYD posts record sales in 2024," *Financial Times*, January 2, 2025, https://www.ft.com/content/b9797e5a-1346-4779-9125-686932c9d8ec.

[51] Reuters, "BYD aims to double overseas sales to 800,000 in 2025, chairman tells analysts," *Reuters*, March 27 2025, https://www.reuters.com/business/autos-transportation/byd-aims-double-overseas-sales-800000-2025-chairman-tells-analysts-2025-03-26/; BYD, "BYD concludes 2023 with record 3 million annual sales, leading global NEV market," news release, 2024, https://en.byd.com/news/byd-concludes-2023-with-record-3-million-annual-sales-leading-global-nev-market/.

[52] Jennifer Mossalgue, "BYD overtakes VW's 15-year-run as top seller in China," *Electrek*, January 23, 2024, https://electrek.co/2024/01/23/byd-overtakes-vws-15-year-run-as-top-seller-in-china.

[53] Tom Krisher and Bernard Condon, "Tesla sales dropped 1.1% in 2024, its first annual decline in a dozen years," *AP*, January 3, 2025, https://apnews.com/article/tesla-sales-2024-drop-electric-vehicles-69af17c4e606625694af8293db25b2f3.

[54] Statista, "Best-selling passenger car worldwide in 2024," *Statista*, November 19, 2025, https://www.statista.com/statistics/239229/most-sold-car-models-worldwide/.

[55] Florian Zandt, "Tesla and BYD Claim a Third of the Global BEV Market," *Statista*, 2025, https://www.statista.com/chart/27733/battery-electric-vehicles-manufacturers/.

[56] Tesla Inc., *2023 Impact Report* (2024), https://www.tesla.com/ns_videos/2024-tesla-impact-report.pdf.

191,800 BEVs (+1.6% yoy), reflecting weak momentum against Chinese rivals.[57] Flagship models included the VW ID.4, ID.3, and Audi Q4 e-tron. VW is accelerating its EV rollout, with the €25k ID.2all slated for 2025 to defend its European market share.

Legacy manufacturers showed uneven progress in 2024. **BMW** increased BEV deliveries to over 420,000, but **Mercedes-Benz** saw a double-digit decline, signalling difficulties in sustaining momentum amid growing Chinese competition.[58] **Hyundai-Kia** strengthened its position in the US, becoming the second-largest EV seller after Tesla, though its global EV volumes remain modest.[59] In the US, **Ford** and **GM** expanded electrified sales, but volumes were still a fraction of Tesla's.[60] **Toyota** lifted BEV sales by a third to around 140,000 units, yet EVs remained under 2% of its global portfolio, underscoring its continued reliance on hybrids.[61] Collectively, these firms account for important regional market shares, but none exceeded 5% of the global BEV market in 2024. Their transition remains gradual, reflecting both strategic caution and structural challenges compared with EV-focused competitors.

New entrants, particularly from China, accelerated strongly in 2024, reshaping the global competitive landscape. **Li Auto** became the first Chinese startup to surpass half a million annual sales, while **Nio** and **XPeng** each grew by more than a third, consolidating their positions in China's premium EV segment.[62] **Geely's Zeekr** nearly doubled its deliveries, reinforcing the group's rapid electrification pivot.[63] Beyond China, **Vietnam's VinFast** almost

[57] Henk Bekker, "2024 (Full Year) Global: Volkswagen Group Electric Car Sales Worldwide by Brand and Model," *BestSellingCars*, 2025, https://www.best-selling-cars.com/brands/2024-full-year-global-volkswagen-group-electric-car-sales-worldwide-by-brand-and-model; Christoph Oemisch, "Volkswagen Group with 9 million deliveries after strong fourth quarter," *Volkswagen Group - Press Release*, *Volkswagen Group*, January 14, 2025, https://www.volkswagen-group.com/en/press-releases/volkswagen-group-with-9-million-deliveries-after-strong-fourth-quarter-18965; Christoph Oemisch, "Volkswagen Group posts solid growth in deliveries in 2023 and strong increase in all-electric vehicles," *Volkswagen Group - Press Release*, *Volkswagen Group*, January 12, 2024, https://www.volkswagen-group.com/en/press-releases/volkswagen-group-posts-solid-growth-in-deliveries-in-2023-and-strong-increase-in-all-electric-vehicles-18057.

[58] Reuters, "Mercedes-Benz 2024 car sales fall in tough year for automakers," *Reuters*, January 10, 2025, https://www.reuters.com/business/autos-transportation/mercedes-benz-2024-car-sales-fall-tough-year-automakers-2025-01-10; Henk Bekker, "2024 (Full Year) Global: BMW and Mini Worldwide Car Sales," *BestSellingCars*, January 10, 2025, https://www.best-selling-cars.com/brands/2024-full-year-global-bmw-and-mini-worldwide-car-sales/.

[59] Bill Pierce, "Hyundai Motor Group Wins Number Two EV Seller Spot in America for 2024," *EVinfo*, January, 2025, https://evinfo.net/2025/01/hyundai-motor-group-wins-number-two-ev-seller-spot-in-america-for-2024.

[60] Michael Phoon, "GM Powers Ahead: 50% Jump In EV Sales Reaches New Milestones In 2024," 2025, https://ev.com/news/gm-powers-ahead-50-jump-in-ev-sales-reaches-new-milestones-in-2024; Umar Shakir, "Ford is extending its free at-home EV charging promotion," *The Verge*, January 4, 2025, https://www.theverge.com/2025/1/3/24335123/ford-power-promise-2025-free-ev-charger-extension.

[61] Reuters, "Toyota to boost EV models to 15, targets producing 1 million by 2027, Nikkei says," *Reuters*, April 7, 2025, https://www.reuters.com/business/autos-transportation/toyota-boost-ev-models-15-targets-producing-1-million-by-2027-nikkei-says-2025-04-06.

[62] Jiri Opletal, "China EV global sales in Dec: Xpeng 36,695, Huawei 49,474, Geely 116,206, BYD 509,440," *CarNewsChina*, 2025, https://carnewschina.com/2025/01/01/china-ev-global-sales-in-dec-xpeng-36695-huawei-49474-geely-116206-byd-509440/; James Rogers, "Chinese EV makers BYD, Nio, Li and XPeng end 2024 on a sales high," *MarketWatch*, January 2 2025, https://www.marketwatch.com/story/chinese-ev-makers-byd-nio-li-and-xpeng-end-2024-on-a-sales-high-0299997a.

[63] Opletal China EV global sales in Dec: Xpeng 36,695, Huawei 49,474, Geely 116,206, BYD 509,440.

tripled sales to nearly 100,000 units, though its overseas expansion remained limited,[64] while **Türkiye's Togg** scaled domestic deliveries in 2024 and is expanding into Europe from 2025.[65] These players benefit from aggressive pricing, fast product cycles, and strong home-market policy support. Their expansion into Europe, North America, and emerging markets suggests that by the mid-2020s, competition will no longer be defined solely by Tesla and BYD, but by a crowded field of challengers increasingly capable of eroding legacy incumbents' market share.

4. Consumer preferences

Consumers in 2023-25 show rising willingness to adopt EVs, driven by improved range, lower running costs, expanding charging networks, and heightened awareness. Surveys consistently highlight **driving range, purchase price, and charging convenience** as the leading factors influencing EV purchase decisions.[66]

Technological progress has alleviated some barriers. The average driving range of new EVs in 2025 is around 350-400 km, with many premium models achieving higher figures—roughly double the typical 200 km range of EVs five years earlier.[67] Infrastructure is also expanding: global public charging points increased by over 30% yoy in 2024, with the EU network growing by more than 35% yoy.[68] China alone added over 4.2 million charging posts in 2024, bringing its total to 12.8 million by year-end.[69] Fast-charging capability is spreading, with many new EVs supporting 100 kW+ charging, though only a subset can consistently recharge to 80% in under 30 minutes.[70]

Consumer tastes in vehicle type are also shifting. Crossovers and SUVs dominate EV sales globally, mirroring ICE market trends, with models like the Tesla Model Y, BYD Song, and VW ID.4 leading demand. In China, mini-EVs such as the Wuling Hongguang Mini remain highly popular for urban commuting, especially in smaller cities where their affordability and

[64] VinFast, "VinFast Announces 4Q24 Global Deliveries, January 2025 Domestic Deliveries, 2025 Guidance and Sets Date for the Release of Full Year 2024 Results," news release, 2015, https://vinfastauto.us/investor-relations/news/vinfast-announces-4q24-global-deliveries-january-2025-domestic-deliveries; Reuters, "VinFast speeds up EV deliveries, struggles to sell outside Vietnam," *Reuters*, February 13, 2025, https://www.reuters.com/business/autos-transportation/vinfast-speeds-up-ev-deliveries-struggles-sell-outside-vietnam-2025-02-13.

[65] Reuters, "Turkish EV maker Togg launches sedan in Germany in bid for sales, profit," *Reuters*, September 8, 2025, https://www.reuters.com/business/retail-consumer/turkish-ev-maker-togg-launches-sedan-germany-bid-sales-profit-2025-09-08.

[66] Patrick Hertzke et al., "New twists in the electric-vehicle transition: A consumer perspective," *McKinsey & Company*, *McKinsey Center for Future Mobility*, 2025, https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/new-twists-in-the-electric-vehicle-transition-a-consumer-perspective; Chirag Bhardwaj, "How AI is Accelerating the Future of Electric Vehicles — Benefits, Use Cases, Real Examples," *appinventiv*, September 5, 2025, https://appinventiv.com/blog/ai-in-electric-vehicles/.

[67] Fadhil and Shen Global EV market monitor for LDV in key markets 2024; Govind Bhutada, "ElectrificationVisualizing the Range of Electric Cars vs. Gas-Powered Cars," *VisualCapitalist*, September 25, 2022, https://elements.visualcapitalist.com/range-of-electric-cars-vs-gas; EV-Database, "Range of full electric vehicles," 2025, accessed September 21, 2025, 2025, https://ev-database.org/cheatsheet/range-electric-car.

[68] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[69] D1EV, "2025 年中国电动汽车充电模块的市场现状和趋势分析," *第一电动*, March 12, 2025, https://d1ev.com/kol/264390.

[70] 赵佳, "最高充电功率可达 600kW 体验国家电网华为液冷充电桩," *21CNEV*, May 16, 2023, https://www.21cnev.com/html/202305/792571_1.html; IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

compact size suit short-trip travel. At the same time, there is rising consumer interest in premium EVs, with luxury and performance models gaining visibility in the Chinese market, though volumes remain far smaller than in the mass segment.[71] In North America, electric pickup trucks—notably Ford's F-150 Lightning and Rivian's R1T—are tapping into new consumer bases. Commercial adoption is also accelerating: logistics firms and ride-hailing fleets are deploying EV vans and delivery vehicles in Europe, China, and the US, drawn by lower operating and maintenance costs.[72]

5. Global market outlook

The trajectory for EV adoption remains robust through 2030, though shaped by macroeconomic and policy dynamics. In 2024, global EV sales surpassed 17 million units, giving EVs more than 20% of new car sales worldwide for the first time. Looking ahead, projections diverge by scenario. The IEA's Stated Policies Scenario projects that EVs will exceed 40% of new car sales globally by 2030, with China reaching around 80% penetration, Europe close to 60%, and the US near 20%; its more ambitious Net Zero Emissions pathway envisions even faster uptake.[73] BloombergNEF's baseline forecast aligns with the IEA's conservative case, at about 42% by 2030, while McKinsey projects a far steeper trajectory, with BEV sales expanding six-fold from 2021 to 2030 to around 40 million units annually, implying well over half of global new sales if realized.[74]

Policy frameworks remain decisive. In China, direct EV purchase subsidies ended in 2022, but purchase tax exemptions continue through 2027, albeit declining in value. In the EU, several member states are phasing out acquisition subsidies, while fiscal regimes shift: Germany will tax new BEVs from 2026, and the European Commission has proposed ending tax breaks for fossil-fuel company cars to favour EV fleets.

Crucially, China's NEV industry is explicitly reframing itself from 'policy-driven' to 'technology-driven,' with 'smart manufacturing' (*智能制造*) highlighted as a strategic fulcrum. The early growth phase (2009-2020) was subsidy-led, but competitiveness now hinges on advances in battery chemistry, intelligent connected vehicles, digitalized manufacturing, and AI-enabled supply chains. This shift makes clear that China is no longer leaning on subsidies, but is betting its NEV future on innovation—pushing forward with better batteries, smarter cars, and factories powered by digital intelligence.

[71] Fadhil and Shen Global EV market monitor for LDV in key markets 2024.

[72] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[73] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[74] Kersten Heineke, Philipp Kampshoff, and Timo Möller, "Spotlight on mobility trends," *McKinsey & Company*, March 12, 2024, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/spotlight-on-mobility-trends; BloombergNEF, *Electric Vehicle Outlook 2025*, BloombergNEF (2025), https://about.bnef.com/insights/clean-transport/electric-vehicle-outlook/#download-report-summary.

Despite short-term headwinds from high financing costs and policy volatility, structural forces remain favourable. Battery pack prices fell by over 25% between 2023 and 2024, reaching US$115/kWh, with projections of about US$80/kWh by 2026, and further material cost declines anticipated into the 2030s.[75] In China, power battery demand reached about 690 GWh in 2023 and estimated to hit 850 GWh in 2024, with material prices declining about 40% from 2019.[76] Automakers worldwide have announced hundreds of billions of dollars in EV investments through 2030, indicating long-term confidence.

Taken together, these developments suggest that **while subsidies are waning, the next growth wave will be driven by technological progress, manufacturing transformation, and supply chain scale-up**. By 2030, EVs are likely to dominate new vehicle sales in China and Europe, with the US and emerging markets following more gradually. The challenge lies less in consumer acceptance than in ensuring the industrial and technological backbone can sustain the pace.

III. Breaking Down the EV Value Chain

The EV industry rests on a globally distributed yet increasingly contested value chain. From upstream extraction and processing of critical minerals to mid-stream battery and motor manufacturing and downstream vehicle assembly and logistics, each stage involves distinct technological capabilities, policy incentives, and regional strengths. Together, these tiers determine cost competitiveness, innovation speed, and supply-chain resilience.

1. Raw materials for EVs

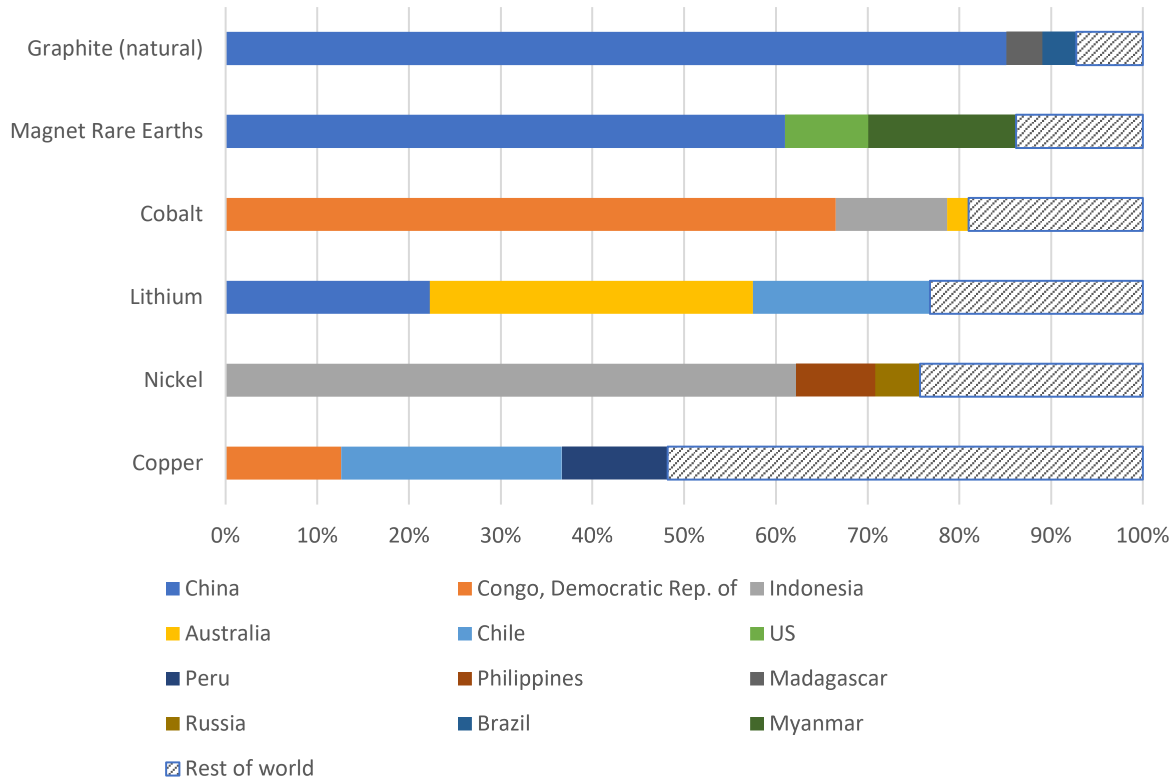
Modern electric vehicles (EVs) rely on a far broader set of critical raw materials than conventional cars. A typical mid-sized EV requires about six times more mineral inputs than an internal combustion engine vehicle, equivalent to roughly 200 kilograms compared with 30-40 kilograms for a petrol car.[77]

[75] BloombergNEF, "Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour," *BloombergNEF*, December 10, 2024, https://about.bnef.com/insights/commodities/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/; Goldman Sachs Research, "Electric vehicle battery prices are expected to fall almost 50 percent by 2025," *Goldman Sachs*, October 7, 2024, https://www.goldmansachs.com/insights/articles/electric-vehicle-battery-prices-are-expected-to-fall-almost-50-percent-by-2025.

[76] 郑赟 and 罗焕塔, *2024 年新能源汽车与动力电池产业展望报告*, Roland Berger, Da Dong Times (Roland Berger and Da Dong Times, January 2024), https://www.rolandberger.com/publications/publication_pdf/NEV-Battery-Report.pdf; Goldman Sachs Research, "Electric vehicle battery prices are expected to fall almost 50 percent by 2025."

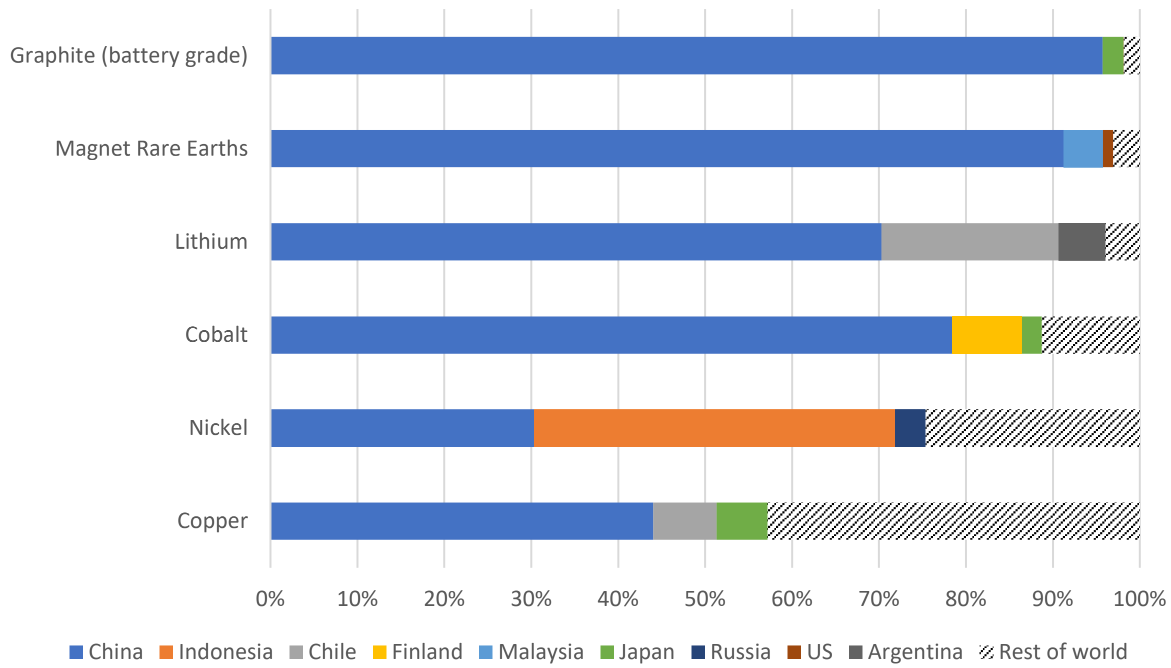
[77] HKUST Li & Fung Supply Chain Institute, *Global Supply Chain Report – Electric Vehicle (February 2025)*, Hong Kong University of Science and Technology (Hong Kong, February 2025), https://ustlfsci.hkust.edu.hk/sites/default/files/Global_Supply_Chain_Report_Electric_Vehicle.pdf.

Figure 15: Share of top three producing countries in mining of selected minerals, 2024



Source: IEA, compiled by LFSCI

Figure 16: Share of top three producing countries in refining of selected minerals, 2024



Source: IEA, compiled by LFSCI

1.1 Lithium

Lithium is the cornerstone of today's battery chemistries, being essential for cathodes, electrolytes, and anode additives. Global lithium mine output rose from 146,000 tonnes of contained lithium in 2022 to about 180,000 tonnes in 2023. Australia remained the dominant producer, supplying nearly half of global lithium output in 2023, followed by Chile with about one-quarter and China with around one-fifth.[78] Lithium production in Australia is primarily from hard-rock spodumene, whereas Chile's output derives mainly from brine resources. Beyond mining, China controls roughly 70% of global lithium refining capacity.[79]

Emerging producers in Africa are increasingly shaping supply dynamics. In Zimbabwe, several lithium projects have seen active development, notably the Arcadia mine operated by Prospect Lithium Zimbabwe (a unit of Zhejiang Huayou Cobalt) and Bikita Minerals, which is owned by China's Sinomine. Other Chinese investors, including Chengxin and Canmax, have expanded their stakes across both mining and processing facilities to build local refining capacity.

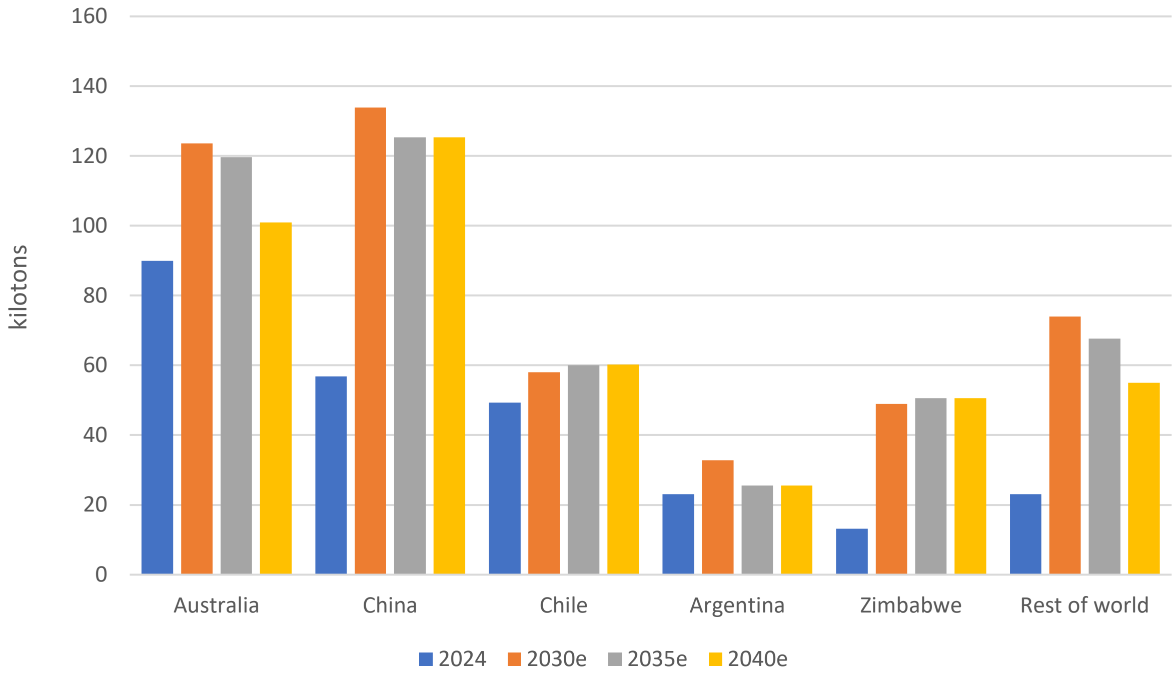
Prices have remained highly volatile, surging to around RMB575,000 per tonne of lithium carbonate (over US$80,000) in late 2022 before plunging by more than 70% during 2023. The decline continued into mid-2025, when prices briefly touched RMB59,000 per tonne (approximately US$8,300), representing barely one-tenth of their 2022 peak.[80] Despite cyclical swings, analysts project sustained growth in demand, requiring large-scale new capacity in Argentina, Canada, and Australia.

[78] The US was excluded in this statistics. USGS, *Mineral Commodity Summaries 2024*, U.S. Geological Survey, (Reston, VA, January 31, 2024), https://pubs.usgs.gov/publication/mcs2024.

[79] IEA, *Global Critical Minerals Outlook 2025*, International Energy Agency, (Paris, May 21 2025), https://www.iea.org/reports/global-critical-minerals-outlook-2025.

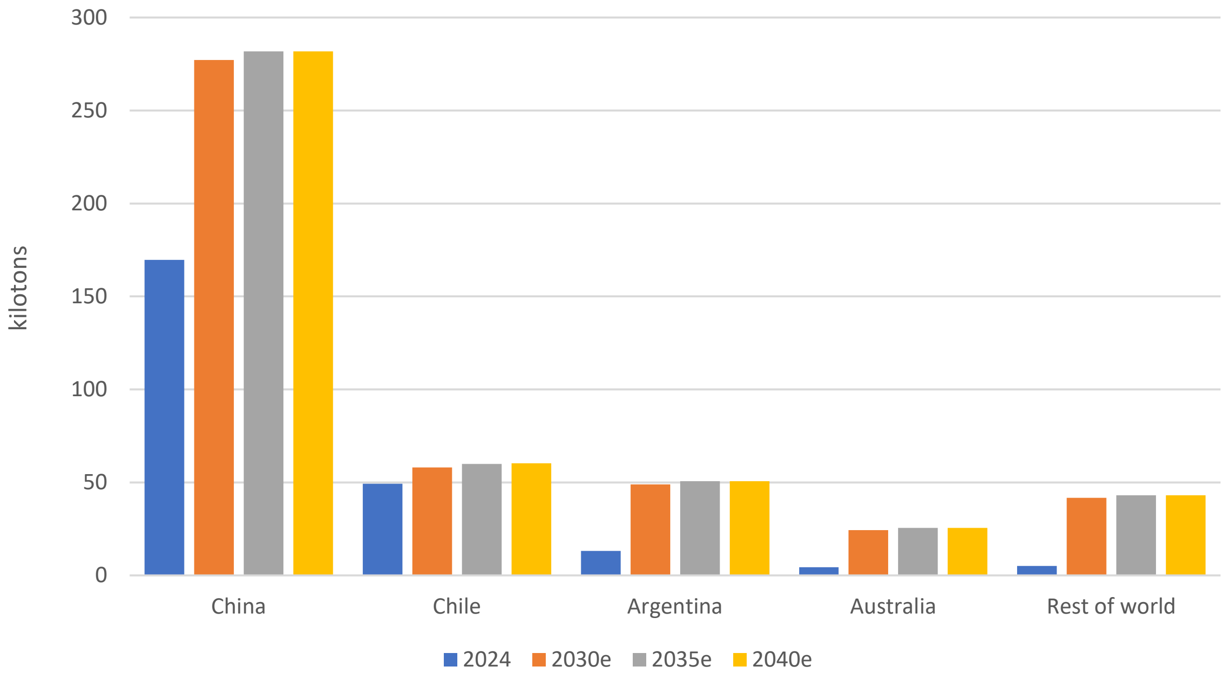
[80] Trading Economics, "Price of Lithium Carbonate," (Trading Economics). https://tradingeconomics.com/commodity/lithium.

Figure 17: Top producing countries in mining of lithium



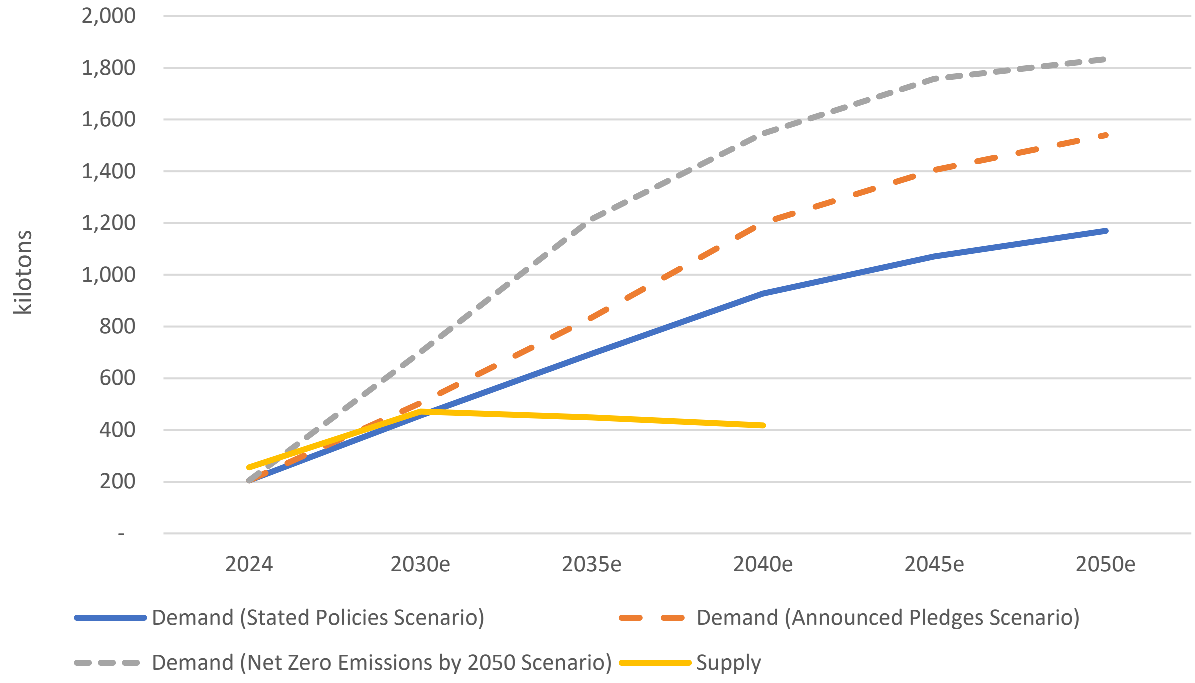
Source: IEA, compiled by LFSCI

Figure 18: Top producing countries in refining of lithium



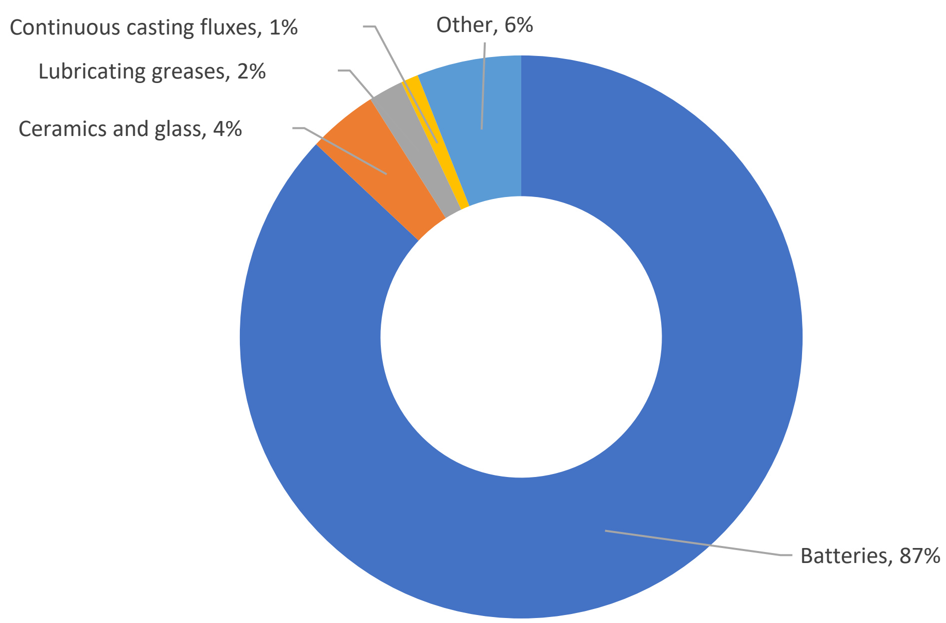
Source: IEA, compiled by LFSCI

Figure 19: Global demand and supply for lithium



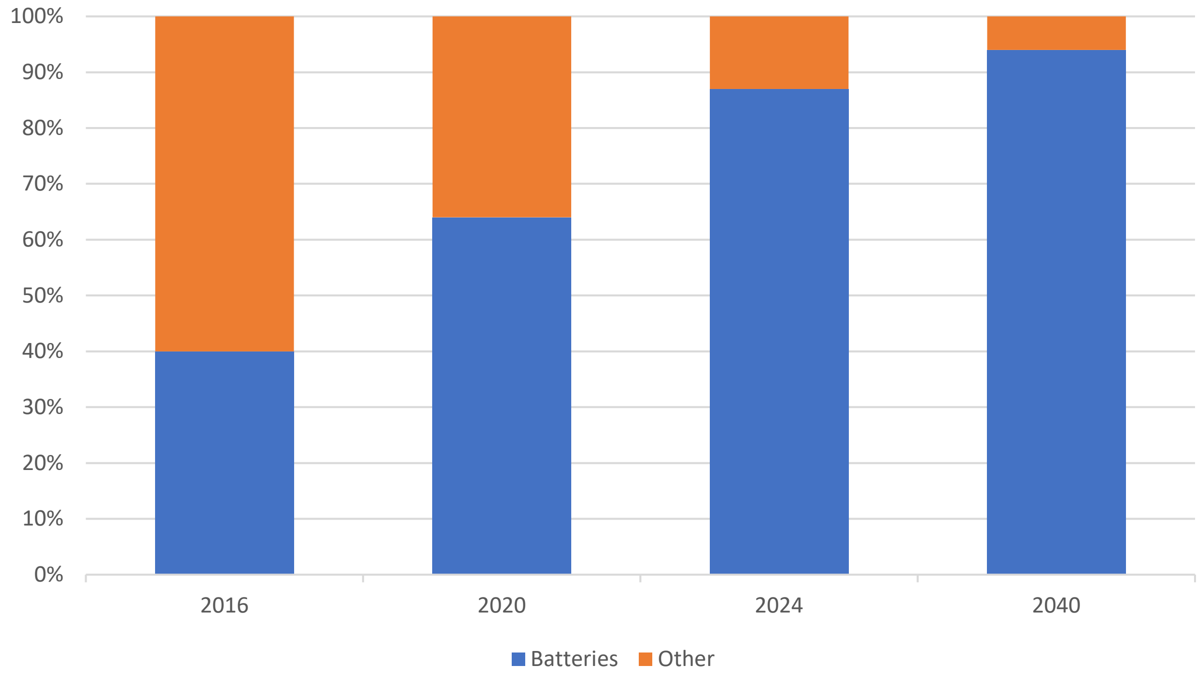
Source: IEA, compiled by LFSCI

Figure 20: Global use of lithium, 2023



Source: Natural Resources Canada, compiled by LFSCI

Figure 21: Lithium demand by application



Source: Lithium Harvest, compiled by LFSCI

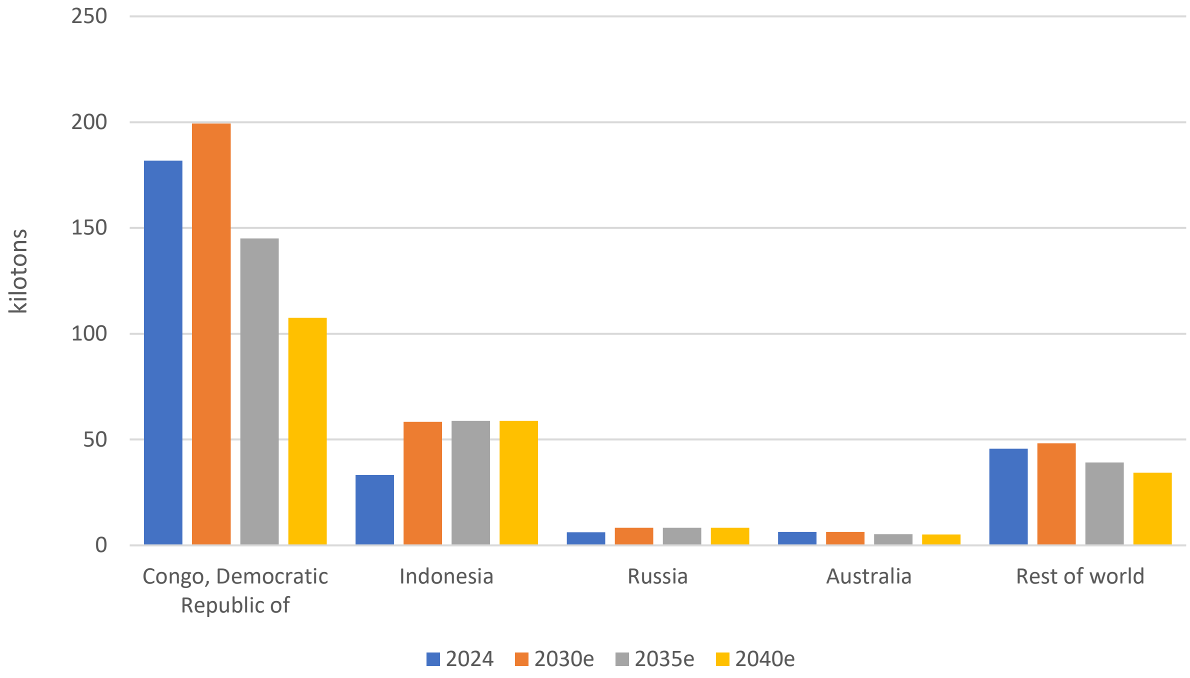
1.2 Cobalt

Cobalt, long valued for its stabilising properties in nickel-manganese-cobalt (NMC) cathodes, has seen EVs overtake consumer electronics as the largest source of demand. In 2023, global mine output was approximately 230,000 tonnes, with the DRC supplying about 74%, often as a by-product of copper mining. This concentration poses risks linked to governance challenges and the persistence of artisanal mining, which is associated with poor labour conditions and child labour. Indonesia has emerged as a secondary supplier through cobalt recovery from nickel laterite refining, producing over 7% of global output in 2023.[81]

Cobalt prices, which experienced sharp spikes in 2018 and again in 2022, have remained comparatively subdued since 2023. This moderation reflects both the expansion of global supply and the industry's gradual shift towards lower-cobalt or cobalt-free chemistries, including high-nickel NMC and lithium iron phosphate (LFP) batteries. While cobalt intensity per battery is falling, absolute demand is expected to remain steady or rise modestly due to EV volume growth.

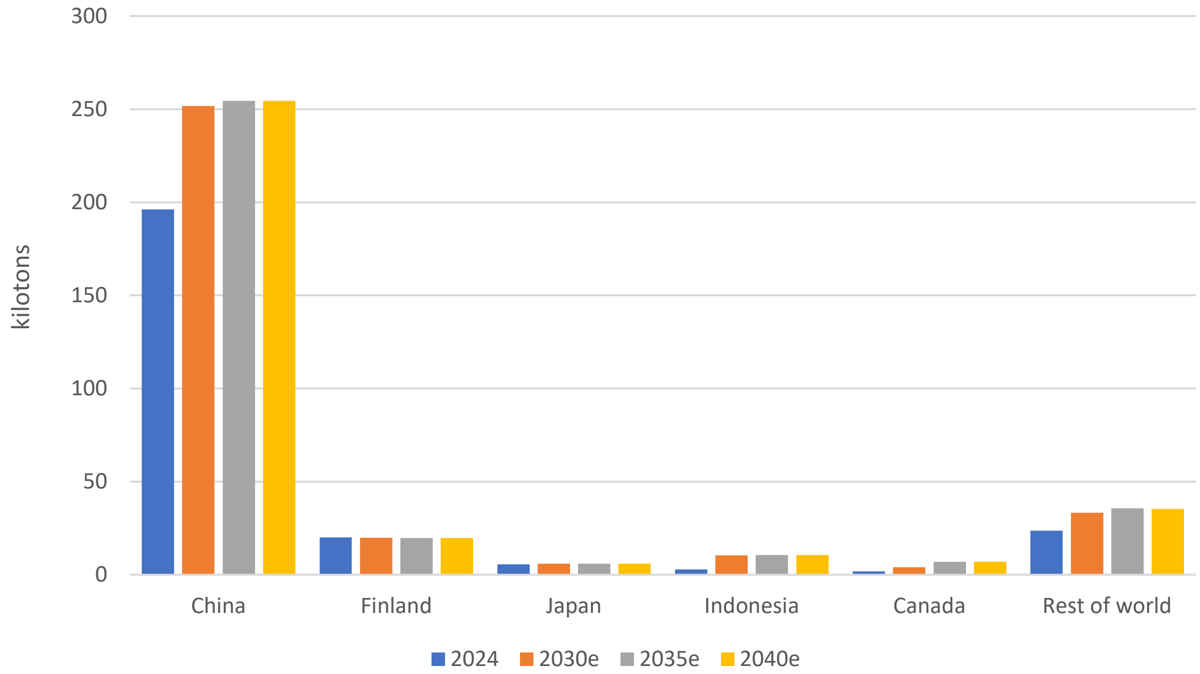
[81] USGS, *Mineral Commodity Summaries 2024*.

Figure 22: Top producing countries in mining of cobalt



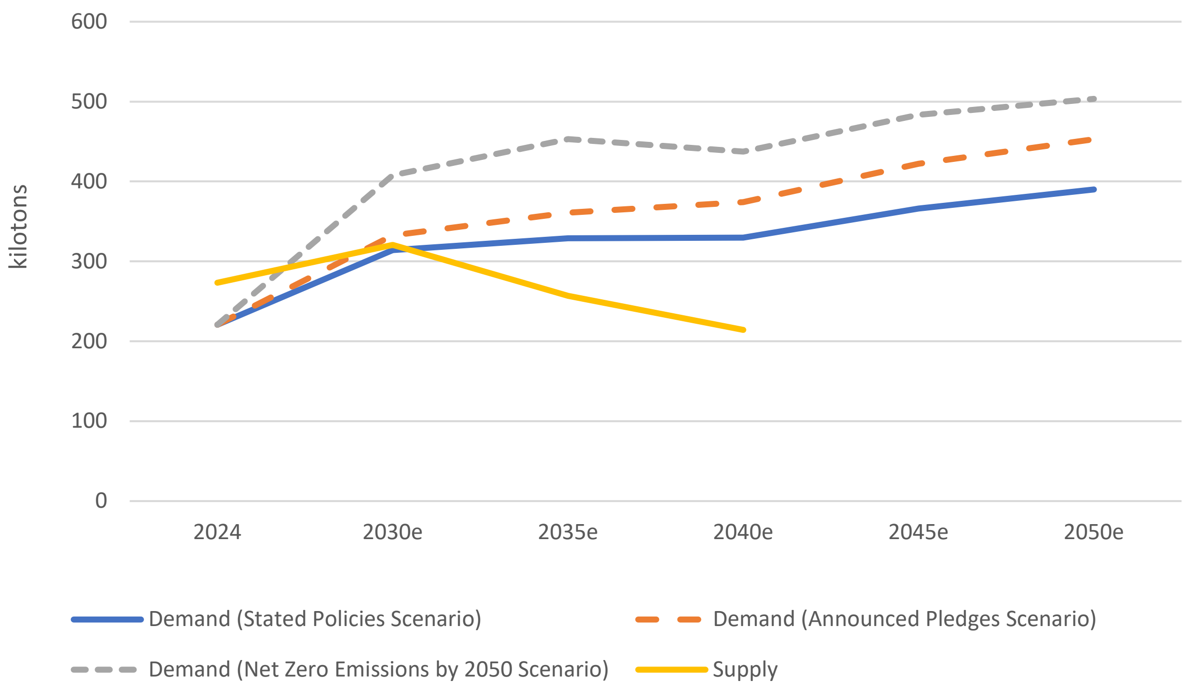
Source: IEA, compiled by LFSCI

Figure 23: Top producing countries in refining of cobalt



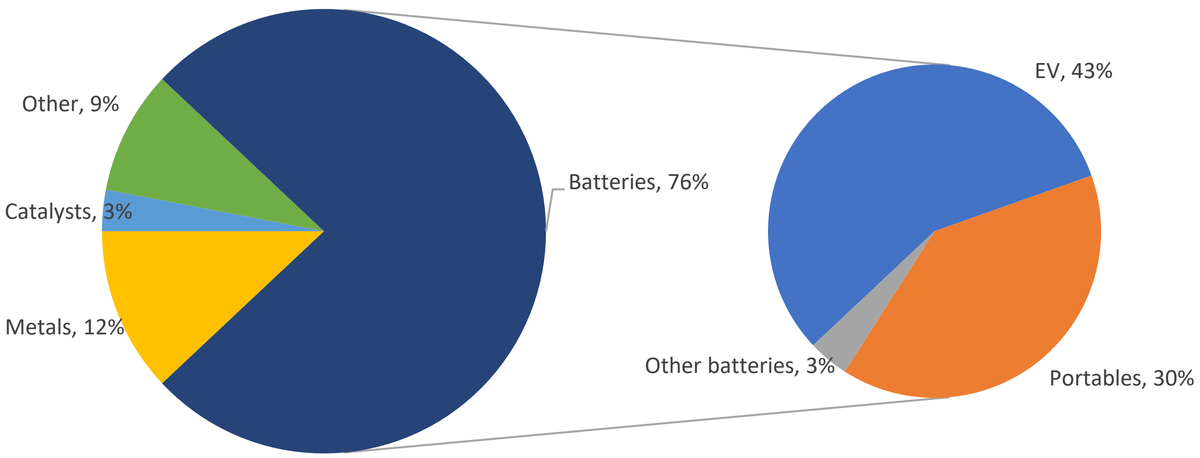
Source: IEA, compiled by LFSCI

Figure 24: Global demand and supply for cobalt



Source: IEA, compiled by LFSCI

Figure 25: Global use of cobalt, 2023



Source: Cobalt Institute, compiled by LFSCI

1.3 Nickel

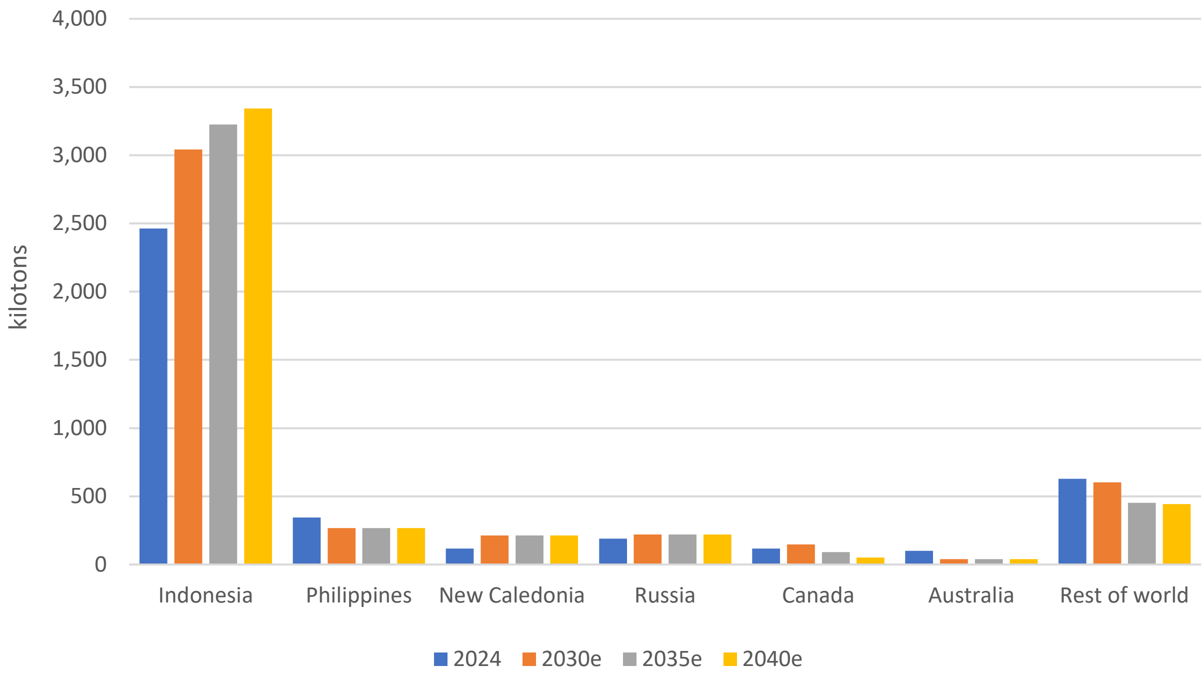
Nickel is another critical cathode material, particularly in high-energy NMC and nickel-cobalt-aluminium (NCA) chemistries. A mid-sized battery electric vehicle typically contains about 20-30 kilograms of nickel, depending on pack size and cathode composition. Nickel demand from the battery sector continues to expand rapidly, yet stainless steel production remains the dominant end use, accounting for more than half of global nickel consumption.[82]

Indonesia has become the dominant producer, mining 1.8 million tonnes in 2023, equivalent to nearly half of global supply.[83] The government's ban on raw nickel ore exports, in effect since January 2020, has catalysed a rapid build-out of domestic refining capacity through high-pressure acid leach (HPAL) facilities. Many of these projects—often led by Chinese and Korean investors—are designed to produce mixed hydroxide precipitate (MHP) and other battery-grade nickel intermediates for global cathode supply chains. However, the HPAL process presents significant environmental and safety challenges, as it produces large volumes of acidic tailings and slurry whose safe management is complicated by Indonesia's heavy rainfall, seismic activity, and limited waste-storage infrastructure. Russia, historically a major supplier of high-grade 'Class 1' nickel, has faced partial market exclusion following the Ukraine War, with flows redirected towards Asian buyers. Canada and Australia remain the preferred 'clean' sources, offering lower-carbon and ethically traceable supply that meets ESG standards. Automakers such as Tesla are in talks with Canadian miners to secure such responsible nickel. Nickel prices underwent extreme volatility in March 2022, surging from around US$27,000 to over US$100,000 per tonne in just a few days due to a short squeeze before collapsing back. Over 2023 and into 2024, prices largely settled in the range of US$15,000 to US$25,000 per tonne. In 2025, prices remain in the mid-teens range. The concurrent rise of LFP batteries and early development of sodium-ion alternatives point to a gradual diversification away from nickel dependency.

[82] Benchmark Minerals, "Nickel Supply Chain Data," accessed October 12, 2025, https://www.benchmarkminerals.com/nickel/supply-chain-data.

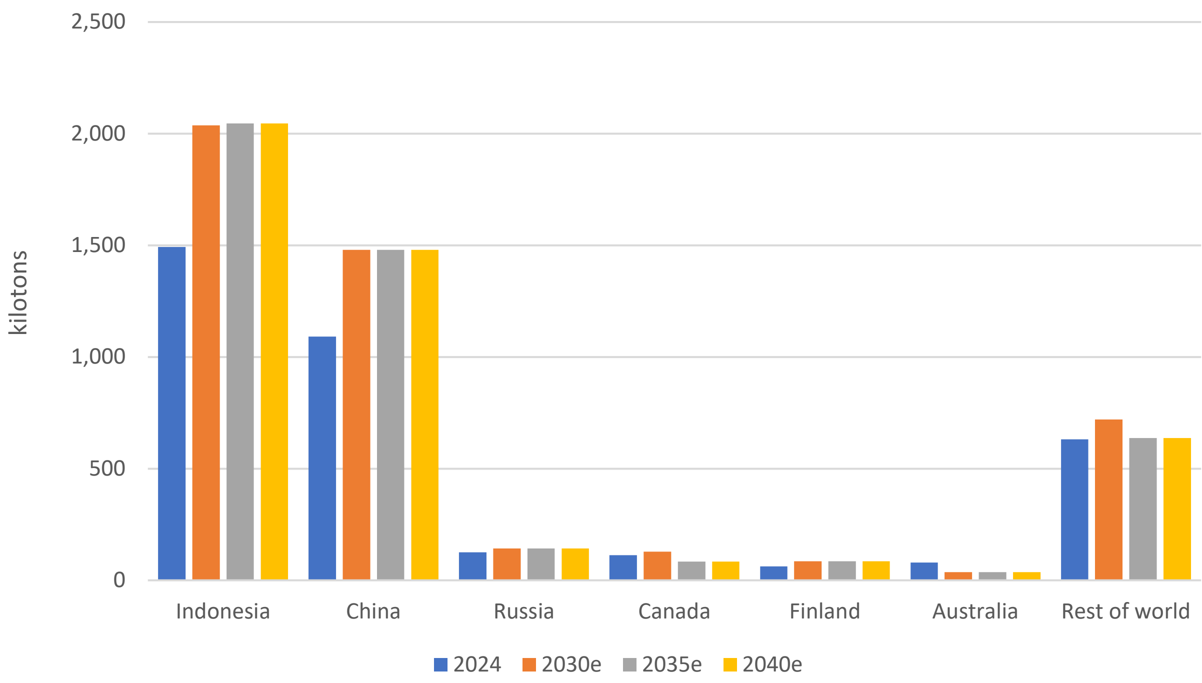
[83] USGS, *Mineral Commodity Summaries 2024*.

Figure 26: Top producing countries in mining of nickel



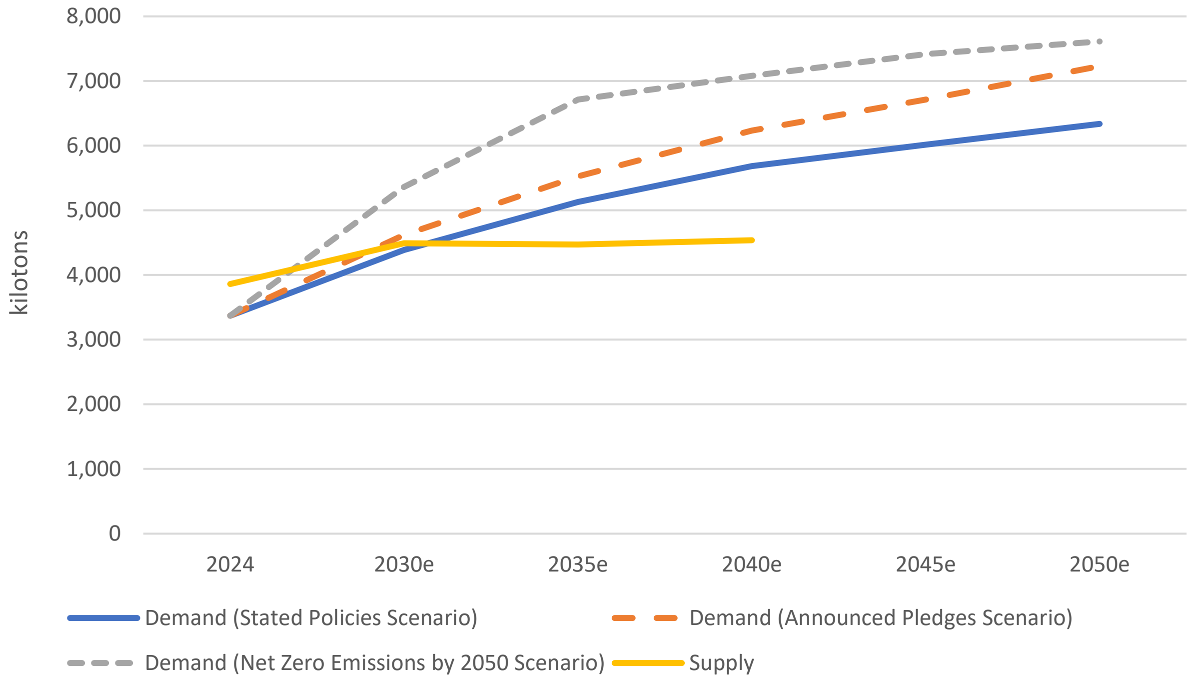
Source: IEA, compiled by LFSCI

Figure 27: Top producing countries in refining of nickel



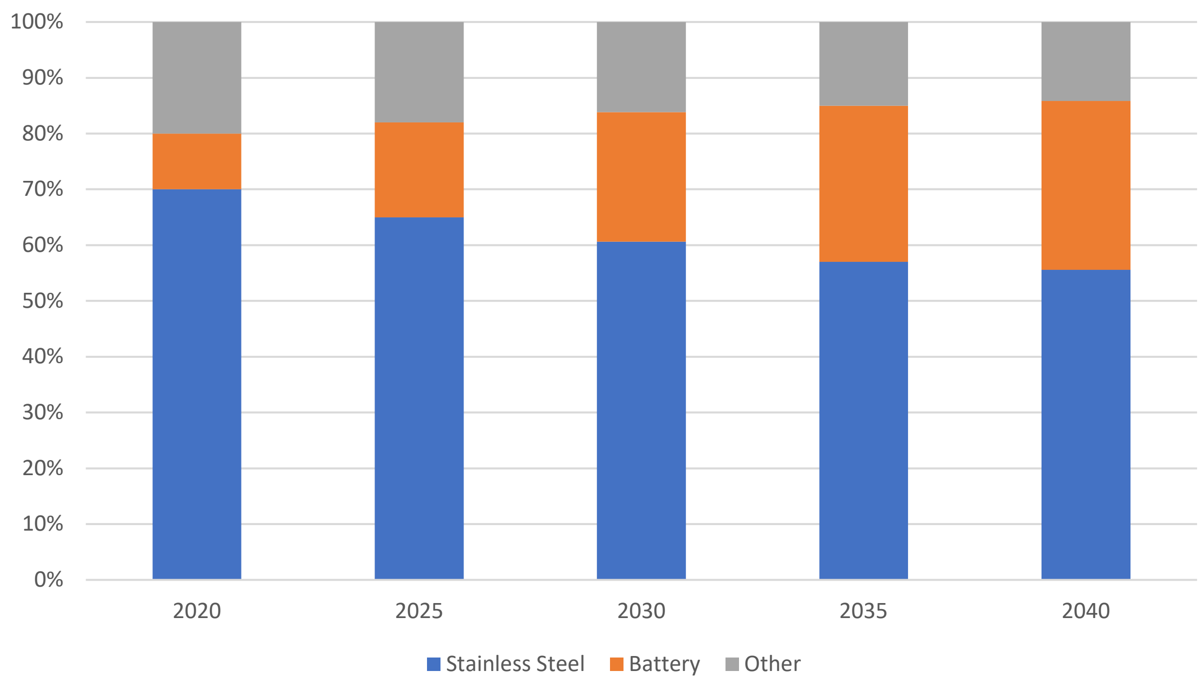
Source: IEA, compiled by LFSCI

Figure 28: Global demand and supply for nickel



Source: IEA, compiled by LFSCI

Figure 29: Nickel demand by application



Source: Benchmark Minerals, compiled by LFSCI

1.4 Rare earth elements

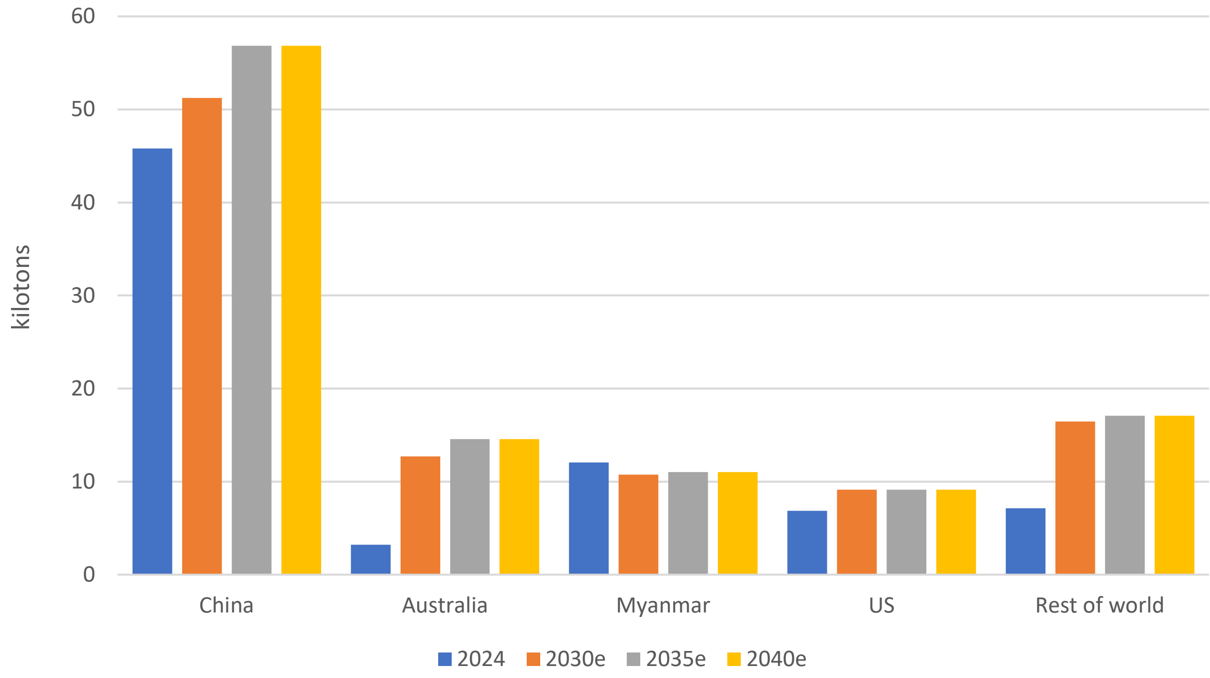
Rare earth elements (REEs) such as neodymium, praseodymium, dysprosium, and terbium are vital for the permanent magnets used in the majority of EV traction motors. In most electric vehicles using permanent-magnet synchronous motors, each traction motor contains about 1-2 kilograms of neodymium-iron-boron (NdFeB) magnets, depending on power and design. Producing 1.7 kilograms of NdFeB alloy requires roughly 0.5 kilograms of rare-earth metals—mainly neodymium and praseodymium, with smaller amounts of dysprosium and terbium—which in turn consume about 0.6 kilograms of rare-earth oxides. Overall, manufacturing 100 kilowatts of permanent-magnet motor capacity creates demand for roughly 0.6 kilograms of rare-earth oxides.

In 2023, global REE production reached 350,000 tonnes, of which about 70% was mined in China.[84] China also processed 74% of rare earths and produced nearly all high-performance rare earth magnets.[85] This concentration has long been seen as a strategic vulnerability for EV multinationals, with China having restricted exports in the past. In 2023, Beijing imposed controls on gallium and germanium, reinforcing concerns that REEs could be subject to similar measures. More recently, in 2025, China expanded controls, adding five more rare-earth elements under export licensing, and tightened export rules for magnets and processing technologies. Projects in the US, Canada, and Australia are slowly adding alternative capacity, though environmental hurdles remain significant. GM is establishing a domestic supply chain for the rare earth magnets needed in its electric motors. The strategy involves partnering with MP Materials for raw materials from the sole active US rare earth mine (Mountain Pass, CA), collaborating with VAC to construct a new US magnet production facility, and sourcing from Noveon Magnetics, the only US manufacturer of sintered rare-earth magnets before the VAC plant is ready. Automakers are also innovating to reduce reliance: Tesla announced in 2023 that its next-generation drive units will eliminate rare earths, likely through induction motor designs. Nonetheless, most EVs continue to rely on REE magnets for efficiency, and dysprosium remains particularly costly due to limited sources.

[84] USGS, *Mineral Commodity Summaries 2024*.

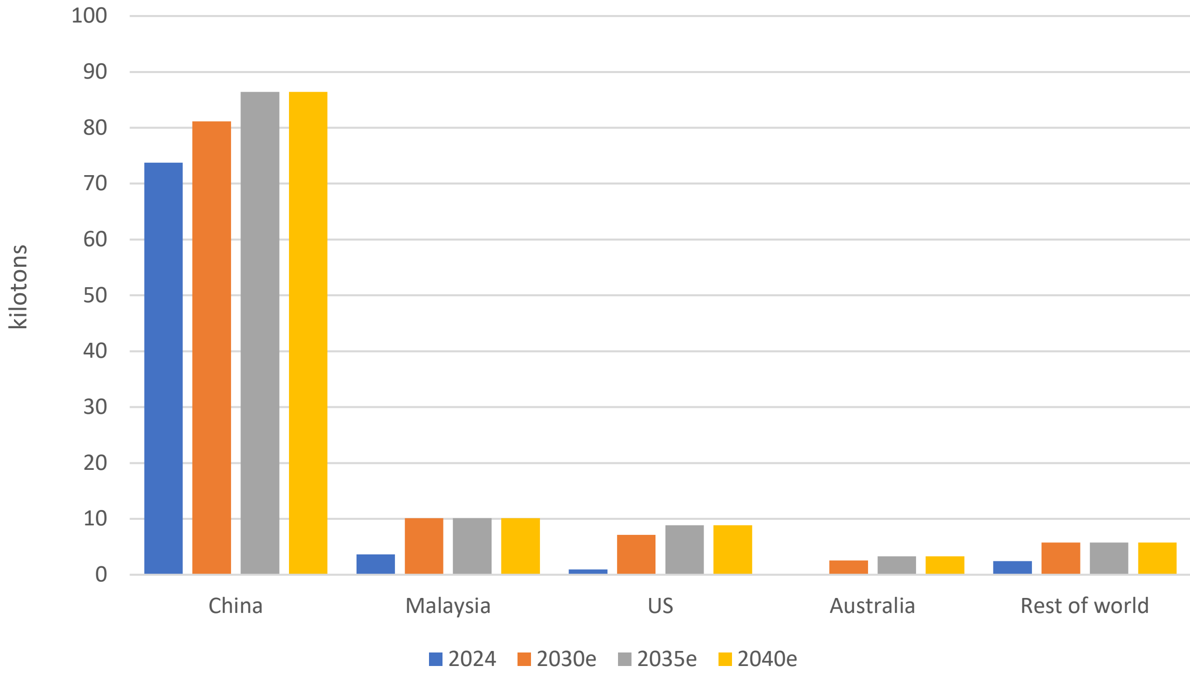
[85] IEA, *Global Critical Minerals Outlook 2025*; Keith Bradsher, "U.S. Dependence on China for Rare Earth Magnets Is Causing Shortages," *The New York Times*, June 2 2025, https://www.nytimes.com/2025/06/02/business/china-rare-earths-united-states-supplies.html.

Figure 30: Top producing countries in mining of magnet rare earth elements



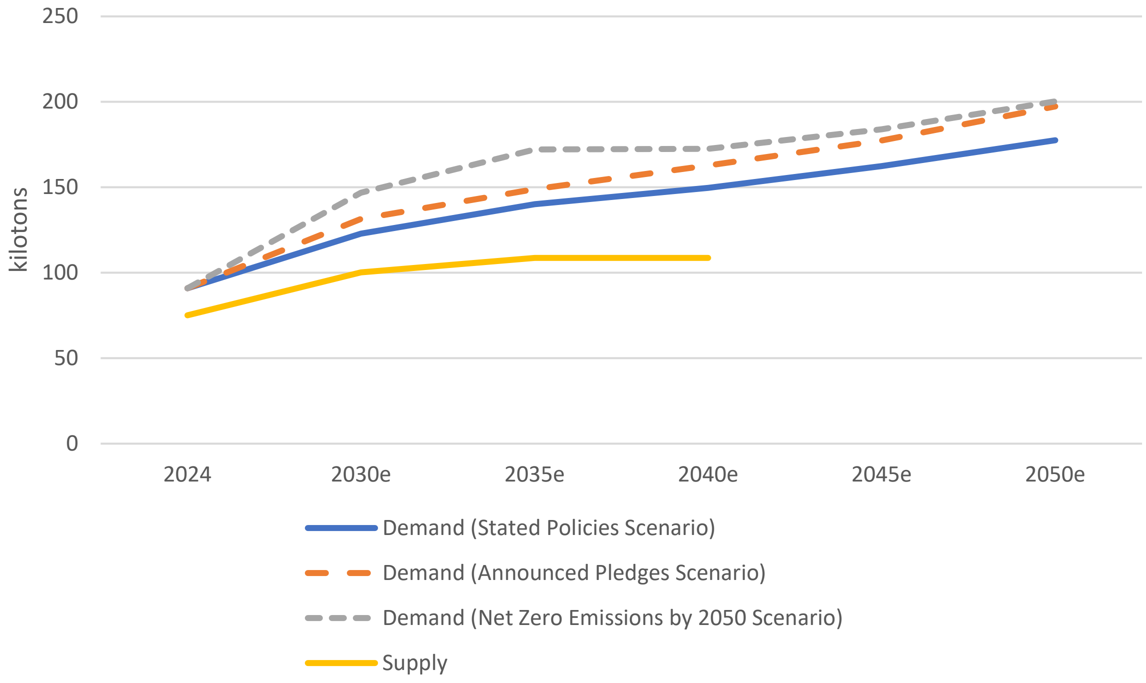
Source: IEA, compiled by LFSCI

Figure 31: Top producing countries in refining of magnet rare earth elements



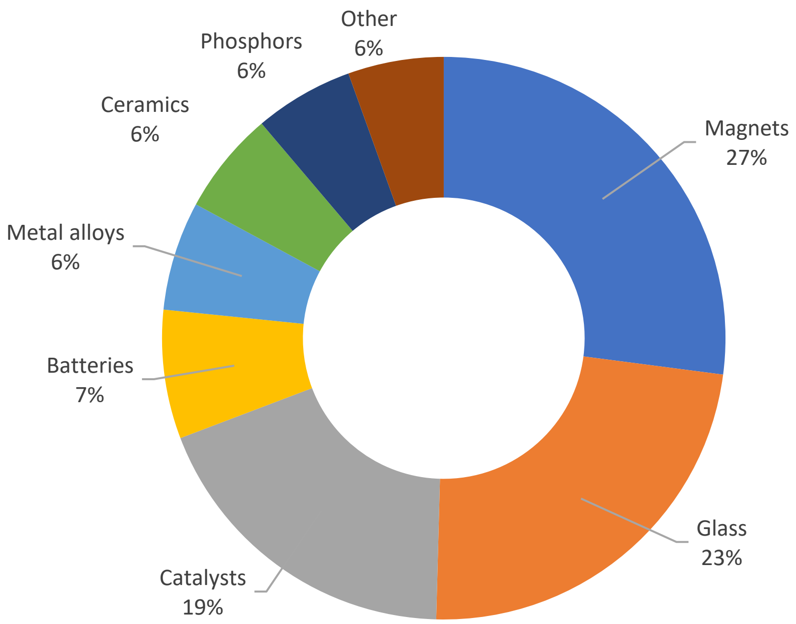
Source: IEA, compiled by LFSCI

Figure 32: Global demand and supply for magnet rare earth elements



Source: IEA, compiled by LFSCI

Figure 33: Estimated global use of rare earth oxides by application, 2025

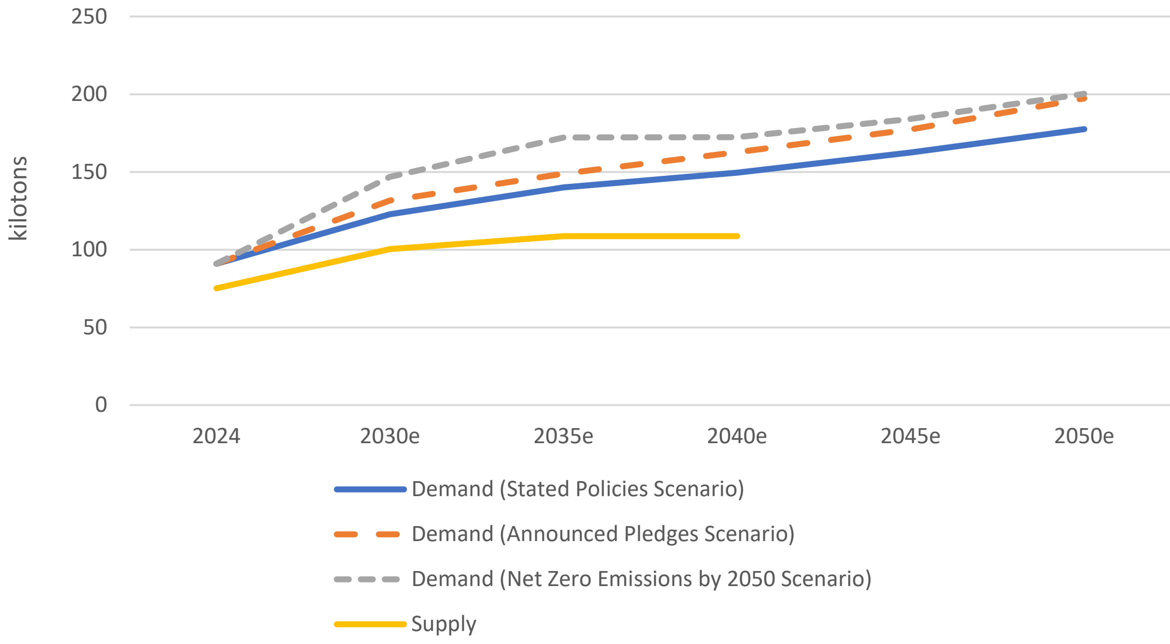


Source: Statista, compiled by LFSCI

1.5 Graphite

Graphite, both natural and synthetic, is indispensable for Li-ion battery anodes, with each EV battery typically containing 50-100 kilograms depending on pack size and chemistry. Global natural graphite output was 1.6 million tonnes in 2023, with about 77% from China.[86] China also dominates downstream processing: Chinese producers are estimated to manufacture around 99% of spherical (battery-grade) graphite and 93% of graphite anode materials, giving them effective control over more than 90% of the global anode processing capacity.[87] China's export permit requirements for certain high-purity and synthetic graphite products, introduced in October 2023 and implemented in December 2023, added regulatory uncertainty but did not immediately tighten global supply. Ample inventories and weak demand kept prices subdued into 2024, following declines of roughly 30-45% during 2023.[88] Nonetheless, the policy heightened supply-chain risk awareness among automakers and battery producers, prompting accelerated investment in alternative graphite sources—including new projects in Mozambique, Madagascar, and North America—and spurring further research into silicon-based and composite anodes that could reduce long-term reliance on graphite.

Figure 34: Global demand and supply for magnet rare earth elements



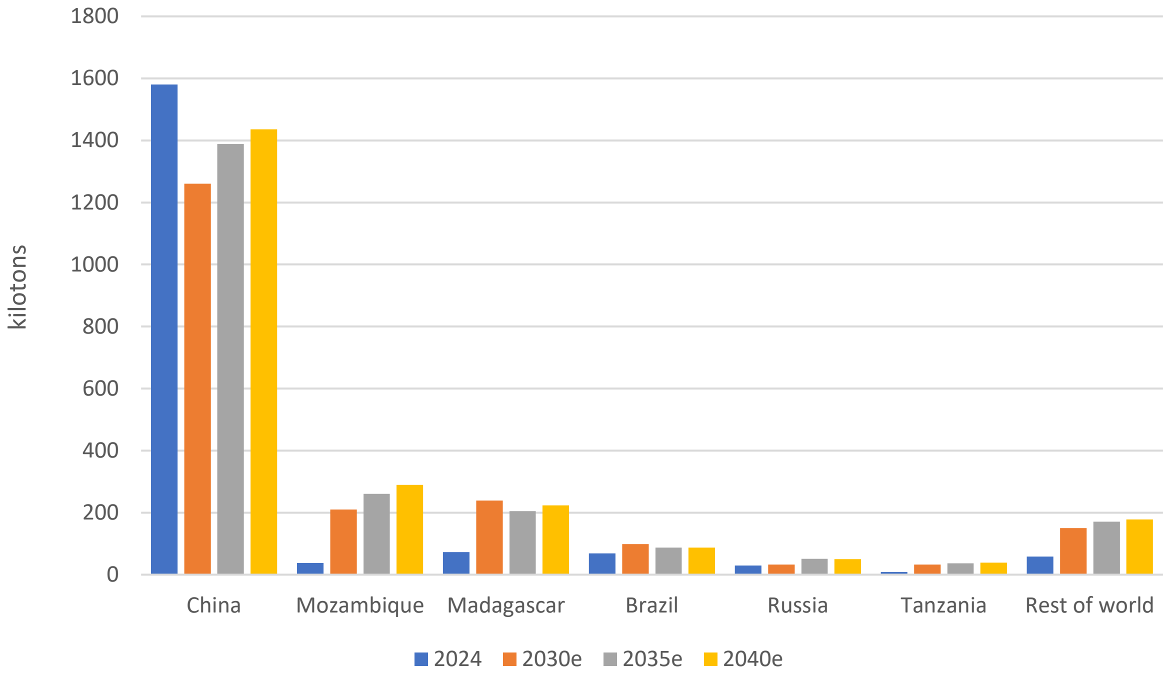
Source: IEA, compiled by LFSCI

[86] USGS, *Mineral Commodity Summaries 2024*.

[87] Matt Blois, "China restricts exports of graphite used to make battery anodes," *Chemical & Engineering News*, October 26, 2023, https://cen.acs.org/policy/trade/China-restricts-exports-graphite-used/101/i36; Benchmark Minerals, "China's graphite export regulation shift puts anode in the spotlight," *Benchmark Minerals*, October 20, 2023, https://source.benchmarkminerals.com/article/china-graphite-export-restrictions-could-hinder-ex-china-anode-development.

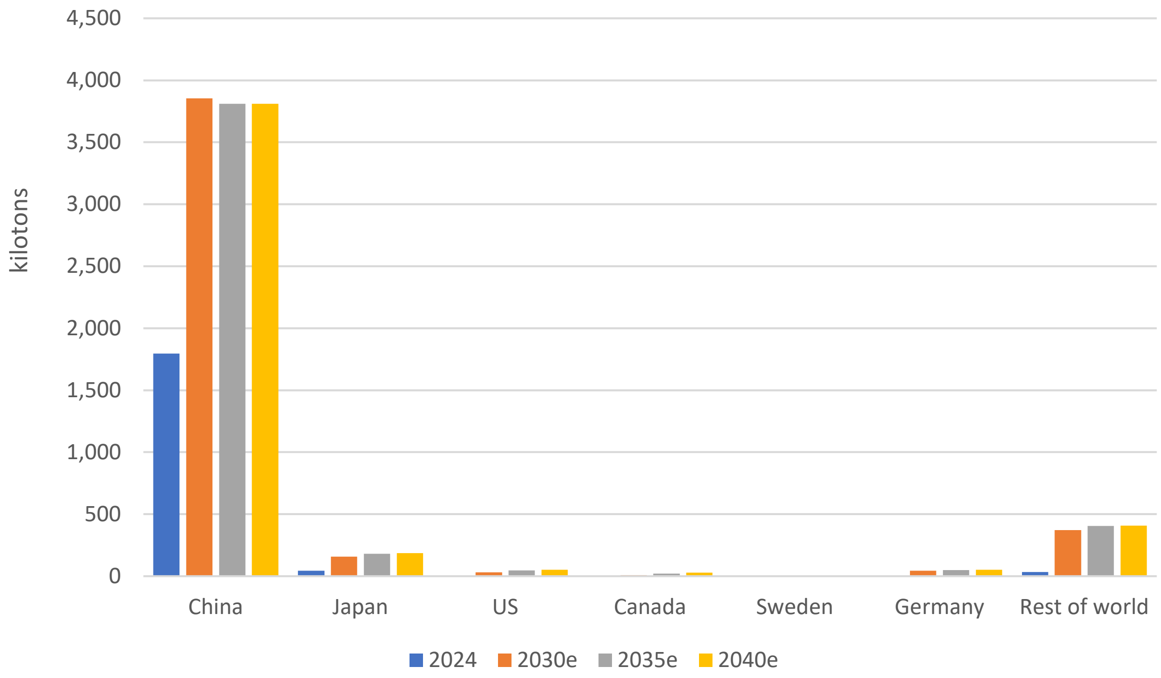
[88] IEA, *Global Critical Minerals Outlook 2025*.

Figure 35: Top producing countries in mining of graphite (natural)



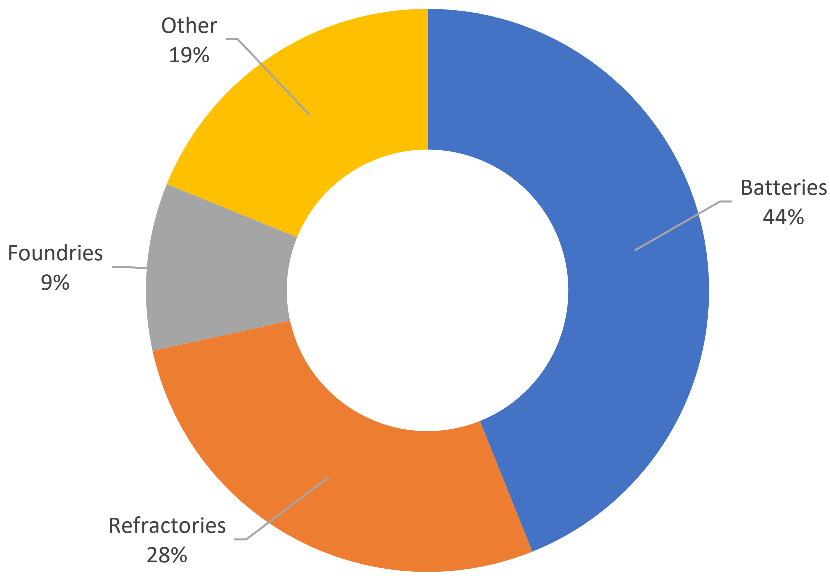
Source: IEA, compiled by LFSCI

Figure 36: Top producing countries in refining of graphite (battery grade)



Source: IEA, compiled by LFSCI

Figure 37: Estimated global use of natural graphite by application, 2025



Source: Statista, compiled by LFSCI

1.6 Manganese

Manganese plays a supportive but important role in battery cathode formulations, particularly within nickel-manganese-cobalt (NMC) chemistries, and is increasingly considered for incorporation into higher-manganese or hybrid cathode architectures such as lithium manganese iron phosphate (LMFP). Although manganese is not as constrained as cobalt or nickel, supply risks emerge at the downstream refining stage. In 2023, global manganese ore production remained broadly stable, with Gabon and South Africa prominent among exporters. Yet, publicly available data on battery-grade manganese sulphate monohydrate is limited. Market and project reporting suggest that Chinese firms dominate the processing and conversion to battery chemicals, representing a concentration that mirrors China's control over other battery raw material value chains. Under the EU's *Critical Raw Materials Act* (CRMA), high-purity manganese (battery grade) has been specifically designated a strategic raw material, and the legislation mandates actions to diversify processing and reduce reliance on concentrated supply chains.

1.7 Copper and aluminium

Copper and aluminium form foundational elements in both the electrical and structural systems of electric vehicles. An average BEV requires over 80 kilograms of copper, roughly four times that of a comparable ICE vehicle. Global copper mine output in 2023 was 22 million tonnes, with Chile, Peru, and the DRC as the largest suppliers.[89] Supply constraints are increasingly visible, as new mine projects face delays due to permitting processes, environmental reviews, and social opposition.

Meanwhile, aluminium is widely used in EVs for body panels, structural components, and battery housings. Aluminium, typically accounts for over 15% of an EV's weight, is used in lightweight body structures and battery trays. Automakers are facing growing pressure to source aluminium from operations powered by low-carbon energy sources, such as hydropower in Canada or Norway, rather than coal-dependent smelters in China. Mercedes-Benz, for instance, has partnered with Norsk Hydro to employ low-carbon aluminium in its next electric models, claiming a 40% emissions reduction in body materials. Meanwhile, industry analyses and OEM sustainability goals increasingly highlight 'green aluminium' as a necessary component of Scope 3 emissions management.[90] Benchmarking data shows that China is among the highest carbon-intensity aluminium producers, while low-intensity producers like Norway and Canada benefit from cleaner energy grids.[91]

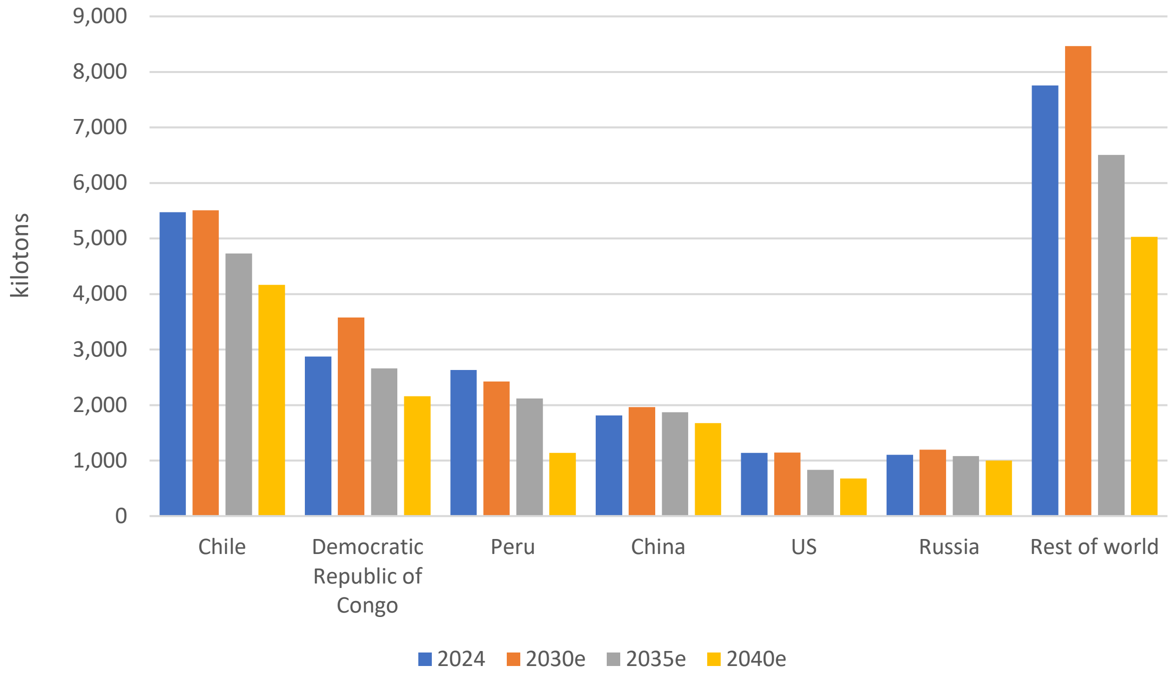
In 2024, the US Department of Labor added aluminium from China to its *List of Goods Produced by Child Labor or Forced Labor*, signalling potential compliance risks, though no blanket import bans have been enacted.

[89] USGS, *Mineral Commodity Summaries 2024*.

[90] Ducker & Carlisle, *The Future of Green Aluminum: Opportunities and Uncertainty in a Changing Market* (April 2025), https://www.duckercarlisle.com/the-future-of-green-aluminum-opportunities-and-uncertainty-in-a-changing-market/; Carbon Chain, "2025 State of Low-Carbon Aluminium," *Carbon Chain*, April 4, 2025, https://www.carbonchain.com/blog/2025-state-of-low-carbon-aluminium.

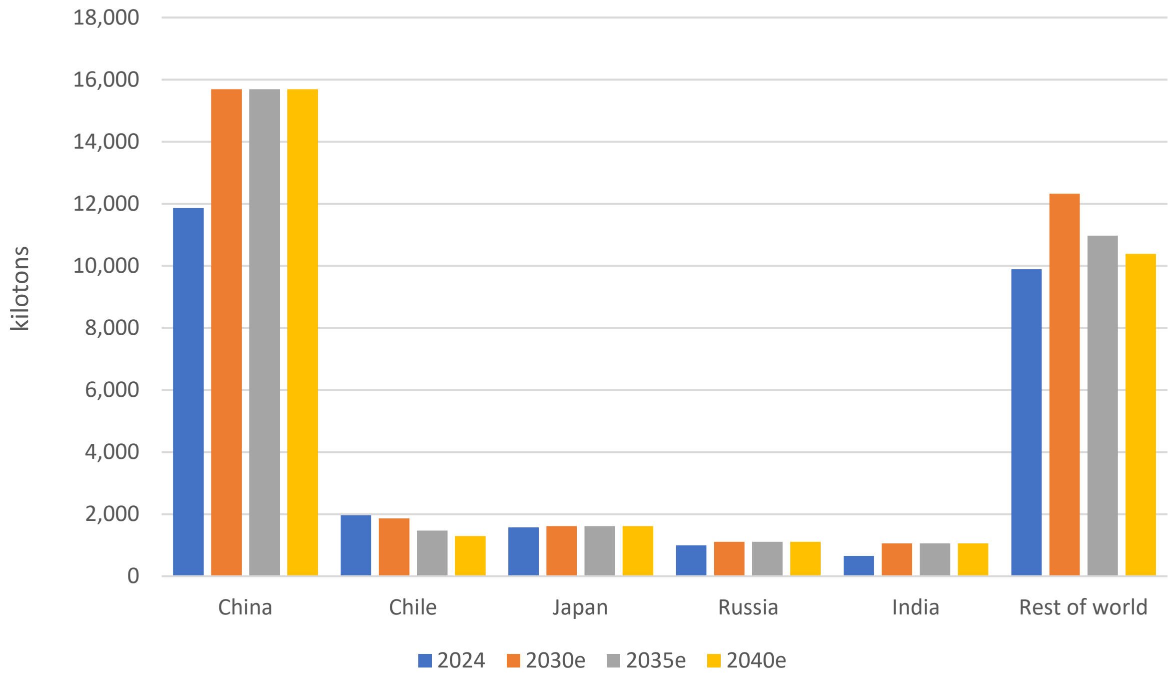
[91] Ali Hasanbeigi, "Cleanest and Dirtiest Countries for Primary Aluminum Production," *Global Efficiency Intelligence*, March 29, 2022, https://www.globalefficiencyintel.com/new-blog/2022/cleanest-and-dirtiest-countries-for-primary-aluminum-production.

Figure 38: Top producing countries in mining of copper



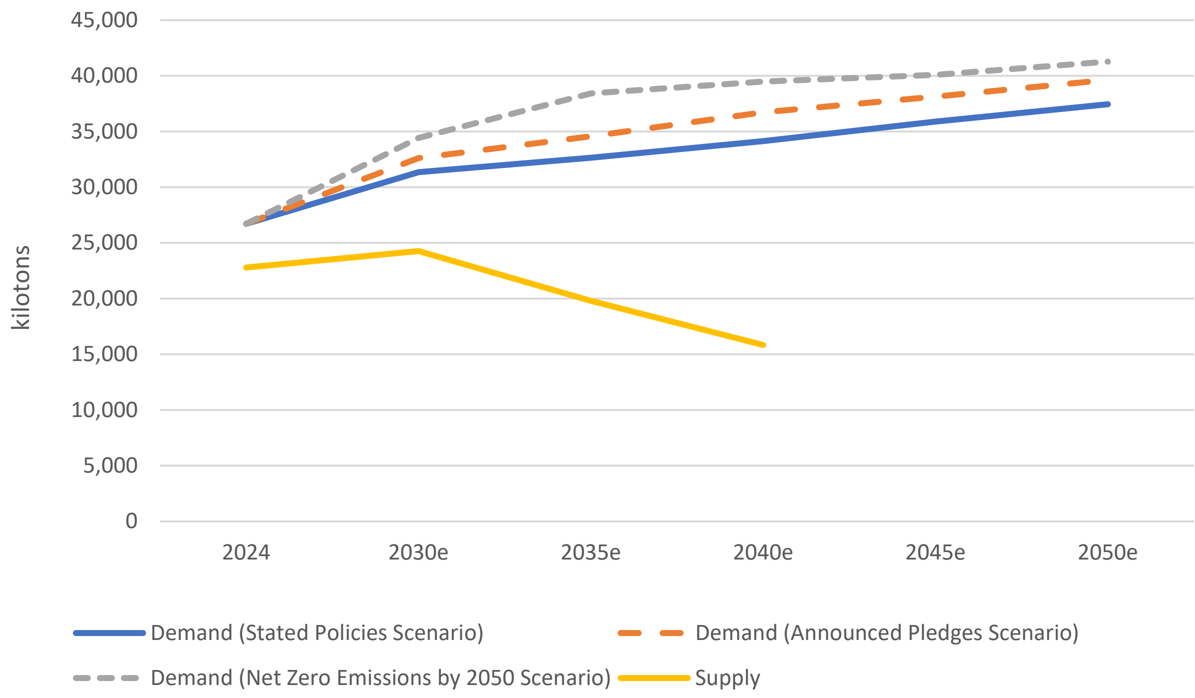
Source: IEA, compiled by LFSCI

Figure 39: Top producing countries in refining of copper



Source: IEA, compiled by LFSCI

Figure 40: Global demand and supply for copper



Source: IEA, compiled by LFSCI

To mitigate these material risks, automakers and battery producers are adopting a multi-pronged strategy. First, they are pursuing supply diversification through long-term offtake agreements and joint ventures—for example, Tesla has secured a multi-year agreement with Piedmont Lithium in the US to purchase spodumene concentrate, a processed ore that is rich in lithium. Hybrid models of upstream and downstream integration are increasingly observed in Indonesia, where mineral processing companies Huayou Cobalt and Tsingshan Group are working with automakers and battery producers to develop integrated nickel and precursor refining projects in Morowali and Weda Bay. Meanwhile, government-level initiatives support these efforts via strategic alliances. The US and EU launched a Minerals Security Partnership in 2022, and the EU signed strategic agreements with Namibia and Kazakhstan in the same year to secure diversified supplies of lithium, rare earths, and green hydrogen. In October 2025, Washington signed a critical-minerals framework with Australia to accelerate investment in mining and refining, followed shortly afterward by rare-earth cooperation agreements with Japan, Thailand, and Malaysia. These frameworks explicitly aim to reduce overreliance on China, with the EU's *Critical Raw Materials Act* requiring that no more than 65% of any key mineral be sourced from a single country by 2030.

Second, innovation in battery chemistry is reshaping the pattern of raw-material demand across the EV industry. The rapid global adoption of lithium-iron-phosphate (LFP) batteries—whose cathodes rely on iron and phosphate instead of nickel and cobalt—has sharply reduced pressure on those two high-risk metals. LFP cells powered nearly half of global EV sales in 2024, up from 38% in 2022, and about three-quarters of sales in China, signalling a structural shift in material intensity.[92] Looking ahead, sodium-ion batteries, which replace lithium with abundant sodium, are entering commercialization: CATL began mass production of its Naxtra sodium-ion battery in 2025, a development that could diversify demand away from lithium if adopted at scale. At the same time, progress towards solid-state batteries—led by Toyota and several others—could lessen reliance on graphite and copper in anodes and current collectors by enabling thinner, more energy-dense designs. Collectively, these technological substitutions point to a gradual easing of supply constraints on scarce minerals such as cobalt, nickel, and lithium, while increasing the strategic importance of more common elements including iron, phosphorus, and sodium.

Third, recycling is emerging as a major secondary supply source for battery materials. By the late 2020s, a substantial wave of end-of-life electric-vehicle batteries will enter recycling systems. Leading recyclers are already expanding capacity to capture this material flow. In China, Brunp Recycling, a subsidiary of CATL, operates some of the world's largest closed-loop facilities recovering lithium, nickel, cobalt, and copper for reuse in new cathodes. In the US, Redwood Materials is developing integrated recycling and anode-cathode material plants in Nevada and South Carolina to build a domestic circular battery supply chain. Meanwhile, the industry is consolidating, as major metals groups acquire specialized recyclers—Glencore's 2025 acquisition of Li-Cycle, following financial restructuring, exemplifies this shift towards industrial-scale integration.

The EU Batteries Regulation (EU Regulation 2023/1542) mandates minimum recycled-content thresholds for batteries entering the market: from 18 August 2031 batteries must contain at least 16% recycled cobalt, 6% recycled lithium, and 6% recycled nickel. These regulatory requirements ensure a more robust demand base for secondary-source materials and strengthen the circular-economy dimension of the EV supply chain.

In sum, raw materials remain both the foundation and the Achilles' heel of the EV supply chain. Between 2023 and 2025, supply expanded through new mines and refining capacity—from lithium projects in Zimbabwe and Namibia to Indonesia's rapid build-out of nickel and cobalt refining—while governments tightened regulations through China's graphite export controls and the EU's CRMA. Price volatility, exemplified by the lithium carbonate surge of 2022 and collapse of 2023, is likely to persist. Yet the overarching trajectory points towards a more diversified but geopolitically contested raw material base, where companies that secure sustainable and ethical sourcing will enjoy a competitive advantage.

[92] IEA, "Electric vehicle battery sales share by chemistry and region, 2022-2024," in *Global EV Outlook 2025* (Paris: International Energy Agency, April 4, 2025). https://www.iea.org/data-and-statistics/charts/electric-vehicle-battery-sales-share-by-chemistry-and-region-2022-2024.

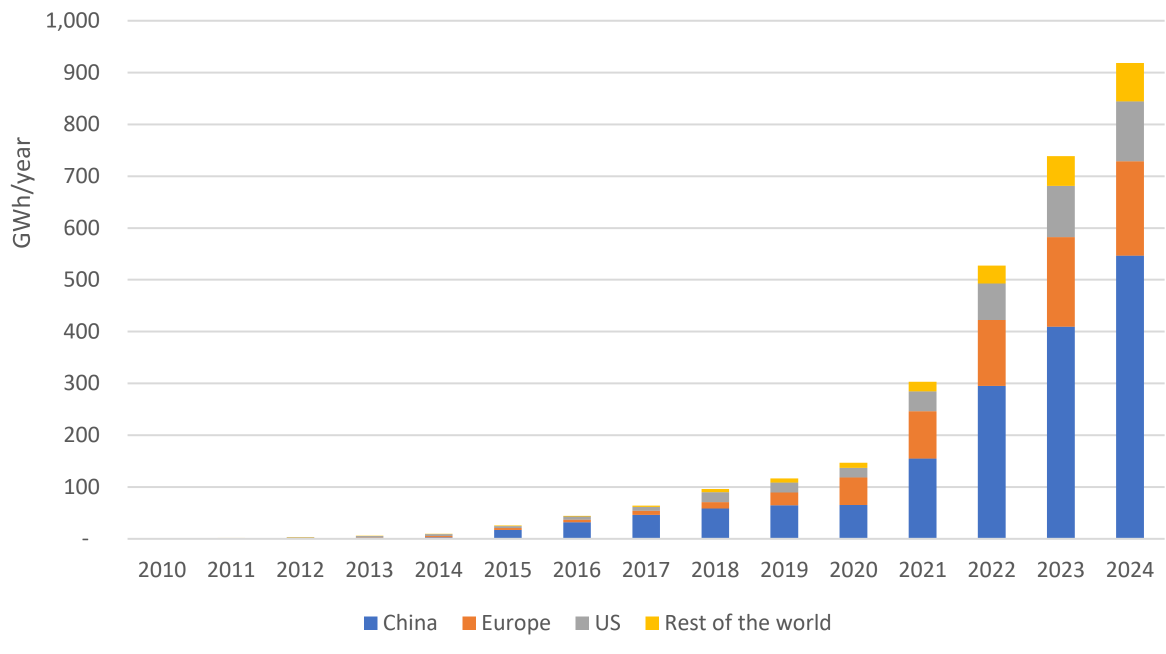
2. Battery production

Battery cells and packs are the core energy-storage system in an EV and typically account for about 30-40% of vehicle manufacturing cost. The EV battery value chain encompasses several stages: processing of raw materials into battery-grade chemicals, synthesis of cathode and anode active materials, cell manufacturing, and final pack assembly.

Between 2022 and 2025, this segment has expanded at an unprecedented pace. Clean-technology manufacturing investment rose by around 50% yoy in 2023, with approximately 80% directed towards solar-photovoltaic and battery production facilities. Global cell-manufacturing capacity additions accelerated sharply in 2023, while average battery-pack prices resumed a steep decline during 2023-2024 due to easing raw-material prices and emerging overcapacity in the supply chain.[93]

Over the same period, significant technological shifts have taken place. The industry has gravitated towards lower-cost chemistries, particularly LFP, which supplied more than 40% of global EV-battery demand by capacity in 2023. New pack architectures such as cell-to-pack and cell-to-chassis designs are being adopted to improve volumetric efficiency and streamline assembly. In parallel, early commercialization of sodium-ion batteries is under way, marking the next stage of diversification in EV-battery technology and contributing to continuing reductions in cost and complexity.

Figure 41: Electric vehicle battery demand by region, 2010-2024



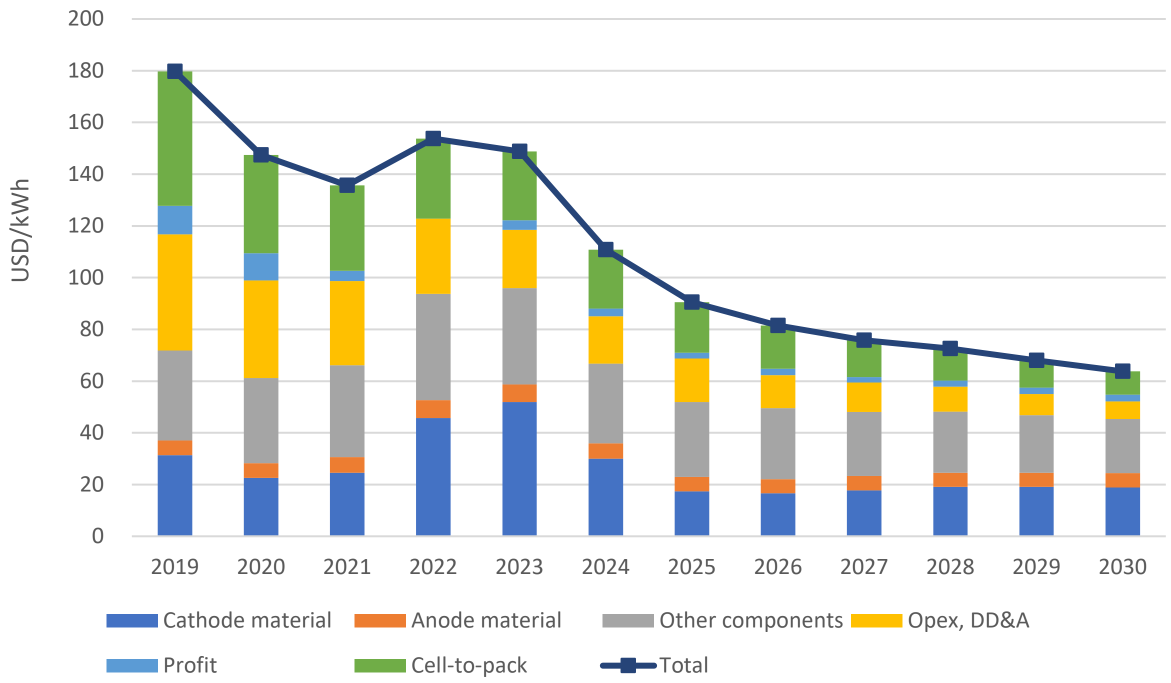
Source: IEA, compiled by LFSCI

[93] IEA, *Energy Technology Perspectives 2024 – Executive summary*, International Energy Agency (Paris, October 30, 2024), https://iea.blob.core.windows.net/assets/a8b8cf1a-5a29-44f6-ba98-e7b2ab05e67f/ETP-24ExecutiveSummary.pdf.

Battery costs, which fell by about 90% from 2010 to 2020,[94] experienced temporary turbulence during 2021-2022 due to surging raw-material prices—especially lithium and nickel. After dropping steadily for a decade, the average lithium-ion pack price rose from US$136 per kWh in 2021 to US$154 per kWh in 2022, marking the first year-on-year increase. As raw-material prices corrected in 2023, average pack costs resumed their downward trend, falling slightly to USD$148 per kWh. By late 2024, average global pack price was around US$111 per kWh, with LFP packs in China priced averaged at US$53 per kWh.[95]

Industry benchmarks suggest that around US$80 per kWh remains the rough threshold for cost parity between EVs and internal-combustion vehicles at the retail level.[96] This target may be reached later this decade as production scales up, lower-cost chemistries proliferate (LFP, LMFP, sodium-ion), and new manufacturing technologies mature. However, solid-state batteries—despite higher energy density—are expected to remain costlier in the near term.

Figure 42: Average battery pack prices



Note: 2024-2030 are estimates
Source: Goldman Sachs, compiled by LFSCI

[94] James Frith, "Battery Price Declines Slow Down in Latest Pricing Survey," *Bloomberg*, November 30, 2021, https://www.bloomberg.com/news/articles/2021-11-30/battery-price-declines-slow-down-in-latest-pricing-survey.

[95] Goldman Sachs Research, "Electric vehicle battery prices are expected to fall almost 50 percent by 2025;" Colin McKerracher, "China's Batteries Are Now Cheap Enough to Power Huge Shifts," *Bloomberg* 2024, https://www.bloomberg.com/news/newsletters/2024-07-09/china-s-batteries-are-now-cheap-enough-to-power-huge-shifts.

[96] Goldman Sachs Research, "Electric vehicle battery prices are expected to fall almost 50 percent by 2025."

In the US, the IRA provides a US$35 per kWh tax credit for domestically produced cells and US$10 per kWh for battery modules, effectively reducing the net cost of US-made packs by up to one-third.[97] For example, a nominal pack cost of US$100 per kWh could fall to an effective cost of about US$65 per kWh after tax incentives. This substantial advantage has raised competitiveness concerns in Europe, where manufacturers warn that US-produced EV batteries could undercut EU output unless comparable support mechanisms are implemented.

2.1 Global battery manufacturing hubs

Battery manufacturing remains heavily concentrated in East Asia, particularly in China, South Korea, and Japan, although globalization is accelerating as new gigafactories come online in Europe and North America.

China is the undisputed hub of global battery production, accounting for around 80% of worldwide EV-battery cell-manufacturing capacity in 2024, despite decrease from 85% in 2023.[98] The country's leading firms, CATL and BYD Battery, dominate the market both domestically and abroad. Battery production in China is far more vertically integrated than in the US or Europe, reflecting its control not only over cell manufacturing but also the upstream stages of cathode and anode materials.

China represents around 90% of global cathode- and anode-active-material capacity.[99] It also hosts virtually all large-scale production of LFP cells, accounting for about 98% of global capacity, and approximately 65% of NMC cell production capacity—a position far ahead of both South Korea and Japan.[100] China's strength extends not just through cathode, anode, and assembly of cells but into the full value chain: electrolyte and separator manufacture also have significant shares of global output located in China. This integration is underpinned by long-term government-led industrial policy for new-energy vehicles, infrastructure, and materials processing. As a result, even batteries assembled in other regions frequently depend on Chinese-made inputs.

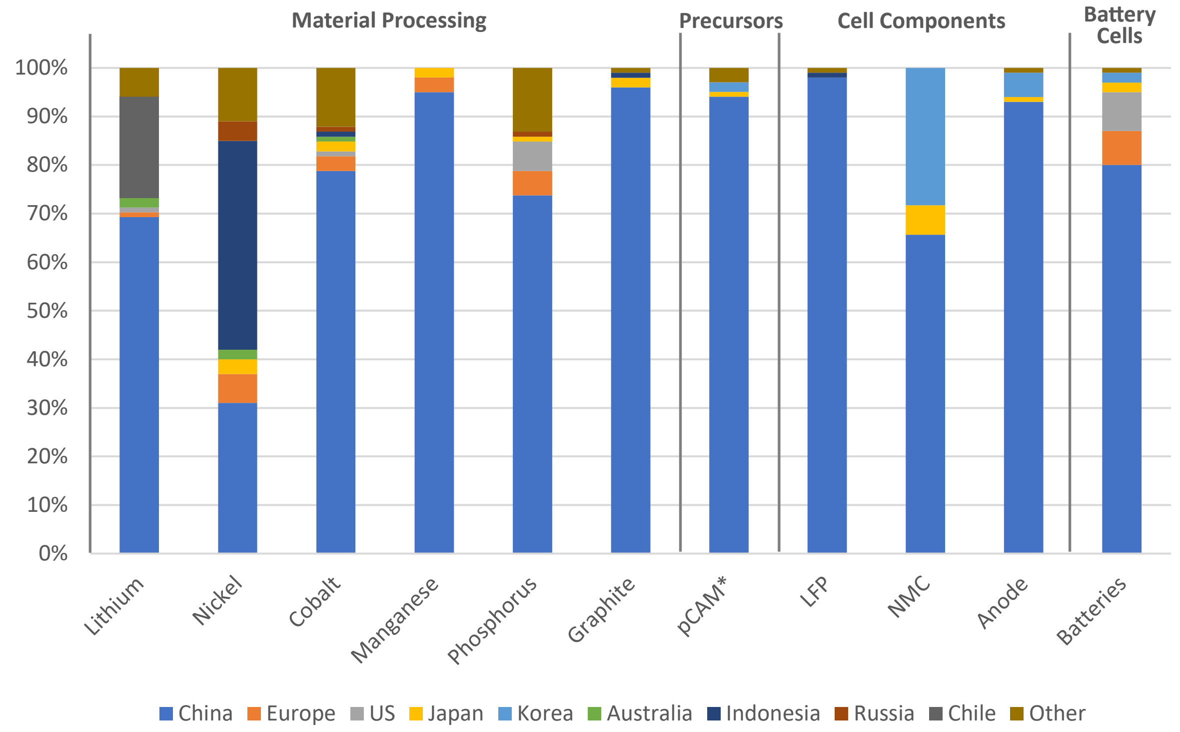
[97] U.S. Department of the Treasury and Internal Revenue Service (IRS), "U.S. Department of the Treasury, IRS Release Proposed Guidance to Continue U.S. Clean Energy Manufacturing Boom, Strengthen America's Energy Security," news release, December 14, 2023, https://home.treasury.gov/news/press-releases/jy1989.

[98] IEA, *Batteries and Secure Energy Transitions*, International Energy Agency (Paris, 2024), https://www.iea.org/reports/batteries-and-secure-energy-transitions; IEA, "The global midstream and downstream battery supply chain, 2024," in *With new export controls on critical minerals, supply concentration risks become reality* (Paris: International Energy Agency, October 17, 2025). https://www.iea.org/data-and-statistics/charts/the-global-midstream-and-downstream-battery-supply-chain-2024.

[99] IEA, *Batteries and Secure Energy Transitions*; IEA, "The global midstream and downstream battery supply chain, 2024."

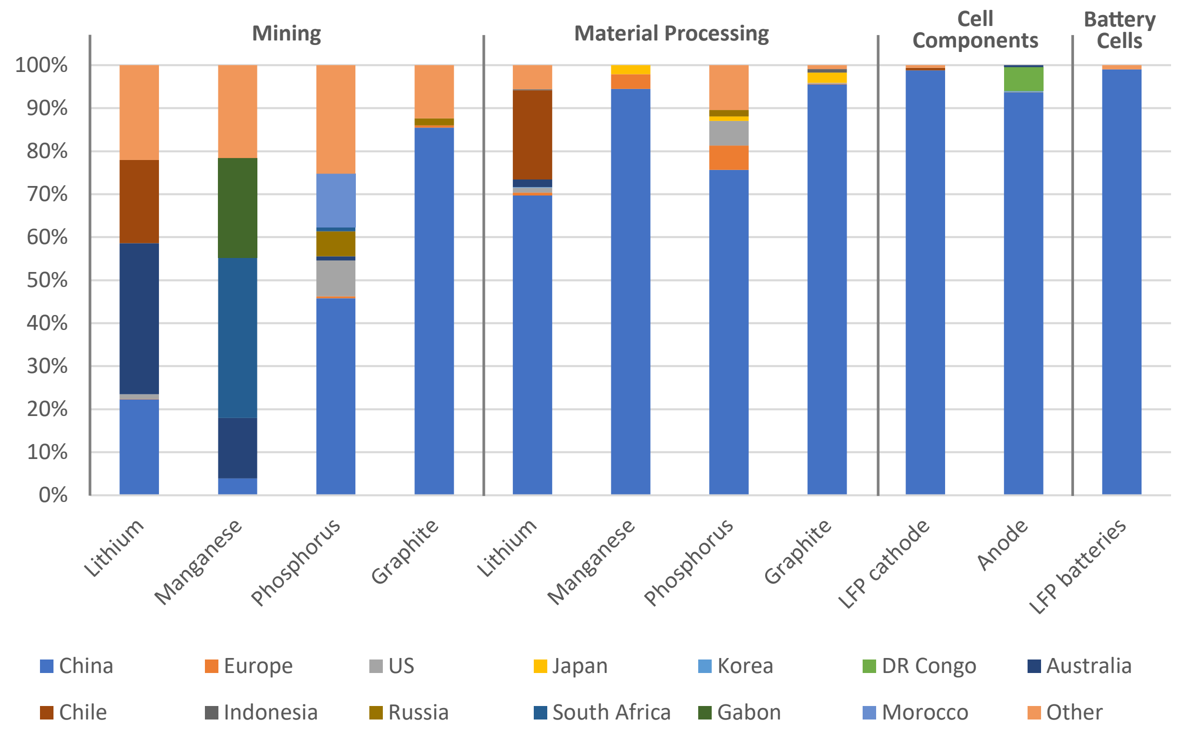
[100] IEA, "The global midstream and downstream battery supply chain, 2024."

Figure 43: The global midstream and downstream battery supply chain, 2024



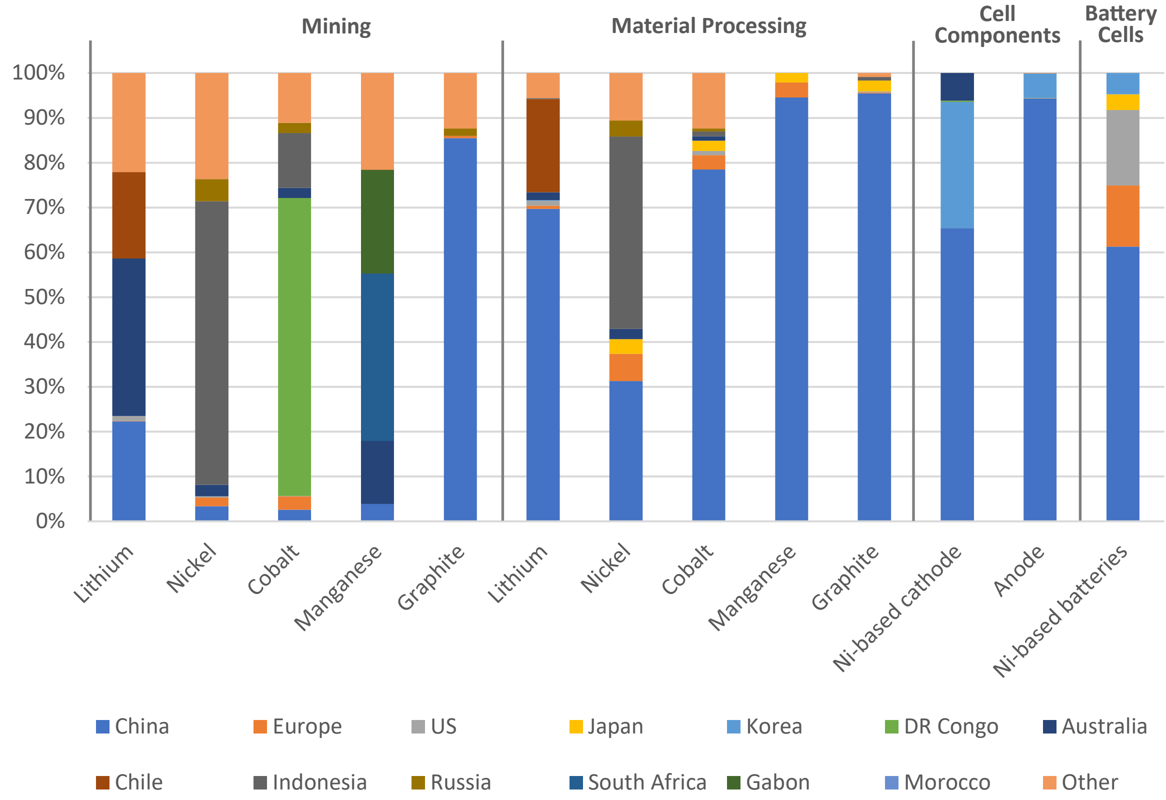
Note: pCAM stands for precursor cathode active material. It is an intermediate material used to make the cathode active material (CAM) in lithium-ion batteries, produced by combining and heat-treating metal compounds with lithium.
Source: IEA, compiled by LFSCI

Figure 44: Geographical distribution of the LFP battery supply chain, 2024



Source: IEA, compiled by LFSCI

Figure 45: Geographical distribution of the nickel-based lithium-ion battery supply chain, 2024



Source: IEA, compiled by LFSCI

In **South Korea** and **Japan**, the legacy of lithium-ion technology remains strong. Companies such as LG Energy Solution (LGES), SK On, Samsung SDI, and Panasonic Corporation continue to play significant roles in global supply. In 2024, Korean and Japanese companies together still accounted for roughly 25-30% of cell manufacturing output.[101] Both countries are now investing heavily overseas to maintain competitiveness and meet local-content requirements. South Korean firms, in particular, are building extensive capacity in the US and Eastern Europe to benefit from the IRA and European policy incentives.

Europe's battery manufacturing industry is expanding rapidly from a low base of 44 GWh in 2020.[102] By the second quarter of 2025, the continent's nominal lithium-ion cell-production capacity had reached an estimated 210 GWh per year, and announced projects could lift this figure to around 2 TWh annually by 2030, representing roughly 10-20% of projected global capacity.[103] Leading initiatives include the Automotive Cell Company (ACC) joint venture

[101] Teo Lombardo et al., "The battery industry has entered a new phase," *International Energy Agency*, March 5, 2025, https://www.iea.org/commentaries/the-battery-industry-has-entered-a-new-phase.

[102] Guillaume Ragonnaud, *Powering the EU's future: Strengthening the battery industry*, European Parliamentary Research Service (January 2025), https://www.europarl.europa.eu/RegData/etudes/BRIE/2025/767214/EPRS_BRI%282025%29767214_EN.pdf.

[103] Tim Wicke et al., "Forecasting Battery Cell Production in Europe: A Risk Assessment Model," *Batteries* 11, no. 2 (2025), https://www.mdpi.com/2313-0105/11/2/76; Aiko Bünting and Kai Giringer, *Rising Electric Vehicle Registrations and New EU Measures: Is*

between Stellantis, TotalEnergies/Saft, and Mercedes-Benz, alongside major Asian investments such as LG Energy Solution's plant in Poland, SK On and Samsung SDI's facilities in Hungary, and CATL's gigafactory in Germany. Many of these operations are concentrated in Poland, Hungary, and the Nordic countries, creating a nascent 'battery belt' across Eastern and Northern Europe.

Despite rapid growth, Europe's battery build-out faces mounting headwinds. Several flagship projects have suffered delays, insolvency, or restructuring, exposing the fragility of the region's capital-intensive manufacturing drive. Northvolt AB (Sweden), once heralded as Europe's leading battery champion, filed for bankruptcy in March 2025, leading to the winding-down of its Swedish operations and the sale of its assets to the US firm Lyten later that year. Britishvolt Ltd (the UK), another high-profile start-up, entered administration in early 2023 and was later liquidated after failing to secure sustained investment. Similar financial pressures have affected other European ventures facing cost overruns and slower-than-expected EV demand. These setbacks illustrate the risks of rapid capacity expansion in a globally competitive market dominated by Chinese and Korean incumbents. Moreover, cost and environmental asymmetries—with producers in regions operating under less stringent regulatory or energy-price conditions—continue to challenge Europe's competitiveness.

In **North America**, capacity remains on a smaller scale but is accelerating strongly. As of 2023, announced EV battery production capacity in the US was around 131 GWh, and the number has reached 200 GWh in 2024, doubling the number in 2022.[104] The country is expected to have an estimated capacity of 1,037 GWh annually by 2028.[105] The US federal founded Argonne National Laboratory projects that North American battery-cell production will exceed 1,200 GWh per year by 2030, enough to supply 12-15 million new EVs annually.[106] The pipeline is very active: EV is the industry among the clean energy sectors that was affected most by the passage of the IRA and related incentives. By mid-2025, there have been 151 projects announced since the adoption of IRA in 2022, representing US$78.3 billion investment and creating about 59,400 jobs.[107] This change was led by Japanese and Korean automobile and battery manufacturers, such as Toyota, LGES, and Hyundai. Canada is

Europe's Battery Industry Thriving?, IPCEI Batteries (June 2025), https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/market-updates/2025-06-BZF_Kurzinfo_Marktanalyse_Q2_ENG.pdf.

[104] Environmental Defense Fund, *U.S. Electric Vehicle Battery Manufacturing on Track to Meet Demand*, Environmental Defense Fund (December 2023), https://www.edf.org/sites/default/files/2023-12/EDF%20Analysis%20on%20US%20Battery%20Capacity%2012.13.23%20final%20v3.pdf; IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

[105] Environmental Defense Fund, *U.S. Electric Vehicle Battery Manufacturing on Track to Meet Demand*.

[106] U.S. Department of Energy, "Battery Cell Production in North America is Expected to Exceed 1,200 GWh per Year by 2030, Providing Enough Cells for at Least 12 Million New EVs annually," *Fact of the Week*, *U.S. Department of Energy*, June 17, 2024, https://www.energy.gov/eere/vehicles/articles/fotw-1347-june-17-2024-battery-cell-production-north-america-expected-exceed.

[107] Kate Magill and Julia Himmel, "Tracking the Inflation Reduction Act's impact on US manufacturing," *Manufacturing Dive*, May 16, 2024, 2025, https://www.manufacturingdive.com/news/inflation-reduction-act-tracker-clean-energy-manufacturing/715116/.

also a key part of the regional build-out, with Volkswagen's PowerCo gigafactory in Ontario planned to reach up to 90 GWh/year capacity, and NextStar Energy, the Stellantis-LGES plant, in Windsor, Ontario targeting above 45 GWh/year, both backed by substantial federal and provincial subsidy support.

2.2 Battery Technology and Chemistry

Battery chemistry diversification has accelerated between 2023 and 2025, revealing a clear divergence between high-energy nickel-rich chemistries and cost-efficient formulations such as **lithium iron phosphate (LFP)**. LFP batteries—which contain neither nickel nor cobalt—have gained popularity for their low cost, enhanced safety, and steadily improving energy density. Globally, LFP accounted for 38% of the EV-battery market in 2022 and has continued to expand thereafter.[108] In China, about three-quarters of new EVs now use LFP cells.[109] Chinese producers such as BYD and CATL have been leading this resurgence. BYD's Blade Battery has become emblematic of LFP's safety and cost advantages, and is now used in Tesla's Model Y.

In contrast, **nickel-manganese-cobalt (NMC)** and **nickel-cobalt-aluminium (NCA)** chemistries remain dominant for longer-range, high-performance vehicles, particularly in Europe and North America. To reduce dependence on cobalt, manufacturers are shifting towards high-nickel compositions such as NMC 811, which contains around 80% nickel.

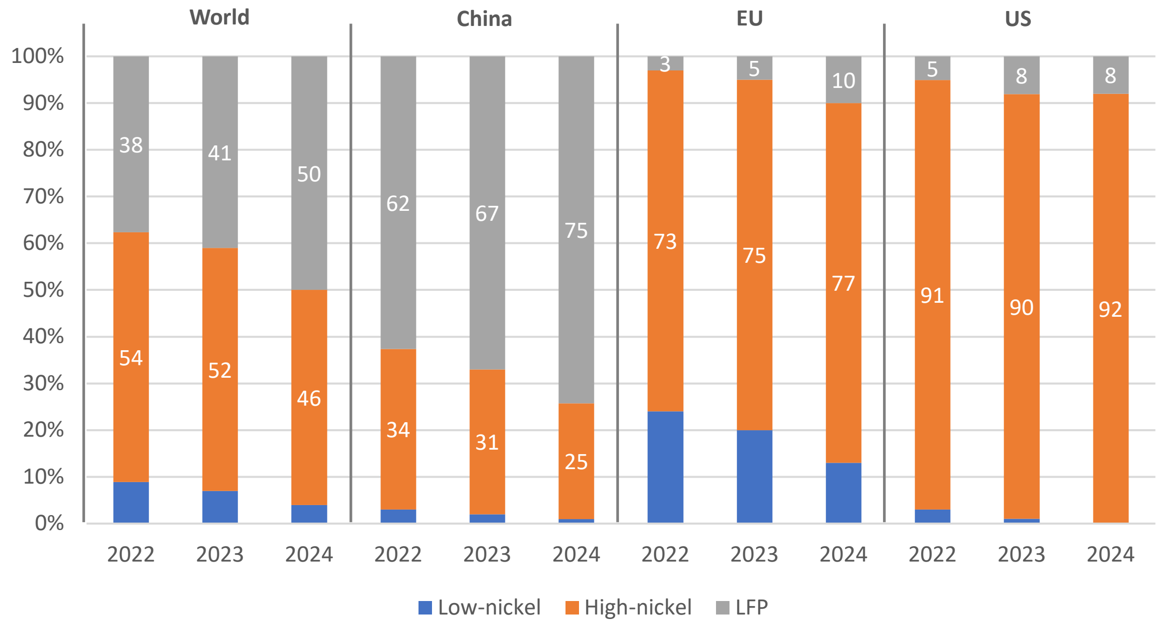
Meanwhile, research and pilot production of **lithium manganese iron phosphate (LMFP)** are advancing. This variant of LFP incorporates manganese to boost energy density by around 15-20% while remaining free of nickel and cobalt.[110] Both CATL and BYD have begun early commercial deployment of LMFP cells, potentially extending LFP's competitiveness into the mid-range EV segment.

[108] IEA, "Electric vehicle battery sales share by chemistry and region, 2022-2024."

[109] IEA, "Electric vehicle battery sales share by chemistry and region, 2022-2024."

[110] Jian Zhao, *Lithium manganese iron phosphate (LMFP) batteries receiving renewed attention in China: expected to be installed mainly in middle-class EVs*, Mitsui & Co. Global Strategic Studies Institute (August 2023), https://www.mitsui.com/mgssi/en/report/detail/__icsFiles/afieldfile/2023/09/19/2308t_zhao_e.pdf.

Figure 46: Electric vehicle battery sales share by chemistry and region, 2022-2024



Source: IEA, compiled by LFSCI

Another frontier is **sodium-ion technology**: CATL in 2023 demonstrated Naxtra, a prototype sodium-ion battery, and began mass production in 2025, achieving 175 Wh/kg energy density. Although sodium-ion batteries have a lower energy density, typically in the range of 120-160 Wh/kg, and are therefore not yet suitable for long-range EVs, they offer notable advantages in cost, cold-climate performance, and resource availability, owing to the abundance of sodium and the absence of lithium, nickel, and cobalt.

Meanwhile, **solid-state batteries**—which replace the liquid electrolyte with a solid medium and can employ a lithium-metal anode—remain the most anticipated breakthrough. Companies such as QuantumScape, Solid Power, and Toyota have achieved notable laboratory- and pilot-scale breakthroughs during 2023-24 and are expected to commercialize all-solid-state batteries by 2027-28. Chinese battery leaders, including CATL and BYD, are also advancing all-solid-state technologies but are expected to reach large-scale production closer to 2030. However, full-scale automotive production remains contingent on overcoming persistent technical barriers—including interface stability between solid electrolytes and electrodes, limited ionic conductivity at ambient temperature, material costs, and the complexity of large-scale manufacturing and quality control.

2.3 Battery pack innovations

Battery integration in vehicles is shifting rapidly as manufacturers adopt **cell-to-pack (CTP)** and **cell-to-chassis/body** architectures that remove intermediate modules and incorporate the pack as a structural element. These approaches reduce inactive materials and raise energy density at the pack level. BYD's Blade Battery is a leading example of CTP design, prioritizing safety and space efficiency; it famously passed nail-penetration tests without ignition. Tesla's 4680 structural packs, used in Austin-built Model Y and the Cybertruck, integrate the cells directly into the vehicle chassis, cutting weight and manufacturing cost. Chinese OEMs are pursuing similar concepts: Xpeng's **CIB (Cell-Integrated-Body)** platform merges the battery top cover with the vehicle floor, and NIO employs CTP packs with defined dismantling and recycling protocols in its latest models. This architectural shift reduces part counts, improves volumetric efficiency, and streamlines assembly operations.

Battery swapping has become a distinctive parallel pathway compare to charging, concentrated mainly in China. NIO operated 2,995 battery-swap stations nationwide at the end of 2024 and exceeded 3,000 early in 2025, with more than 3,500 sites by the end of October 2025. The company's goal is to reach more than 4,000 stations globally by the end of 2025. Swapping typically takes about three to five minutes and the below-five-minute standard is gaining policy support through China's GB/T 40032-2021 technical standard, which is the first mandatory standard of EV battery swapping in China. CATL's EVOGO system and similar state-linked projects are extending the model beyond NIO. Outside the Chinese mainland, uptake remains limited but visible in two-wheelers: Gogoro runs over 2,500 GoStation swap stations in Taiwan, China, and with 620 swap points across India, SUN Mobility is rolling out networks for scooters and rickshaws. Despite infrastructure intensity and design uniformity requirements, swapping continues to serve as an alternative means of alleviating charging delays in high-utilization fleets.

Thermal-management and safety systems have advanced markedly since 2023, with widespread adoption of **heat pumps**, optimized **coolant channels**, and experimental **immersion-cooling** for high-power applications. Although the statistical incidence of EV battery fires remains very low, public scrutiny has prompted regulators to tighten safety standards.[111] The UNECE R100 Rev. 3 regulation now requires a minimum five-minute warning period before a hazardous thermal event, while the US FMVSS 305a standard, finalized in 2024, mandates a thermal-event warning that must trigger within three minutes of onset and remain active for a minimum of five minutes across all electric-vehicle categories. China has gone significantly further: the new GB 38031-2025 standard, taking

[111] Logan Pierce, "Clearing the air: Emerging data and battery trends suggest EVs could bring lower fire risk," *International Council on Clean Transportation (ICCT)*, October 9, 2024, https://theicct.org/clearing-the-air-evs-could-bring-lower-fire-risk-oct24/; NFPA, "Electric vehicle safety information," National Fire Protection Association, 2025, accessed October 27, 2025, https://www.nfpa.org/education-and-research/electrical/electric-vehicles.

effect in July 2026, mandates that no fire or explosion occur for two hours after thermal runaway begins—far exceeding the earlier five-minute rule. The emphasis on thermal stability reinforces demand for LFP chemistries, which are inherently less volatile and increasingly deployed in buses and heavy-duty fleets where safety margins are paramount.

2.4 Major battery manufacturers and market share

By mid-2025, the global EV battery supply landscape remains highly concentrated, dominated by a handful of large manufacturers benefiting from economies of scale. CATL of China continues to hold a clear lead, installing around 190.9 GWh of EV batteries in the first half of 2025 and maintaining its approximately 37.9% global market share from 2024. BYD, also from China, ranks second with an estimated 17.8% share in January-June 2025, up from 17.2% in 2024, driven by robust domestic demand and expanding overseas sales. LGES of South Korea follows in third place with about 9.4% share in the first half of 2025, down from 10.8% in 2024 as Chinese rivals consolidate their dominance.[112]

Among the remaining leaders, SK On of South Korea held roughly 3.9% market share in the first half of 2025, declining from 4.4% in 2024, while Panasonic of Japan slipped slightly from 3.9% in 2024 to 3.7% in early 2025. China's mid-tier producers, including CALB and Gotion High-Tech, continue to expand internationally; CALB, for instance, accounted for around 4.4% of the global market in 2024.[113]

The degree of concentration is notable. In January-July 2025, CATL and BYD together accounted for about 55.7% of all EV battery installations worldwide. Overall, the top five suppliers controlled well over 70% of global EV battery shipments, underscoring a pronounced 'winner-takes-most' dynamic in the sector.

2.5 Supply chain constraints

During 2021-2022, there were significant shortages in **semiconductors** affecting EV production, but by 2023 the chip shortage eased for most components, though some electronics remained tight into 2024.

For **batteries**, the main constraints in 2023-2024 were upstream, stemming from limited availability of processed materials and slow capacity ramp-up in new cell-manufacturing capacity. Some automakers reported production impacts linked to battery supply shortages. In 2022, Rivian's CEO warned that the impending EV-battery shortage could surpass the

[112] Lei Kang, "Global EV battery market share in H1 2025: CATL 37.9%, BYD 17.8%," *CNEVPost*, August 4, 2025, https://cnevpost.com/2025/08/04/global-ev-battery-market-share-h1-2025/; Lei Kang, "Global EV battery market share in 2024: CATL 37.9%, BYD 17.2%," *CNEVPost*, 2025, https://cnevpost.com/2025/02/11/global-ev-battery-market-share-2024.
[113] Kang Global EV battery market share in H1 2025: CATL 37.9%, BYD 17.8%; Kang Global EV battery market share in 2024: CATL 37.9%, BYD 17.2%.

semiconductor shortage in scale, later describing supply constraints as the company's 'biggest constraint' on output in 2023.[114]

To mitigate such risks, OEMs have become increasingly involved in the battery supply chain, either by co-investing in cell plants through joint ventures or by developing in-house cell manufacturing capabilities. In 2019, General Motors partnered with LGES to form Ultium Cells LLC, a joint venture for producing battery cells in the US. Tesla continues to source cells from CATL, Panasonic, and other partners but has also begun producing its own 4680 cells to enhance control over cost, design, and performance. BYD has pursued a fully integrated model—designing and producing its own cells, packs, and vehicles—positioning itself as both a leading automaker and a global battery supplier.

By 2025, the battery segment of the EV supply chain is characterized by **rapid expansion, technological diversification, and strategic importance**. What began as a potential bottleneck has evolved into a global arms race for manufacturing capacity. Nations and companies that secure strong battery production now not only gain economic benefits but also energy security advantages.

The next few years will likely see further shake-ups as new chemistries—sodium-ion and solid-state—move closer to commercialization, while regional rebalancing plays out. Sustained innovation in battery technology, coupled with efficient scaling, remains central to making EVs affordable and widespread—cementing batteries as the core strategic pillar of the global EV transition.

3. Electric motors and electronics

Battery-electric vehicles replace the complex internal combustion engine and multi-speed transmission of a conventional car with a set of comparatively simpler but still critical components—namely the electric motor, power electronics (inverters, converters), and the associated control systems. The supply chain for these components is adapting quickly in response to EV-market growth, yet remains dependent on key inputs such as semiconductors and rare-earth materials.

3.1 Electric motor technologies

Most passenger EVs use **permanent magnet synchronous motors (PMSM)** due to their high efficiency and power density. These motors typically rely on high-performance **neodymium-iron-boron (NdFeB)** permanent magnets, which incorporate neodymium and praseodymium for magnetic strength and often dysprosium or terbium for high-temperature operation. In

[114] Akash Sriram and Abhirup Roy, "Rivian shares fall as supply chain snarls hamper production forecast," *Reuters*, March 1, 2023, https://www.reuters.com/business/autos-transportation/rivian-sees-2023-production-well-below-estimates-recalls-over-12700-vehicles-2023-02-28/; Grace Kay, "Rivian CEO warns the looming EV battery shortage will make the chip shortage feel like 'a small appetizer' for what's to come," *Business Insider*, April 19, 2022, https://www.businessinsider.com/rivian-ceo-warns-electric-car-battery-shortage-chip-shortage-2022-4.

certain high-performance or extreme-temperature applications, **samarium-cobalt (SmCo)** magnets are also employed, offering superior thermal stability though at higher cost. As discussed in section 'III. 1. Raw Materials for EVs', these rare earth elements largely come from China, meaning most EV motors indirectly rely on Chinese magnet supply. In 2024, more than 86% of EV traction motors worldwide contained rare earth magnets.[115] China produced about 240,000 tonnes of NdFeB and SmCo magnets in 2023, accounting for roughly 85-90% of global output.[116]

However, alternatives exist. **Induction motors**, which rely on electromagnetic rotor currents rather than permanent magnets, avoid rare-earth magnets but tend to be slightly less efficient, heavier, and require more intensive cooling. At its Investor Day in March 2023, Tesla announced that its next-generation drive unit will use a permanent-magnet motor designed to eliminate the use of REEs entirely. European automakers such as BMW and Renault S.A. are likewise adopting externally excited synchronous motors (EESMs), which employ copper windings instead of permanent magnets to achieve magnet-free operation.

Manufacturing of EV traction motors is less geographically concentrated than battery-cell manufacturing, but strong clustering remains: many automakers build motors in-house or source from dedicated specialists. Tesla manufactures its own traction motors within its gigafactories, while Volkswagen has established dedicated motor production lines for its MEB platform to secure supply and control quality. In China, many EV manufacturers either produce motors in-house or source them from leading domestic suppliers such as Jing-Jin Electric, which specializes in high-efficiency drive systems.

Germany, Japan, and China remain global centres of motor design and engineering expertise. Nidec Corporation of Japan, formerly known as Nippon Densan Corporation, is one of the world's largest suppliers of electric motors and has invested heavily in new factories across Europe, China and North America. Germany's Bosch, an early pioneer in integrated e-axle technology, serves as a leading Tier-1 supplier of complete electric-drive systems to major automakers. Magna International, based in Canada, has also emerged as a leading developer of eDrive and eBeam axle solutions, supplying integrated drive units and torque-vectoring systems to OEMs such as General Motors, BMW and Mercedes-Benz. China's BYD also designs and manufactures its own traction motors and increasingly exports drive components to overseas markets.

Beyond material substitution, motor innovation is advancing towards higher efficiency and power density. One major trend is **increasing motor rotational speed**. For instance, Lucid's

[115] Bruno Venditti and Sam Parker, "Why Rare Earths Are Critical to EV Motors," (August 30, 2025), https://elements.visualcapitalist.com/why-rare-earths-are-critical-to-ev-motors/.
[116] Daniel, "China's Dominance in Rare Earth Magnet Manufacturing," *Rare Earth Exchanges*, June 16, 2025, https://rareearthexchanges.com/news/chinas-dominance-in-rare-earth-magnet-manufacturing/.

compact drive unit reportedly reaches around 20,000 rpm in its motor-inverter-transmission assembly. Achieving such speeds requires precise bearing systems, lightweight rotors and advanced cooling solutions, drawing on high-performance racing drive-unit know-how.

Multi-motor configurations began as a technological innovation but are now becoming mainstream across the EV industry. These systems mark a shift from traditional single-motor layouts to distributed propulsion, where separate motors drive the front and rear axles to deliver stronger acceleration, better traction, and improved stability. By enabling software-based torque vectoring, they allow power to be distributed intelligently between wheels in real time, enhancing handling, safety, and overall energy efficiency.

Another emerging innovation is the **hub motor**, in which the drive motor is integrated directly into the wheel hub, eliminating traditional axles and enabling novel vehicle architectures—particularly for light-commercial or ultra-compact EVs. However, significant challenges remain: the added unsprung mass from wheel-mounted motors can degrade ride comfort and handling; heat dissipation is more difficult given limited space and exposure; and long-term durability is unproven under real-world conditions, which has limited widespread commercial adoption.

3.2 Power electronics and control systems

Electric vehicles depend critically on **power-electronic components**—chiefly the inverter, which converts direct-current (DC) battery power into alternating current (AC) for the traction motor; the DC/DC converter, which steps down the high-voltage battery output to supply 12-volt vehicle systems; and the on-board charger, which manages AC charging input. In addition, the battery management system (BMS) monitors and regulates the condition of the battery cells and is becoming increasingly sophisticated in its electronic design.

These components rely on semiconductor devices, particularly power semiconductors such as insulated-gate bipolar transistors (IGBTs) and, increasingly, silicon carbide metal-oxide-semiconductor field-effect transistor (SiC MOSFETs) for inverters. The global market for SiC devices is projected to grow at a compound annual growth rate of around 26% between 2022 and 2030, driven by rapid adoption in electric vehicles, renewable energy systems, and industrial power electronics.[117] SiC power-semiconductor devices have become highly sought after in EV inverters because they offer lower switching and conduction losses compared to traditional silicon-IGBT modules. Studies suggest that using SiC in traction inverters can increase driving range by up to around 7% and allow smaller, lighter inverter

[117] Albert Brothers et al., "New silicon carbide prospects emerge as market adapts to EV expansion," October 17, 2023, https://www.mckinsey.com/industries/semiconductors/our-insights/new-silicon-carbide-prospects-emerge-as-market-adapts-to-ev-expansion.

units.[118] Tesla pioneered the use of SiC MOSFET power modules via STMicroelectronics in the Model 3's traction inverter, and by around 2023 many other OEMs—including Hyundai and several Chinese manufacturers—were moving towards SiC-based main inverters, particularly on 800V EV platforms.

Supply of SiC wafers and devices was tight during 2021-22, as leading firms such as Wolfspeed, Onsemi, ROHM, and Infineon invested heavily to expand capacity. By 2024, the supply situation had improved somewhat, though constraints remained, especially among Chinese EV makers that still rely predominantly on foreign SiC chip supply and in some segments continue to use silicon-IGBT modules.

Globally, the power-electronics supply chain spans key geographies: for example, Infineon (Germany), ON Semiconductor (US), STMicroelectronics (Europe), Mitsubishi Electric and ROHM (Japan) all produce IGBT and SiC modules for automotive use. At the same time, Chinese entrants—motivated by export controls and import dependencies—are accelerating localization; for instance, SanAn Optoelectronics initiated SiC MOSFET wafer development in China in 2023. Nevertheless, many advanced-SiC wafer capacities remain dominated by Western firms.

In addition to traction inverters and DC/DC converters, EVs rely on numerous **electronic control units (ECUs)** that coordinate functions such as battery management, powertrain dynamics, and driver assistance. The global semiconductor shortage of 2020-22 exposed this dependence, forcing production halts across major automakers when suppliers such as Renesas Electronics and NXP Semiconductors faced factory disruptions. By 2023, OEMs were collaborating more closely with chipmakers to co-design domain controllers—integrated computing platforms that consolidate multiple ECUs—in order to improve performance, streamline software integration, and strengthen supply resilience. For example, notable collaborations include Volkswagen Group and Qualcomm for next-generation system-on-chips (SoCs); Hyundai Motor Group and NVIDIA for AI-driven mobility solutions; Honda and Renesas for high-performance SoC development; and Mercedes-Benz and Athos Silicon for advanced computing platforms.

Similar power-electronic architectures also underpin the charging infrastructure essential to EV deployment. High-power DC fast chargers (typically 150-350 kW) employ advanced inverter and rectifier modules—often based on SiC technology—and are produced by firms such as ABB Ltd., Siemens AG, and Tritium NV. Meanwhile, lower-power AC and mid-power

[118] John Li, "The Emerging Adoption and Future Trends of SiC and GaN in EVs," *IDTechEx*, June 13, 2024, https://www.idtechex.com/en/research-article/the-emerging-adoption-and-future-trends-of-sic-and-gan-in-evs/31201; Lucas Barroso Spejo, Tanya Thekemuriyil, and Renato Amaral Minamisawa, "Estimation of Energy-Saving Potential Using Commercial SiC Power Converters," *Energies* 17, no. 18 (2024), https://www.mdpi.com/1996-1073/17/18/4570; Maurizio Di Paolo Emilio, "Silicon carbide (SiC) inverter extends EV range by over 7%," *Power Electronic News*, April 4, 2023, https://www.powerelectronicsnews.com/silicon-carbide-sic-inverter-extends-ev-range-by-over-7/.

DC chargers account for the bulk of installed units worldwide, particularly in residential and workplace settings. Together, these systems extend the demand for automotive-grade semiconductors into the wider EV ecosystem and link vehicle electrification to broader grid and infrastructure challenges.

3.3 E-axles and integrated power-domain platforms

A notable industry trend emerging since the late 2010s is the growing adoption of **integrated e-axle systems**—modular drive units that package the motor, inverter, and gearbox within a single housing. Leading Tier-1 suppliers, including GKN Automotive, Dana Incorporated, and ZF Friedrichshafen have introduced scalable e-axle platforms that simplify vehicle architecture, reduce weight, and improve drivetrain efficiency.

As these integrated drive units become more common, their production and installation require close coordination between automakers and system suppliers. The assembly of motors and inverters into the vehicle is typically carried out either by the automaker, when these components are built in-house, or by Tier-1 suppliers that deliver ready-to-install drive systems to OEMs.

Building on this, the industry is now moving towards next-generation **'power-domain' integration**, which incorporates the e-axle within a wider electrical and electronic architecture. These advanced systems merge the motor, inverter and gearbox with components such as the DC/DC converter, on-board charger (OBC), and vehicle-control unit (VCU), sometimes even integrating battery-management and thermal-control functions. The goal is a unified, software-defined powertrain that improves efficiency, reduces parts count and supports over-the-air optimization.

Chinese manufacturers are at the forefront of this transition. Huawei's DriveONE platform integrates seven key functions—the motor, motor controller, reduction gear, OBC, DC/DC converter, power distribution unit, and vehicle-control system—into a single 'integrated power-domain' unit. BYD's 8-in-1 system takes a similar approach, merging drivetrain, power electronics and control hardware into one cohesive platform. These architectures effectively incorporate the e-axle as a sub-module, representing a higher level of system-wide integration that blurs traditional boundaries between Tier-1 suppliers and OEMs.

3.4 Supply chain characteristics and challenges

Motors and power-electronics components differ from battery packs in shipping and manufacturing dynamics: they are smaller, less heavy, and typically contain fewer hazardous materials, which allows for more geographically centralized production. Historically, many motor components—such as electrical-steel laminations and magnet assemblies—have been processed in China or ASEAN countries and exported. For example, Vietnam and Thailand have increasingly attracted investment in producing electrical components for EV motors (such as coils), particularly as Japanese suppliers diversify from China. India's PLI scheme is encouraging domestic manufacture of EV motor components and advanced automotive technologies, and several Indian component firms are forming partnerships with foreign technology companies. Although EV-component exports from India remain limited, the country's large auto-component manufacturing base positions it to become a niche exporter of motor-part sub-assemblies.

A key bottleneck during the early 2020s was the supply of advanced **electrical steel** for traction motors. The market for this specialized silicon steel has expanded rapidly as EV and wind-turbine demand grows, with Chinese producers such as Baowu and Ansteel, and global firms like ArcelorMittal, investing to increase output. **Rare-earth magnet materials** remain another point of vulnerability: prices rose sharply in early 2022 before easing in 2023 amid weak electronics demand, yet any new Chinese export restriction on neodymium-praseodymium (NdPr) would quickly drive motor costs higher.

On the **power-electronics** front, some automakers in 2023 continued to report extended lead times for high-voltage transistors, though new capacity—such as Infineon's Dresden expansion and Bosch's Reutlingen line—is gradually coming online. Many OEMs are maintaining higher inventories of critical chips rather than relying solely on just-in-time practices. The fragility of this segment was highlighted again in 2025 by the Nexperia crisis, when the Dutch government intervened in the operations of the Chinese-owned semiconductor manufacturer on national-security grounds. The dispute triggered retaliatory measures and temporarily disrupted supplies of legacy power-electronic devices to European automakers. The episode underscored how even mature, lower-margin semiconductor segments can become choke points when geopolitics intrudes on corporate governance and trade flows.

In conclusion, the EV motors and electronics segment is entering a stage of maturity: modern drive systems typically achieve overall motor efficiencies exceeding 85%.[119] The current priorities are cost reduction, critical-material substitution, and strengthened supply security—especially for semiconductors, magnets and electrical steel. While public attention remains concentrated on batteries, the motors-and-electronics tier is equally vital: an EV's performance and reliability depend fundamentally on its motor and inverter. Although rare-earth supply poses an enduring risk, the presence of capable producers across Asia, Europe, and North America suggests that this part of the supply chain is comparatively robust and flexible.

119 Synopsys, "What is Vehicle Electrification?," n.d., accessed November 1, 2025, https://www.synopsys.com/glossary/what-is-vehicle-electrification.html.

4. Vehicle assembly and logistics

EVs have transformed automotive manufacturing by replacing engines and fuel tanks with battery packs, e-axles, and sophisticated electronic systems. Yet, the factory sequence—body stamping and welding, painting, and final assembly—remains broadly similar to that of internal-combustion vehicles. What has changed is the industrial geography and policy environment: localization, trade incentives, and technology adoption now determine where and how EVs are built.

By 2025, global EV assembly capacity is projected to exceed near-term demand as dozens of new factories reach completion. Worldwide EV production rose to about 17.3 million units in 2024, while sales totalled roughly 17 million, signalling an emerging risk of overcapacity. The imbalance is most pronounced in China, which produced around 12.4 million EVs—over 70% of global output—and where fierce competition has triggered price cuts and industry consolidation.[120] Several smaller start-ups have exited the market as leading players such as BYD, Geely, and SAIC captured scale advantages. The surplus is fuelling an aggressive export push: China exported 1.25 million EVs in 2024, mainly to Europe and emerging Asia, up 78% yoy.[121]

The EU has become the principal destination for these exports. Imports of BEVs from China into the EU reached 438,000 units in 2023, worth €9.7 billion.[122] In response, the European Commission imposed definitive countervailing duties of up to 45.3% (including the existing 10% tariff) on Chinese-built BEVs in October 2024 for a five-year period, citing the distortionary effects of state subsidies and below-market financing.[123]

4.1 Global EV assembly footprint and localization strategies

As of the end of October in 2025, there were 1,180 vehicle plants worldwide, of which 407 are in the Chinese mainland, followed by the US, which is home to 89.[124] EVs are increasingly assembled on retooled lines within existing facilities or in newly built, dedicated plants designed around high-voltage architectures and digital manufacturing systems. In

[120] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*; Opletal China EV global sales in Dec: Xpeng 36,695, Huawei 49,474, Geely 116,206, BYD 509,440.

[121] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

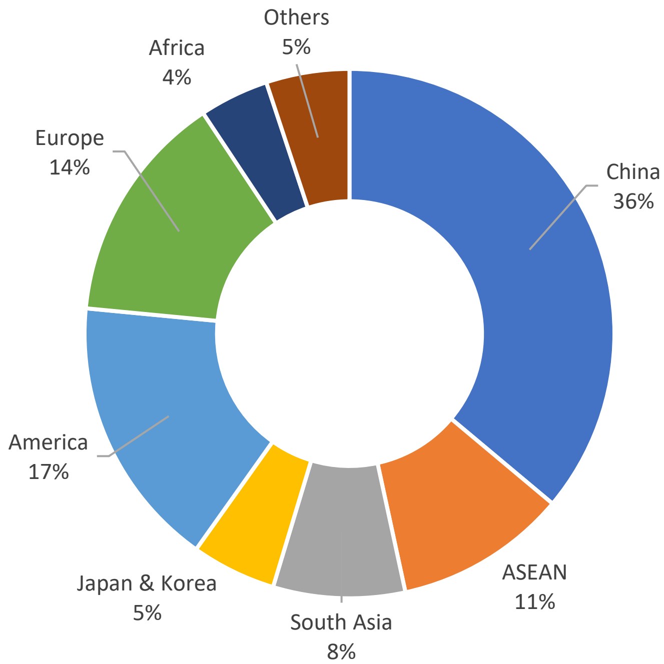
[122] ACEA, "Fact sheet: EU-China vehicle trade," *European Automobile Manufacturers' Association*, June 12, 2024, https://www.acea.auto/fact/fact-sheet-eu-china-vehicle-trade-2024/.

[123] European Commission, "Questions and Answers on the disclosure to interested parties of draft definitive findings of anti-subsidy investigation into imports of battery electric vehicles from China," updated August 20, 2024, https://ec.europa.eu/commission/presscorner/detail/en/qanda_24_4302; Lisa O'Carroll, "EU to put tariffs of up to 38% on Chinese electric vehicles as trade war looms," *The Guardian*, June 12, 2024, https://www.theguardian.com/business/article/2024/jun/12/eu-import-tariffs-chinese-evs-electric-vehicles-trade-war.

[124] MarkLines, "OEM Plants Interactive Map (2,388 listed locations as of end of October)," updated November 1, 2025, accessed November 4, 2025, https://www.marklines.com/en/global/index.

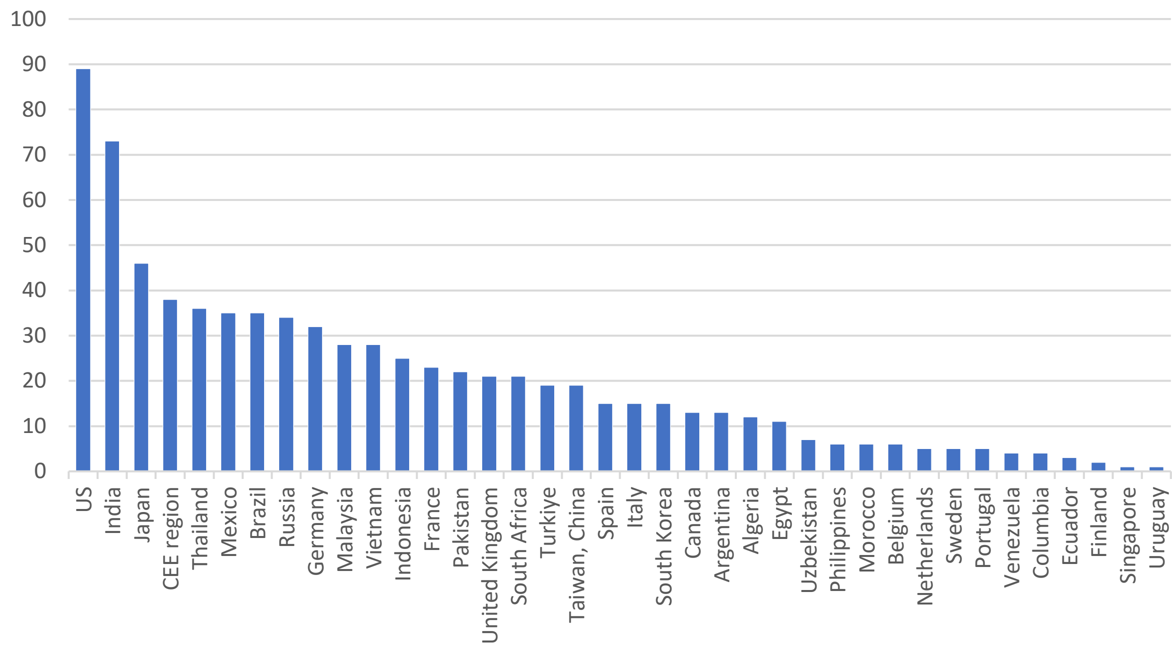
2024, China produced 12.4 million EVs, representing more than 70% of global output, while Europe produced about 2.8 million and North America 1.8 million.[125]

Figure 47: Number of vehicle plants by region (as of the end of 2025)



Source: MarkLines, compiled by LFSCI

Figure 48: Number of vehicle plants (as of the end of 2025, Chinese mainland excluded)



Source: MarkLines, compiled by LFSCI

[125] IEA, *Global EV Outlook 2025: Expanding sales in diverse markets*.

In **China**, production remains concentrated in coastal industrial belts such as Guangdong, Shanghai and Jiangsu, but has rapidly diffused inland. Anhui Province, led by Hefei and Wuhu, produced around 2.4 million vehicles between January and September 2025, surpassing Guangdong to become China's top automotive province. New-energy vehicles (NEVs) in Anhui represented roughly 1.22 million units, representing more than one out of every 10 NEVs made in China.[126] The Hefei cluster hosts BYD, NIO, JAC-Volkswagen and Chery, supported by local battery and component ecosystems. Other inland nodes such as Wuhan in Hubei and Changsha in Hunan are expanding rapidly, while coastal megacities including Shenzhen and Shanghai continue to anchor high-volume export production.

Across **Europe**, EV manufacturing is centred in Germany, France and Central-Eastern Europe. Volkswagen's Zwickau complex was fully converted to all-electric output by 2022, while Renault's Douai plant in northern France integrates battery-pack assembly on site. Central-Eastern Europe is growing in importance as a lower-cost production corridor: Volvo's Košice plant in Slovakia, Mercedes-Benz Kecskemét in Hungary, and Škoda Mladá Boleslav in the Czech Republic are adding significant EV capacity, while BYD's factory in Szeged, Hungary, is scheduled to begin mass production in 2026.

In **North America**, the US remains the regional hub of EV assembly expansion. Tesla's Fremont (California) and Austin (Texas) plants anchor the west and south, while Ford's Rouge Electric Vehicle Centre in Michigan and Volkswagen's Chattanooga (Tennessee) facility serve the Midwest and southeast. Hyundai's Metaplant America in Georgia began production in late 2024 with a targeted annual capacity of 300,000 units, while General Motors' Ramos Arizpe plant in Mexico produces the Blazer EV and Equinox EV for continental markets. Tesla's planned Nuevo León Gigafactory, announced in 2023, remains delayed amid macroeconomic uncertainty.

In **Northeast Asia**, Japan continues a retrofit-first strategy. Nissan's Oppama plant still produces the Leaf for domestic and export markets, and Toyota's Motomachi facility builds the bZ4X on a dedicated EV line formerly shared with hybrid models. South Korea, by contrast, operates large-scale, export-oriented EV production at Ulsan and Gwangmyeong and is expanding capacity in the US to qualify under IRA local-content rules. **India** is also emerging as a South-Asian assembly base, supported by the PLI scheme and high import duties that encourage localization. Tata Motors, Mahindra & Mahindra and MG Motor India are ramping up BEV lines, while Hyundai, BYD and Suzuki-Maruti are adding capacity for domestic and regional markets.

[126] Xiuzhong Li, "Anhui Overtakes Guangdong to Become China's Top Auto Production Province in First Three Quarters," *YiCai*, October 28, 2025, https://www.yicaiglobal.com/news/anhui-overtakes-guangdong-to-become-chinas-top-auto-production-province-in-first-three-quarters; 贤言强语, "安徽登顶，江浙晋升，广东跌落第八！新能源汽车产量格局大洗牌！," *懂車帝*, October 29, 2025, https://www-lf.dongchedi.com/article/7566630918308332047.

Government incentives, tariffs and logistics considerations now play decisive roles in localization. Because EVs are heavy and costly to ship, producing close to the target market lowers freight costs and avoids import duties. Under the *United States-Mexico-Canada Agreement* (USMCA), vehicles must meet a 75% regional-value-content requirement for tariff-free access. The IRA further ties federal tax credits to North-American final assembly and to the sourcing or processing of critical minerals in the US or its free-trade-agreement partners. This framework continues to drive upstream localization in North America. Canada is positioning itself as a regional refining and processing hub, with Electra Battery Materials' cobalt refinery in Ontario under development, and FPX Nickel planning the Baptiste Project in British Columbia. Meanwhile, Australia continues to supply raw minerals under the *US-Australia Climate, Critical Minerals and Clean Energy Transformation Compact*.

In Europe, the CRMA in 2023 encourages regional autonomy and mid-stream investment. Umicore in Poland and Rock Tech Lithium in Germany are adding cathode and refining capacity to reduce import dependence. Orano and XTC New Energy Materials have formed joint ventures in Dunkirk, France, to produce precursor and cathode active materials for electric-vehicle batteries, while Verkor is constructing a large-scale battery manufacturing complex nearby integrating low-carbon production and circular-economy practices. Together, these initiatives illustrate the global re-routing of EV supply chains, aligning assembly geography with trade and subsidy frameworks while diversifying away from single-source risk.

Plant-location economics also vary by region. In the US, most new EV and battery-manufacturing plants are concentrated in southern 'right-to-work' states such as Georgia, Tennessee and North Carolina, where lower unionization, land and labour costs, and generous incentives create competitive advantages. In Europe, Central and Eastern European countries have drawn substantial automotive investment thanks to lower wages, proactive national incentives and proximity to Western European markets. In China, manufacturers benefit from deep supply-chain ecosystems, large domestic market scale and high plant utilization, yielding a cost advantage of about 20-30% over Western plants.[127] Automation levels are typically higher in next-generation EV plants than in legacy ICE lines—because many EV plants were designed from the outset with advanced robotics and digitalized workflows. Nonetheless, companies such as Tesla, Inc. have publicly acknowledged that 'excessive automation was a mistake' and moved towards a hybrid approach combining robotic precision with human flexibility.

[127] Stephen Dyer and Yichao Zhang, "AlixPartners 2025 Global Automotive Outlook: China's "New Operating Model" Redefines Speed, Efficiency, and Market Leadership in Automotive Industry Amid Accelerating disruptions," *AlixPartners*, July 3, 2025; Melissa Cyrill, "China's Electric Vehicle Supply Chain and Its Future Prospects," n.d., accessed November 5, 2025, 2025, https://www.china-briefing.com/doing-business-guide/china/sector-insights/china-s-electric-vehicle-supply-chain-and-its-future-prospects.

4.2 Logistics challenges

Delivering EV components and finished vehicles presents distinct logistical challenges compared with conventional automobiles.

Transporting lithium-ion batteries remains among the most complex aspects of EV logistics because these units are classified as Class 9 hazardous goods (UN 3480) under IATA and IMO regulations owing to their high energy density and flammable electrolytes. Updated *IATA Dangerous Goods Regulations* (DGR 66th edition, 2025) impose stricter testing, packaging and state-of-charge limits for air shipments, while the International Maritime Organization (IMO) is now in the process of developing mandatory rules for maritime carriage of EVs and battery packs. As compliance costs rise, manufacturers increasingly prefer to localize cell and pack production within major markets, since shipping processed raw materials or precursors is less expensive and administratively simpler than transporting assembled packs. Earlier practices—such as Nissan's trans-Pacific shipment of Leaf battery packs from Japan to the UK—are being replaced by regional gigafactories designed to serve domestic assembly plants.

Finished-vehicle logistics also face new physical and regulatory constraints. EVs typically weigh 20-30% more than comparable internal-combustion models, reducing the number of units per truck or ship and slightly increasing per-vehicle freight costs. Fire-risk perception has grown since the 2022 *Felicity Ace* cargo-ship blaze, which resulted in total vessel loss and heightened insurer scrutiny. In response, maritime insurers have raised premiums for EV cargoes, and shipowners are investing in fire-suppression upgrades and battery-risk monitoring systems for roll-on/roll-off (Ro-Ro) vessels.

The COVID-19 pandemic and the ensuing semiconductor shortage exposed severe weaknesses in just-in-time logistics. During 2021-22, global chip production disruptions forced temporary shutdowns at major OEMs, by 2024, manufacturers had implemented structural countermeasures. Automakers diversified suppliers, increased buffer inventories for critical chips and sensors, and in some cases chartered dedicated cargo flights or vessels to maintain production continuity. Because key power-semiconductor devices such as SiC MOSFETs and automotive MCUs remain concentrated among a few producers—Infineon, STMicroelectronics, onsemi, and ROHM—OEMs are adopting dual-sourcing, long-term capacity agreements, and regional fabrication strategies to mitigate future disruptions. These adjustments signal a gradual shift from efficiency-oriented to resilience-oriented logistics management throughout the EV industry.

4.3 Vehicle assembly process and innovations

EV assembly is in some respects simpler than that of internal-combustion vehicles: there are fewer moving parts, and no complex engine or transmission marriage. However, **EVs**

introduce distinctive manufacturing steps—notably the installation of large, high-voltage battery packs, electrical testing, and integration of the thermal-management system. Most automakers have reorganized production lines accordingly. Dedicated 'battery marriage' stations are now common, where the underbody or chassis is joined with the battery pack from below by robotic lifts. As battery packs typically weigh 400-700 kg, this process is highly automated. Safety procedures are paramount: high-voltage protocols require special worker training, isolated zones, and strict control of charge levels during assembly to mitigate fire risk.

The relative simplicity of EV powertrains also affects factory design. Traditional engine and transmission machining—often housed in separate plants—is largely eliminated. Electric drive units (motor + inverter + gearbox) are compact modules and can be supplied pre-assembled by Tier-1 manufacturers such as Bosch, ZF, or BorgWarner. This reduces in-house complexity and frees up space for battery assembly or electronics integration.

A particularly visible manufacturing innovation is the use of ultra-large die-casting machines to produce substantial sections of a car's structure in a single piece of aluminium—popularly called **'gigacasting'** or **'megacasting'**. Tesla pioneered this approach with the Model Y, replacing more than 70 smaller stamped and welded parts in the rear underbody with one casting—a change that reportedly cut costs for that section by around 40% and removed hundreds of welds.[128] The approach has influenced peers: by 2025, Toyota, General Motors, Volvo, Hyundai, and Chinese OEMs such as Geely (Zeekr) and NIO have all moved to adopt or pilot gigacasting. Toyota unveiled a prototype EV body using front- and rear-gigacast sections in 2023, while GM applied large castings to its Ultium-based SUVs. The technology requires immense machines—such as the Idra Group's 'Giga Press' of up to 9,000 tons clamping force—and advanced aluminium alloys. Bühler of Switzerland and LK Technology of China are now major competitors, supplying equipment to multiple EV OEMs.

Gigacasting substantially simplifies the body shop and can remove hundreds of welding robots: Tesla claimed to have eliminated more than 600 in switching from the Model 3's welded rear to the Model Y's cast structure.[129] The trade-off is that repairs can be more complex, as damage to a cast section may require full replacement. Still, most automakers consider the efficiency, cost, and weight benefits to outweigh these drawbacks.

[128] Ilkhan Ozsevim, "Production minimalism: How Megacasting is reshaping automotive manufacturing," *Automotive Manufacturing Solutions*, August 28, 2025, https://www.automotivemanufacturingsolutions.com/editors-pick/production-minimalism-how-megacasting-is-reshaping-automotive-manufacturing/660564; Edwin Pope and Mengyin Tao, "Gigacasting: The hottest trend in car manufacturing," *S&P Global*, November 1, 2023, https://www.spglobal.com/mobility/en/research-analysis/gigacasting-the-hottest-trend-in-car-manufacturing.html.

[129] Suvrat Kothari, "The Giga Press: Tesla's Game-Changing Manufacturing Process Goes Mainstream," *InsideEVs*, June 21, 2023, https://insideevs.com/news/673158/tesla-giga-casting-manufacturing-becomes-mainstream/.

EV assembly and logistics are thus undergoing a structural transformation characterized by localization—to qualify for incentives and avoid tariffs—combined with process innovation, automation, and partial re-regionalization of supply chains. For businesses, production footprints are becoming multi-continental and more capital-intensive; for policymakers, the challenge is to balance openness that enables scale economies with strategic safeguards for domestic industry. From a supply-chain standpoint, the EV sector is moving towards greater resilience through redundancy and diversification, albeit at the cost of increased coordination complexity across globally distributed plants.

IV. Technological Innovations Reshaping EV Supply Chains

Technological breakthroughs are becoming a decisive force in the reconfiguration of EV supply chains. Whereas the past decade has been driven largely by policy incentives and resource constraints, the competitive frontiers has started to shift towards digitalization, automation, and platformization. Increasingly, EVs are described as the 'next smartphone': not merely a greener vehicle, but a platform technology that integrates mobility, energy, and data into a single ecosystem. Just as smartphones transformed communications and commerce by combining computing power with connectivity and applications, EVs are emerging as 'computers on wheels,' blurring the boundaries between the automotive, robotics, and digital technology sectors.

Just as the smartphone era demanded new supply chains for semiconductors, sensors, and app ecosystems, the EV revolution requires a supply chain capable of supporting software-centric architectures, high-performance batteries, and integrated energy systems. In other words, technological innovation is not only reshaping the product but also restructuring the production networks that deliver it.

One of the most transformative tools is the **digital twin**. By creating real-time virtual replicas of factories, supply chains, and even entire vehicle platforms, manufacturers can simulate production processes, optimize logistics, and anticipate disruptions before they occur. Tesla, Volkswagen, and BYD already use digital twins to reduce development cycles and streamline plant operations, while battery producers such as CATL employ them to forecast cell performance and monitor safety parameters across global production networks. These virtual models not only shorten time-to-market and lower prototyping costs but also provide resilience in the face of volatile mineral markets and geopolitical shocks.

Artificial intelligence is playing a parallel role in redefining quality assurance. AI-driven inspection systems, particularly those using computer vision, are deployed to detect micro-defects in battery electrodes, monitor gigacasting welds, and evaluate the integrity of power electronics. Chinese producers such as BYD and CALB have reported significant reductions in defect rates, while European and Japanese automakers are adopting similar systems to ensure compliance with tightening safety and sustainability regulations. In this sense, quality control is no longer a cost centre but a strategic enabler of market access, especially in regions such as the EU where the Batteries Regulation now mandates stringent traceability and documentation.

At the production level, **flexible manufacturing systems** are replacing rigid assembly lines. EV plants are increasingly designed to accommodate multiple models and powertrains, with reconfiguration enabled by modular assembly, robotics, and automation. Gigacasting—pioneered by Tesla and rapidly adopted by Chinese firms like NIO and XPeng—has further revolutionized production by consolidating dozens of parts into single aluminium castings, slashing costs and assembly times. This flexibility allows firms to respond to volatile consumer demand and to adapt production strategies to localization rules under the US IRA or Europe's CBAM.

Underlying these advances is the broader adoption of the **industrial internet**, which integrates industrial IoT, 5G connectivity, cloud platforms, and big data analytics. China's Industrial Internet Platform (*工业互联网平台*) initiatives, Germany's Industry 4.0, and US digital manufacturing hubs all aim to embed real-time intelligence into production and logistics networks. Automakers now use predictive logistics to monitor battery shipments, dynamic inventory management to optimize component flows, and collaborative platforms where suppliers co-design parts with OEMs. The result is a more transparent and responsive supply chain, though concerns over data security and interoperability remain pressing.

Beyond these core technologies, a wider digital ecosystem is taking shape. **Autonomous driving** and **advanced driver-assistance systems (ADAS)** are shifting the supply chain's value centre from mechanical components to semiconductors, sensors, and AI chips provided by firms such as Nvidia, Mobileye, and Huawei. **Over-the-air (OTA) software updates** are making EVs 'software-defined vehicles,' enabling continuous improvements in performance, safety, and infotainment while generating recurring revenue streams for automakers. **Battery management systems** are evolving into intelligent platforms that predict degradation, optimize charging, and extend the life cycle of cells—an area critical for both cost efficiency and ESG compliance. **Additive manufacturing and collaborative robotics** are enhancing flexibility and customization, while cybersecurity has become a non-negotiable element of the EV supply chain, with regulations such as UNECE WP.29 mandating robust safeguards against hacking and ransomware.

The impact of these technological shifts goes beyond operational efficiency; they are **restructuring the supply chain itself** by altering where value is created, how firms coordinate, and which capabilities are considered strategic. As the locus of value migrates from engines and transmissions to batteries, power electronics, and the safety-critical layers of vehicle software, automakers are increasingly bringing these domains in-house to secure intellectual property, manage costs, and comply with regulatory standards. Firms like BYD exemplify this model by producing cells, packs, motors, and semiconductors internally, while Volkswagen has created PowerCo to take direct control of cell production. Software is also being drawn into tighter vertical ownership when it underpins core vehicle operating systems, battery management, or cybersecurity. By internalizing these functions, OEMs consolidate value capture and ensure regulatory alignment in strategically decisive domains.

At the same time, **advances in digital platforms and industrial internet systems** reduce coordination costs and enable a wider set of actors to interact directly. This dynamic makes the industry more decentralized and ecosystem-oriented in complementary layers, such as infotainment, charging infrastructure, and specialized components. Software illustrates this duality most clearly: while the core architecture and operating system are pulled inside OEMs, the application layer is increasingly open to partners such as Google, Huawei, or regional app developers, resembling the smartphone model of controlled platforms with diverse ecosystems layered on top. Similarly, joint ventures such as IONITY in Europe or the adoption of Tesla's NACS standard in North America demonstrate how rivals cooperate to accelerate charging roll-outs. Initiatives like Catena-X extend this logic deeper into the supply base by enabling Tier-2 and Tier-3 suppliers to share data directly with OEMs and one another, flattening traditional hierarchies and enhancing compliance transparency.

Together, these shifts are fundamentally altering the structure and dynamics of EV supply chains. Automakers are consolidating control over batteries, power electronics, and safety-critical software—where value and risk are concentrated—while opening complementary areas such as infotainment, charging, and digital services to partners, where collaboration accelerates innovation and spreads costs. This dual trend of vertical integration at the core and ecosystem collaboration at the periphery is redrawing supplier-automaker relationships and redefining supply chain governance. Labour-intensive assembly is giving way to tech-intensive automation, enabling production to move closer to end markets. Compliance, once viewed as a regulatory burden, is becoming a source of competitive advantage as AI inspection and digital documentation ease entry into tightly regulated regions. Most importantly, the EV is evolving beyond a vehicle into a platform for services and ecosystems. Much like smartphones catalysed the app economy, EVs are spawning new value networks around charging, energy trading, mobility-as-a-service, and software applications.

Looking ahead to 2030, EV supply chains are likely to be digitally orchestrated, AI-optimized, and regionally diversified. Digital twins will be standard in factory design and supply chain modelling; AI inspection will underpin safety and compliance regimes; flexible gigacasting and robotics will be widely deployed; and industrial internet platforms will provide real-time coordination across continents. As EVs converge with software, data, and connectivity, their role will extend far beyond transport, shaping energy systems, consumer lifestyles, and industrial strategies. For automakers, suppliers, and policymakers alike, the strategic challenge is no longer just building cars but building platforms for the new digital economy.

V. Sustainability and Responsible Sourcing

As EV supply chains scale, scrutiny of Environmental, Social and Governance (ESG) performance has intensified. EVs cut use-phase emissions, but the full climate and social dividends depend on low-carbon manufacturing, responsible raw-material sourcing, and robust end-of-life systems. Between 2023 and 2025, the EU's Batteries Regulation and CBAM, and US forced-labour enforcement materially raised the compliance bar for the sector.

1. Carbon footprint and clean energy

While EVs have largely reduced emissions on the road, producing them—especially battery cells and aluminium parts—remains carbon-intensive. The EU Batteries Regulation (Regulation (EU) 2023/1542) now mandates battery makers to measure and report the carbon footprint of each EV battery model from extraction to production, and by 2027 will set maximum CO_2/km limits per battery, effectively requiring use of cleaner energy or offsets. Digital battery passports, accessible via QR code, are mandated for EV and industrial batteries from 18 February 2027, embedding traceability and due-diligence data.

In response to this groundbreaking requirement, battery firms are already adjusting by building factories in regions with renewable energy. CATL's Sichuan plant reports 100% hydropower and zero-carbon certification, illustrating the push to lower embedded emissions at source. Verkor in Dunkirk, France, is building a gigafactory aimed at producing low-carbon battery cells, explicitly designed with decarbonized energy inputs in mind and located in a port region to facilitate circular supply-chain synergies.

On materials, the EU CBAM enters its definitive regime in 2026 (after an October 2023-December 2025 transitional reporting phase) for iron & steel and aluminium—key EV inputs—nudging OEMs towards 'green steel' and low-carbon aluminium contracts. Mercedes-Benz and BMW have signed supply deals with H2 Green Steel, which produces green steel using green hydrogen. Mercedes has also publicized low-carbon aluminium use with Norsk Hydro. Given that recycled aluminium typically uses about 5% of the energy of primary aluminium, expanding secondary aluminium content is a practical lever to shrink vehicle footprints.[130]

Lifecycle results reflect these shifts. The IEA's Global EV Outlook shows sizeable life-cycle greenhouse gas (GHG) advantages for EVs that widen as grids decarbonize,[131] and recent

[130] International Aluminium Institute, "As well as aluminium recycling, saving 95% of the energy needed for primary aluminium production, the recycling process saves a similar percentage in greenhouse gas emissions," n.d., accessed November 7, 2025, https://international-aluminium.org/landing/as-well-as-aluminium-recycling-saving-95-of-the-energy-needed-for-primary-aluminium-production-the-recycling-process-saves-a-similar-percentage-in-greenhouse-gas-emissions/.
[131] IEA, *Global EV Outlook 2024*.

ICCT work for the EU finds BEVs 73% lower than petrol cars on a full lifecycle basis under current grid mixes.[132]

Major automakers have set portfolio decarbonization goals: GM targets carbon-neutral products and operations by 2040; the Volkswagen Group aims for group-wide net-zero by 2050 and net-zero production sites by 2040; Volvo Cars targets climate-neutral manufacturing by 2025 and value-chain decarbonization en route to 2040.

2. Recycling and circular economy

The EU Batteries Regulation hard-wires circularity. Producer take-back is mandatory, and the regulation sets material recovery targets for all waste batteries to be achieved by 31 December 2027 (≥90% for cobalt, copper, lead, nickel; 50% for lithium), rising by 31 December 2031 to ≥95% for cobalt, copper, lead, and nickel and 80% for lithium. Minimum recycled content in new EV/industrial batteries applies from August 2031 (≥16% cobalt, 6% lithium, 6% nickel, 85% lead) and increases again in 2036. Battery passports (from 2027) will display recycled content and footprint data, enabling market pull for 'low-carbon, high-recycled' batteries.

Recycling technologies have improved: large incumbents like Umicore report >95% recovery for nickel/copper/cobalt and rising lithium recovery using integrated pyro-hydro flowsheets; several hydrometallurgical specialists claim up to 95% overall metal recovery, though independent validations vary by facility and feed.[133] The recycling industry is expected to explode in the early-to-mid 2030s as first-generation EV packs retire, with Europe, North America, and China racing to add capacity. Second-life applications of EV batteries for less demanding use (like stationary solar storage) are gaining traction. For example, Nissan has been using old LEAF batteries for backup power in buildings; Connected Energy, a startup in the UK, repurposes bus batteries for grid storage. At plant level, OEMs are increasingly targeting zero-landfill operations and closed-loop water systems, especially for cell lines where solvent recovery and water-treatment loads are high.[134]

3. Waste governance

Extended Producer Responsibility (EPR) is now standard in the EU battery regime; landfilling or incinerating industrial/automotive batteries is generally prohibited.[135] The US still lacks

[132] Marta Negri and Georg Bieker, *Life-cycle greenhouse gas emissions from passenger cars in the European Union: A 2025 update and key factors to consider* (ICCT, July 8 2025), https://theicct.org/publication/electric-cars-life-cycle-analysis-emissions-europe-jul25/.

[133] EPRI, *Novel Advances in Lithium Ion Battery Recycling and Pretreatment* (December 2024), https://restservice.epri.com/publicdownload/000000003002029517/0/Product; Mark Peplow, "Lithium-ion battery recycling goes large," *C&EN*, November 19, 2023, https://cen.acs.org/environment/recycling/Lithium-ion-battery-recycling-goes/101/i38.

[134] GM, *2023 Sustainability Report: Journey to Zero* (April 30, 2024), https://www.gm.com/content/dam/company/docs/us/en/gmcom/company/GM_2023_SR.pdf.

[135] European Parliament, "Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC," (2006). https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32006L0066.

federal EV-battery EPR laws, but states are moving: California adopted broad battery EPR for portable/embedded batteries (AB 2440), and EV traction-battery stewardship legislation is under active consideration (e.g., California SB 615, 2025). North American recycling capacity is expanding regardless, driven by scrap from gigafactories and early end-of-life returns.

Safety and environmental risk management remain essential. Construction and ramp-up at new gigafactories can expose workers to hazards; in Windsor, Ontario, provincial records show multiple stop-work orders and issues including elevated carbon monoxide during construction at the NextStar Energy site.[136] Upstream, concerns persist around water stress from brine extraction in South America and tailings management for high pressure acid leach (HPAL) of laterite nickel; Indonesia signalled in 2021 that new deep-sea tailings disposal approvals would not proceed amid environmental scrutiny.

4. Responsible sourcing

The social dimension of sustainability in EV supply chains focuses increasingly on responsible sourcing and labour standards. Key concerns include child labour in artisanal cobalt mining in the DRC, alleged forced-labour risks in parts of the polysilicon and mineral-processing sector in China, and indigenous rights linked to lithium extraction in South America. Governments and companies alike are tightening oversight to ensure materials are sourced under verifiable, ethical conditions.

In the US, the *Uyghur Forced Labor Prevention Act* (UFLPA)—in force since June 2022—presumes inadmissibility for goods made wholly or partly in China's Xinjiang region unless firms provide clear evidence of non-involvement in forced labour. Enforcement has expanded beyond solar products to include automotive components and battery materials such as aluminium, tyres, and graphite.[137] This has prompted automakers and battery producers to undertake deeper supply-chain audits—sometimes tracing inputs back to mines or refineries—and to adopt provenance-tracking tools such as blockchain, QR coding, and supplier declarations.

The EU's Batteries Regulation similarly mandates due-diligence and traceability obligations for critical raw materials. From 2027, all EV and industrial batteries placed on the EU market must include a digital 'battery passport' providing origin, recycled-content, and ESG

[136] Emma Loop, "Ontario hit NextStar EV battery plant in Windsor with 10 stop work orders over hazards, documents show," *CBC*, October 20, 2025, https://www.cbc.ca/news/canada/windsor/nextstar-ev-windsor-stellantis-lg-battery-health-safety-ontario-9.6943227.

[137] Nichola Groom, "EV battery imports face scrutiny under US law on Chinese forced labor," *Reuters*, August 20, 2023, https://www.reuters.com/business/us-imports-auto-parts-face-scrutiny-under-law-chinese-forced-labor-2023-08-17/; U.S. Customs and Border Protection (CBP), "FAQs: Uyghur Forced Labor Prevention Act (UFLPA) Enforcement," n.d., accessed November 7, 2025, https://www.cbp.gov/trade/forced-labor/faqs-uflpa-enforcement.

information. These frameworks are shaping global practice and are expected to drive wider harmonization of sustainability reporting standards.[138]

Industry responses complement regulation. Many OEMs and suppliers participate in the Responsible Minerals Initiative (RMI) and the Global Battery Alliance, supporting audit protocols and community-development projects in mining regions. Ford Motor Company supports field programmes in the DRC that formalize artisanal cobalt and copper cooperatives and require OECD-aligned due-diligence audits of mines and refiners; The Volkswagen Group mandates full supply-chain disclosure down to the mine for new battery-material contracts from 2020 onwards.

Labour and social transitions also remain under scrutiny. EV manufacturing requires fewer assembly workers than internal-combustion production, raising concerns about regional job displacement. The EU Just Transition Mechanism and national retraining funds are designed to support reskilling for battery and component industries, while public subsidies for new gigafactories typically include job-creation clauses. At the same time, unions have urged improved conditions for migrant workers employed at construction and production sites in parts of Eastern Europe.[139]

5. Green labelling and consumer pressure

With regulatory data becoming standardized (carbon-footprint classes, recycled content, passport data), 'low-carbon' and 'responsibly sourced' batteries are emerging as differentiators—affecting B2B procurement and, increasingly, consumer perception. Early battery-passport deployments (e.g., Volvo's EX90) suggest the data will also support residual-value assessment in used EV markets.[140]

[138] European Union, "Regulation (EU) 2023/1542 of the European Parliament and of the Council concerning batteries and waste batteries," in *EUR-Lex* (July 28 2023). http://data.europa.eu/eli/reg/2023/1542/oj.

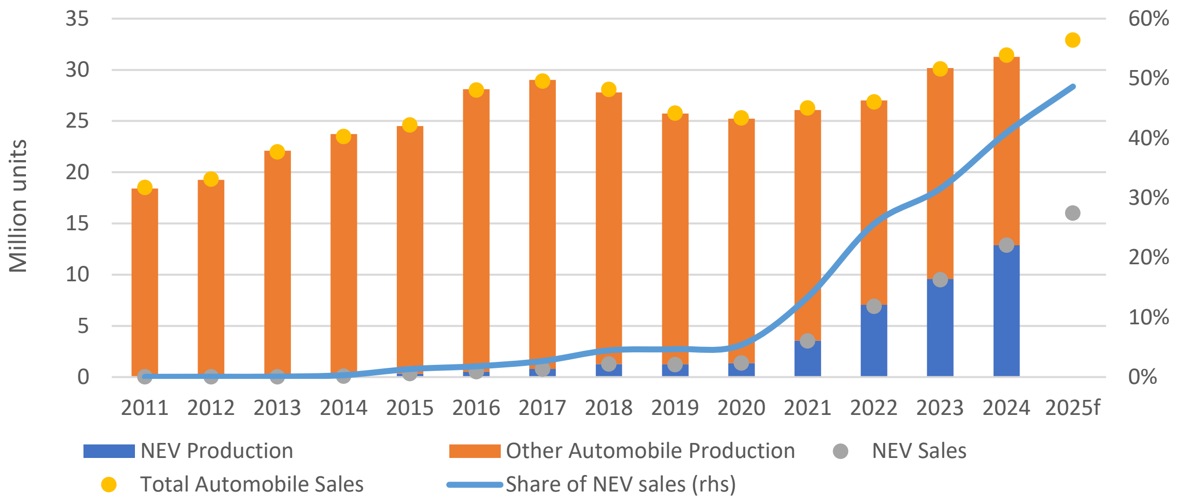
[139] ILO, "Enhancing Social Protection for Migrant Workers: Challenges and Strategies in the East and Horn of Africa," *International Labour Organization*, May 27, 2024, https://www.ilo.org/resource/article/enhancing-social-protection-migrant-workers-challenges-and-strategies-east.

[140] Nick Carey, "Volvo to issue world's first EV battery passport ahead of EU rules," *Reuters*, June 4, 2024, https://www.reuters.com/business/autos-transportation/volvo-issue-worlds-first-ev-battery-passport-ahead-eu-rules-2024-06-04/.

VI. China's EV Industry and its Global Role

China has become the linchpin of the global EV industry, serving simultaneously as the world's largest producer, consumer, and exporter of new-energy vehicles. In 2024, China accounted for roughly 71% of global EV production and close to 65% of sales, with an estimated 36 million electric cars on the road. While the vast majority of output continues to be absorbed by domestic demand, exports have expanded sharply, underscoring China's growing influence on global markets and its transition from an inward-oriented to an outward-integrated EV powerhouse.

Figure 49: EV production and sales in China, 2011-2025



Source: CAAM and various public sources, compiled by LFSCI

The foundations of China's leadership lie in **the completeness of its industrial ecosystem**. From upstream mineral refining to mid-stream battery cell manufacturing and downstream assembly, China maintains unrivalled scale and efficiency. It performs most of the global processing of key minerals such as graphite, rare earth elements, lithium and cobalt. This mid-stream dominance gives Chinese firms decisive leverage over the cost and availability of essential materials. At the technological core, Chinese battery leaders CATL and BYD collectively supply more than half of the world's EV batteries.[141] Their vertical integration—from materials sourcing to pack assembly—underpins China's cost advantage and accelerates innovation in cell chemistry. Meanwhile, a dense domestic supplier base supports the production of motors, inverters, and power-electronics devices. Firms such as Jing-Jin Electric and Huawei enable integration of electrification and digital technologies, further enhancing supply-chain efficiency.

[141] Christopher Chico, "China is the EV market. CATL is the benchmark.," *The Battery Chronicle*, August 18, 2025, https://christopherchico.substack.com/p/china-is-the-ev-market-catl-is-the.

Policy support has been equally decisive. The *New Energy Vehicle Industry Development Plan (2021-2035)* and successive fiscal packages, including the RMB520 billion tax-incentive scheme extended through 2027, have stimulated large-scale investment and sustained consumer adoption. The dual-credit system has pressed automakers to meet fuel-efficiency and new-energy targets, while local governments have fostered regional specialization in battery, motor, and electronics clusters. Meanwhile, Chinese manufacturers are advancing towards next-generation technologies—such as sodium-ion and solid-state batteries, rare-earth-free drive motors, and AI-driven production systems—that promise further cost reductions and performance gains.

1. China's EV supply chain investment goes global

Having achieved dominance at home, Chinese EV automakers are **expanding overseas** to capture new markets and mitigate trade risks. In 2023, China overtook Japan to become the world's largest vehicle exporter, shipping nearly one million EVs, chiefly to Europe, Southeast Asia, and Latin America. Companies such as BYD, SAIC-MG, Geely, and NIO have established or announced assembly facilities in Thailand, Hungary, Brazil, and Mexico to secure local-market access and qualify for regional incentives. By 2023, Chinese OEMs had installed full-process capacity of 1.2 million vehicles across nine countries; forecasts indicate 3.1 million by 2028.[142] However, these advances have triggered heightened scrutiny: the EU's 2023 anti-subsidy investigation into Chinese EV imports and the restrictive sourcing rules under the US IRA illustrate how China's competitive strength has become a focal point of industrial-policy rivalry.

2024 marked a watershed moment in China's EV industry: for the first time, Chinese companies invested more in overseas supply chain capacity—US$16 billion—than the US$15 billion committed at home. This historic shift represents a dramatic reversal from the past decade, when nearly 80% of investment focused on the Chinese market.[143] The reorientation reflects a confluence of push and pull factors reshaping the industry's globalization strategy.

The primary impetus is **severe domestic overcapacity**. Battery production capacity in 2024 was twice domestic demand and 20% above global needs, causing a decrease of new domestic investment by 90% from the 2021-2022 policy-led peak.[144] This glut has fuelled brutal price wars that squeezed margins across the entire supply chain, from cell manufacturers to component suppliers.

[142] Linda Lew and Jinshan Hong, "China Carmakers to Double Overseas Capacity to Beat Tariffs," *Bloomberg*, October 23, 2024, https://www.bloomberg.com/news/articles/2024-10-23/china-carmakers-set-to-double-overseas-capacity-to-beat-tariffs.

[143] Global Times, "China's EV supply chain sees overseas investments outpace domestic ones for the first time in 2024: report," *Global Times*, August 19, 2025, https://www.globaltimes.cn/page/202508/1341210.shtml.

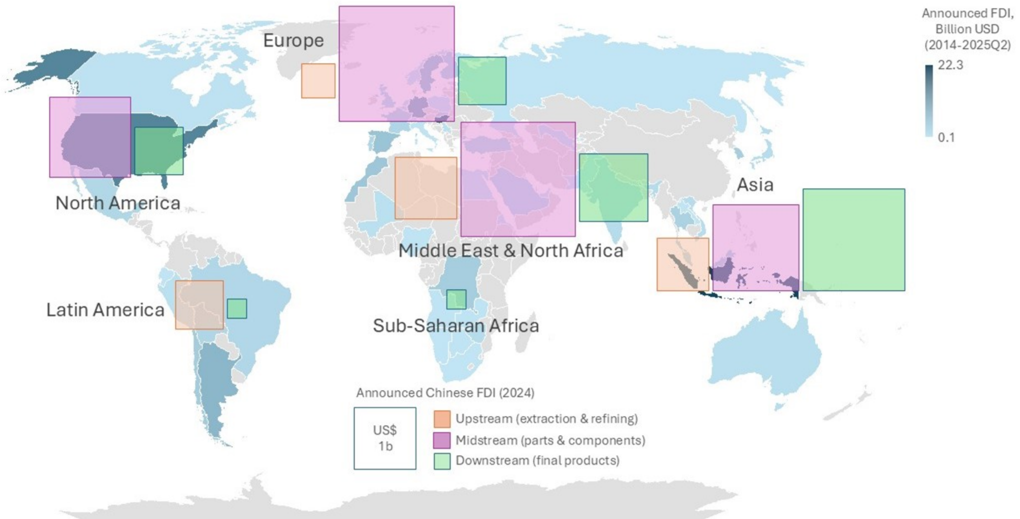
[144] Rhodium Group, "China's Global Investments in the EV Value Chain," China Cross-Border Monitor, 2025, accessed September 30, https://cbm.rhg.com/research-note/chinas-global-investments-ev-value-chain.

Simultaneously, **trade barriers and localization demand** compel Chinese firms to establish foreign production. The EU's anti-subsidy tariffs and the US IRA's restrictive sourcing rules have made exports less viable, pushing companies to build 'behind the border'. Foreign automakers like Tesla and BMW also demand localized supply chains to reduce transport costs and geopolitical risks, prompting Chinese battery giants to follow their clients abroad. These frictions have accelerated a more fundamental transformation: Chinese EV firms are now globalizing their capital at unprecedented scale, moving from an export-led model to a deeply integrated overseas production footprint.

2. Geographic distribution and value chain dynamics

Chinese EV investment has created a globally distributed manufacturing footprint, with cumulative outbound investment reaching US$143 billion between 2014 and 2025.[145] The geographic focus is shifting rapidly:

Figure 50: Announced Chinese FDI in the global EV supply Chain



Source: Rhodium Group, compiled by LFSCI

Europe remains a key hub, particularly **Hungary**, which attracted US$18 billion in investment from 2014 to the second quarter of 2025 and has become the second-largest battery producer outside China.[146] CATL's €7.3 billion gigafactory in Debrecen anchors this cluster. However, Europe's share of new project announcements is declining—from 41% before 2024 to a smaller portion as Chinese firms diversify.[147]

[145] Rhodium Group, "China's Global Investments in the EV Value Chain."
[146] Rhodium Group, "China's Global Investments in the EV Value Chain."
[147] Rhodium Group, "China's Global Investments in the EV Value Chain."

Asia has emerged as the top destination, drawing 33% of new investment since 2024. **Indonesia** leads globally with US$22 billion, leveraging its nickel resources and massive domestic market targeting 2.5 million EVs by 2030.[148] BYD is building a US$1 billion plant in West Java, operational by January 2026. **Thailand** serves as a regional export hub, with BYD's 150,000-unit plant shipping vehicles across ASEAN and to Europe.[149]

Resource-rich regions are gaining importance, with Africa receiving 75% of Chinese raw materials investment in Q2 2024 as firms diversify beyond traditional Asian and Latin American sources.[150]

Middle East and North Africa (MENA) captured 25% of new investment since 2024, with Turkey becoming a strategic bridge to Europe.[151]

China's investments extend along the EV supply chain. **Upstream investment** in mineral extraction peaked between 2021 and 2023 but has since slowed due to price volatility and foreign ownership restrictions. In contrast, **midstream components**—particularly battery manufacturing—and **downstream vehicle assembly** are increasingly becoming the primary focus of China's overseas EV supply chain investment. This shift reflects both market-access requirements and efforts to circumvent tariffs on finished vehicles.

Battery manufacturing now dominates outbound investment, accounting for 74% of overseas investment in 2024. This concentration underscores the capital-intensive nature of cell production and the early-mover advantage of firms such as CATL, which launched a US$2 billion plant in Germany in 2018—the sector's first major overseas foray. Today, China hosts nearly 85% of global battery production capacity, reinforcing its central role in the EV value chain.[152]

3. Outlook: China's lead is likely to persist

Despite ongoing efforts in the US, Europe, and other economies to localize production, **the global EV supply chain remains deeply intertwined with China**. This interdependence is now physically embedded abroad: Chinese battery plants in Hungary supply European automakers; Indonesian nickel processing feeds Thai battery factories; Turkish assembly plants export to the EU. These investments create mutual reliance—local economies gain

[148] Rhodium Group, "China's Global Investments in the EV Value Chain."; ICCT, "Policies to help Indonesia's new president champion electric vehicles," *ICCT*, August 22, 2025, https://theicct.org/policies-to-help-indonesias-new-president-champion-evs-aug25/.

[149] The Nation Thailand, "BYD begins exporting Dolphin EVs from Thailand to Europe," *The Nation Thailand*, August 25, 2025, https://www.nationthailand.com/business/automobile/40054464.

[150] Ananya Bhattacharya, "China's $143 billion push to dominate the global EV industry," Rest of World, 2025, accessed October 29, https://restofworld.org/2025/china-ev-investment-global-expansion/.

[151] Rhodium Group, "China's Global Investments in the EV Value Chain."

[152] Xiaoying You, "'They're just so much further ahead': How China won the world's EV battery race," *BBC*, November 10, 2025, https://www.bbc.com/future/article/20251110-how-china-won-the-worlds-battery-race.

jobs and technology while Chinese firms secure market access—but also new vulnerabilities to host-country regulations and geopolitical shifts.

Looking ahead, **China's central role in the EV ecosystem is likely to persist**, though its trajectory will be shaped by structural challenges. Trade and investment restrictions are tightening, critical-mineral imports remain concentrated, and compliance with increasingly stringent environmental and labour standards will raise operational costs. Nevertheless, China's vast domestic market ensures economies of scale, its mid-stream dominance secures cost advantages, and its outward investment is progressively globalising production. The global EV transition therefore cannot advance without China, yet it can no longer depend solely on it. For businesses and policymakers alike, this dual reality defines the emerging landscape of interdependence and competition in the next phase of electric mobility.

VII. Forecasts and Scenarios

Looking towards 2030 and beyond, the configuration of the EV supply chain will hinge on the interaction between geopolitics, technological innovation, and regulatory convergence. To frame possible trajectories, three illustrative scenarios are outlined below: **Fragmented Blocs**, **Diversified Hybrid**, and **ESG-Driven Localization**. They are not mutually exclusive, but together illustrate the spectrum of strategic futures facing industry and policymakers.

Scenario 1: Fragmented blocs

In this scenario, the world bifurcates into rival geopolitical and industrial blocs, each striving for self-reliance in critical minerals, batteries, and software—a 'dual EV ecosystem.' Escalating strategic rivalry, export controls, and subsidy races entrench the divide between a China-centred network of resource partners in Asia, Africa and Latin America, and a US-EU-aligned network spanning North America, Europe, and allied economies such as Japan, Korea, and Australia. Both sides duplicate capacity in mining, refining, and battery production to reduce exposure to the other. By the late 2020s, Western automakers source nearly all qualifying materials domestically or from free-trade partners, while Chinese firms prioritize internal and Belt and Road supply channels. The result is costlier but more politically secure supply chains, divergent technological standards, and slower global diffusion of innovation. EV adoption still expands—driven by industrial policy rather than efficiency—but market fragmentation reduces global economies of scale.

Scenario 2: Diversified hybrid

A more balanced outcome envisions pragmatic interdependence. Governments and firms diversify suppliers to enhance resilience, yet global trade and investment continue under moderated competition. By 2030, multiple regional production centres—China, North America, Europe, India, and ASEAN—coexist, each with significant battery capacity and localized mineral processing. Cross-investment remains common: Chinese producers operate plants in Europe and the US, while Western and Japanese automakers maintain ventures in China. Supply risks are managed through redundancy rather than decoupling. Global cooperation on standards, recycling, and digital 'battery passports' improves transparency and cost efficiency. Innovation flourishes through cross-border R&D, driving average battery costs towards US$70 per kWh and enabling EVs to reach price parity with internal-combustion cars in most markets by 2030. This scenario delivers the fastest technological progress and broadest market access, provided that trade stability and climate cooperation are maintained.

Scenario 3: ESG-driven localization

Here, the overriding driver is regulatory and consumer demand for verified environmental and social sustainability. The EU Batteries Regulation, the CBAM, and similar initiatives worldwide compel automakers to demonstrate traceable, low-carbon, and ethical sourcing. Production clusters move closer to end-markets to reduce embedded emissions and enhance oversight. Recycling and circular-economy systems expand rapidly; by 2030 a fifth of critical minerals in new batteries originate from recovered materials. Supply contracts prioritize certified low-carbon mines in regions with strong governance, while investment flows to renewable-powered refineries in Europe, Canada, and China's coastal provinces. Costs rise modestly in the short term but are offset by regulatory compliance, reputational gains, and consumer trust. Firms that integrate sustainability early become market leaders; laggards face penalties or exclusion from premium markets.

Strategic takeaways

The future is likely to blend elements of all three paths: partial geopolitical segmentation, continued diversification, and universal tightening of ESG requirements. For businesses, adaptability—through multi-sourcing, regional production, and transparent supply-chain management—will be critical. For policymakers, coordination on standards and data sharing could mitigate fragmentation risks while ensuring that the EV transition remains genuinely sustainable. In every scenario, the electrification of transport proceeds; what differs is *how* and *where* value is created—and under what regulatory and ethical conditions.

VIII. Conclusion: Business and Policy Implications

This *Global Supply Chain Report on Electric Vehicles* highlights that electric vehicles are not merely a technological evolution of the automotive industry, but a strategic reorganization of global production, trade, and resource networks. Between 2023 and 2025, the EV sector matured into an important pillar of industrial policy and climate strategy, with supply-chain resilience emerging as critical to competitiveness alongside innovation and brand strength.

For businesses

For automakers and suppliers, the foremost lesson is the importance of **resilience and flexibility**. The disruptions of recent years—from semiconductor shortages to spikes in critical-mineral prices—have exposed the risks of over-concentrated sourcing and just-in-time logistics. Companies must now diversify supply for core inputs such as battery cells and chips, develop alternative procurement channels, and secure upstream access through offtake agreements or equity participation in mines and refineries. Some will pursue vertical integration, as exemplified by Tesla and BYD, while others will rely on long-term partnerships with material producers and technology firms. The optimal strategy depends on a firm's capabilities and appetite for capital investment, but in every case, the ability to anticipate and absorb shocks will be a decisive advantage.

The scale and complexity of electrification also demand unprecedented **collaboration across industries**. Joint ventures between automakers and battery producers—such as GM-LG's Ultium alliance or Stellantis's ACC venture—have already become central to capacity expansion. Broader cross-sector partnerships linking automotive, energy, technology, and mining companies can accelerate innovation and strengthen circular-economy integration. Examples such as the IONITY charging consortium in Europe or the growing cooperation between utilities and vehicle manufacturers on smart-charging infrastructure demonstrate that competitive interests can coexist with shared investment in enabling systems. In the years ahead, successful firms will likely be those that view supply-chain resilience as an ecosystem challenge rather than a firm-level task.

Sustainability and ethical governance are emerging as equal pillars of competitiveness. Regulatory frameworks such as the EU Batteries Regulation, together with increasing consumer scrutiny, make traceability and carbon transparency non-negotiable. Companies that can certify responsible sourcing and low-carbon manufacturing will enjoy reputational and market advantages, particularly in premium and fleet segments. Investment in digital traceability systems, blockchain-based material passports, and renewable-energy sourcing for production sites is therefore not merely compliance, but value creation. Early movers that internalize these standards will be better positioned as ESG criteria become embedded in trade and finance.

The **human dimension** of the EV transition is also vital. Shifting from combustion engines to electric drivetrains demands new technical and digital skills—from battery chemistry and power electronics to software engineering and data analytics. Manufacturers must retrain existing workforces and attract new talent, using transition programmes and public support where available. Retooling plants for EV production should be approached as both an industrial upgrade and a social commitment to workers and communities, ensuring that the transition contributes to equitable economic renewal.

For policymakers

For policymakers, **stable and predictable frameworks** remain essential to sustain investor confidence. The rapid expansion of EV production in recent years has been driven by clear long-term targets such as the EU's 2035 phase-out of internal-combustion cars, China's NEV mandates, and the US' zero-emission goals. Consistency over political cycles is crucial: abrupt reversals or uncertain funding can deter the scale of investment required to localize manufacturing and expand infrastructure. Governments should therefore prioritize regulatory clarity and bipartisan commitment to long-term electrification strategies.

Policy should also support **balanced localization and diversification**. Building domestic capacity in batteries, semiconductors, and critical materials is strategically important, but over-protectionism risks fragmenting markets and slowing innovation. The optimal approach combines incentives for regional production with open trade among trusted partners, encouraging redundancy without isolation. Streamlined permitting for environmentally responsible mining and refining projects can unlock resources in regions such as Europe, North America, and Africa, provided that strong safeguards and community engagement are maintained.

Infrastructure investment remains a decisive enabler of adoption. National and local authorities must continue to expand charging networks and upgrade power grids, ensuring that EV integration strengthens rather than strains energy systems. Initiatives such as the US *National Electric Vehicle Infrastructure* (NEVI) Formula Program and the EU's *Alternative Fuels Infrastructure Regulation* (AFIR) framework should be extended to urban and underserved areas, while regulatory adjustments should simplify permitting and standardize equipment. Integrating vehicle-to-grid and smart-charging capabilities can transform EVs into assets for renewable-energy balancing, provided that pricing and data standards are harmonized early.

At the international level, **cooperation on standards and sustainability** will determine whether the EV transition proceeds efficiently or becomes mired in incompatible regulations. Harmonized rules for battery safety, charging connectors, and ESG disclosure would lower costs and improve transparency. Governments should reinforce multilateral platforms such as the Global Battery Alliance and the OECD due-diligence framework, using them to align certification systems and prevent regulatory conflicts. Even amid strategic rivalry, dialogue with China and other major producers on recycling and environmental data can yield shared benefits by reducing duplication and improving trust in global supply networks.

Final outlook

The overarching outlook remains one of cautious optimism. The electrification of transport is now irreversible, propelled by technological progress, scale economies, and policy ambition. Yet the pace and quality of this transition will depend on how effectively stakeholders manage supply-chain vulnerabilities, geopolitical frictions, and sustainability expectations. For businesses, the imperative is to invest early, innovate continuously, and embed ESG performance within corporate strategy. For governments, the priority is to provide clarity, build enabling infrastructure, and maintain open yet equitable markets that reward efficiency and responsibility.

If executed well, the EV transition can become a model of industrial modernization aligned with global sustainability goals. A resilient and transparent supply chain—anchored in ethical sourcing, circular resource use, and low-carbon production—would not only decarbonize transport but also catalyse new industries and employment worldwide. The decade to 2030 will be decisive: it will determine whether the shift to electric mobility delivers on its promise of climate progress and economic opportunity, or falls short through fragmented execution. The evidence from 2023-2025 offers strong grounds for confidence that with foresight and cooperation, the world is indeed charging towards a cleaner, more resilient, and inclusive mobility future.

Appendix A. Defining Electric Vehicles: Powertrain and Vehicle-Type Categories

Understanding what is included in 'electric vehicle' (EV) statistics is critical, as definitions vary across countries and organizations. This annex sets out the main categories by **powertrain** and **vehicle type** and clarifies the scope of this report.

A.1. Categories by powertrain

- **Battery Electric Vehicles (BEVs):** Powered solely by an electric motor and battery. They have no combustion engine (e.g., Tesla Model 3, BYD Dolphin).
- **Plug-in Hybrid Electric Vehicles (PHEVs):** Contain both a battery (rechargeable from the grid) and an internal combustion engine (e.g., Toyota Prius PHEV, BMW X5 PHEV).
- **Extended-Range Electric Vehicles (EREVs):** A special subclass of PHEVs. The vehicle runs mainly as an electric car, but carries a small ICE that acts as a generator to recharge the battery once depleted. The ICE usually does not drive the wheels directly (e.g., Chevrolet Volt, BMW i3 REx, Li Auto L series). Most statistical agencies count EREVs within PHEVs.
- **Hybrid Electric Vehicles (HEVs):** Use a small battery and motor to support the engine, but cannot be plugged in. They are *not* included in international EV adoption figures (e.g., Toyota Corolla Hybrid).
- **Fuel Cell Electric Vehicles (FCEVs):** Powered by hydrogen fuel cells. Still niche, but relevant in some fleets (e.g., Toyota Mirai, Hyundai XCIENT truck).

A.2. Categories by vehicle type

- **Passenger cars and light-duty vehicles (LDVs):** The core category in most global EV statistics (IEA, ACEA, CAAM).
- **Commercial vehicles:** Includes buses, delivery vans, and trucks. Prominent in China's 'new energy vehicle' (NEV) reporting.
- **Two- and three-wheelers:** Scooters, motorcycles, and auto-rickshaws. They play a major role in India and Southeast Asia but are reported separately.
- **Micromobility and off-road vehicles:** E-bikes, forklifts, agricultural equipment, etc. Typically excluded from automotive datasets.

A.3. Reporting practices

- **IEA Global EV Outlook:** EVs = BEV + PHEV passenger cars/LDVs. Buses, trucks, and two-/three-wheelers are reported in separate sections.
- **ACEA (Europe):** EVs = BEV + PHEV passenger cars.
- **CAAM (China):** 'New Energy Vehicles (NEVs)' = BEVs + PHEVs (including EREVs) + FCEVs, covering both passenger and commercial vehicles. Two-wheelers are excluded.

- **SIAM (India):** Reports separately for passenger cars, commercial vehicles, three-wheelers, and two-wheelers.

A.4. Scope of this report

Unless otherwise stated, *'EVs'* in this report refers to **battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) in the passenger car and light-duty vehicle segments**.

- **Excluded from core statistics:**
    - Two-/three-wheelers (though discussed for India and ASEAN in regional sections).
    - Commercial vehicles (buses and trucks), unless noted in context.
    - HEVs, which are not externally rechargeable.
- **Included selectively:**
    - Fuel cell vehicles (FCEVs) are mentioned where relevant, but their market share remains negligible.

Appendix B. Comparison of Major EV Battery Chemistries (2023-2025)

Chemistry	Typical Energy Density (Wh/kg)	Relative Cost (2024, USD/kWh)	Safety & Thermal Stability	Advantages	Limitations	Leading Manufacturers / Developers	Commercial Status (as of 2025)
Lithium Iron Phosphate (LFP)	150-180	90-110	Very high (excellent thermal stability, no cobalt/nickel)	Low cost (Co/Ni-free); long cycle life; high safety	Lower energy density limits long-range EVs; performance reduced in cold	BYD (Blade Battery), CATL, EVE Energy	Mass-produced globally; 50% of global EV cell output
Nickel Manganese Cobalt (NMC)	200-270	110-150	Moderate (requires advanced BMS and cooling)	High energy density; established supply chains	Costly metals (Ni, Co); ethical sourcing concerns	LG Energy Solution, SK On, Samsung SDI, CATL	Mature; primary chemistry for Western OEMs
Nickel Cobalt Aluminium (NCA)	230-300	120-160	Moderate	High energy density, long life	Costly; thermal-runaway risk	Panasonic (Tesla supply), Tesla	Mature; mainly Tesla & premium EVs
Lithium Manganese Iron Phosphate (LMFP)	180-210	95-115	High	Improved energy vs LFP; low cost (Co/Ni-free)	Slightly heavier; not yet mass-produced	CATL, BYD, Gotion High-Tech	Pilot stage (2024-25)
Sodium-ion (Na-ion)	120-160	60-90	Very high	Extremely low cost; abundant materials; good cold-weather performance	Low energy density → short range	CATL, HiNa Battery, Farasis	Demo/pilot (mass production target 2025)
Li-metal anode (Solid-State)	350-500 (target)	>200 (est.)	Potentially very safe (non-flammable)	Ultra-high energy density; fast charging potential	High cost; durability issues; new production process required	Toyota, QuantumScape, Solid Power, ProLogium	Prototype/pilot; limited vehicles before 2027

Appendix C. Key Policies Affecting the Electric Vehicle Industry

C.1. China

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
NEV Industry Development Plan (2021-2035)	Enacted since 2021; 2025 target (≥ 20% NEV share) already exceeded.	Long-term roadmap guiding EV R&D, infrastructure and localization.	Provides policy certainty for batteries, motors and electronics; shapes provincial clusters.
NEV / Corporate Average Fuel Consumption (CAFC) Dual-Credit Scheme (2024-25 update)	Active; NEV credit ratios 28% (2024) → 38% (2025).	Acts as de facto EV quota driving OEM model mix and compliance.	Sustains domestic scale and cost leadership in cells and packs.
Graphite Export Controls (Announcement No. 39/2023)	Licensing since Dec 2023.	Tightens permits for natural and synthetic graphite products.	Adds lead-time and compliance risk for non-China anode chains.
EV Subsidies and Purchase Tax Exemption	Direct subsidies (2010-2022) phased out; 10% purchase tax exemption extended through 2027 (full 2024-25, half 2026-27).	Shift from fiscal to market support keeps sales strong.	Maintains consumer demand and production scale mid-decade.
NEV Mandate / ZEV Credit System	In place since 2019; tightening annually.	Requires automakers to meet minimum NEV ratios or buy credits.	Drives domestic production and innovation in EV models.
Charging and Industrial Infrastructure Plans	14th Five-Year Plan targets EV-charger coverage and smart roads.	Expands national charging network and vehicle-to-grid capability.	Boosts demand for chargers, grid equipment and software services.

C.2. EU

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
Batteries Regulation (EU 2023/1542)	Enacted; phased roll-out 2025 → 2031.	Establishes EU-wide carbon footprint, due diligence and recycling framework.	Mandates traceability and low-CO_2 inputs; stimulates EU recycling sector.
Critical Raw Materials Act (CRMA)	In force 2024; 2030 targets (≥ 10% extract, ≥ 40% process, ≥ 25% recycle in EU).	Strengthens resource security and strategic autonomy.	Incentivizes EU refining and supplier diversification.
Carbon Border Adjustment Mechanism (CBAM)	Transitional reporting since Oct 2023; financial charges from 2026.	Applies carbon cost to imports of steel, aluminium and other inputs.	Drives low-CO_2 material choices across the EV value chain.
CO_2 Standards for Cars and Vans (Reg. 2019/631)	Tightens 2030 targets; 2035 → 0g/km.	Locks OEM product planning towards ZEVs.	Accelerates BEV demand and charging infrastructure.
Alternative Fuels Infrastructure Regulation (AFIR 2023/1804)	In force Apr 2024; binding charging power & spacing from 2025/2030.	Guarantees corridor DC fast-charging and uniform UX.	Expands charger hardware, grid services and data integration.
Anti-subsidy Duties on Chinese BEVs (Reg. 2024/2754)	In force 31 Oct 2024 (for five years).	Alters China-EU EV trade economics.	Incentivizes EU-based production or non-CN export bases.

C.3. US

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
Inflation Reduction Act (IRA) §30D Clean Vehicle Credit	Active; final rules May 2024. Foreign Entity of Concern (FEOC) exclusion for components (2024) and minerals (2025).	US$7,500 credit linked to North American and Free Trade Agreement (FTA) sourcing.	Pulls cathode, anode and cell localization into NA supply chains.
Infrastructure Investment and Jobs Act (IIJA) + National Electric Vehicle Infrastructure (NEVI) Program	Valid through Sep 2026; revized NEVI guidance Aug 2025.	Federal funding for fast-charging corridors and grid integration.	Expands US charger hardware, software and O&M ecosystem.
EPA Multi-Pollutant Standards (MY 2027-32 LDV/MDV)	Finalized 2024; effective from MY 2027.	Tight tailpipe limits accelerate electrification.	Pushes supplier retooling and BEV/PHEV mix.
Section 301 Tariffs (China EVs & Inputs)	Final actions 2024; EVs 100% tariff; batteries/graphite rising to 2026.	Restricts China-made EV imports and key inputs.	Reinforces IRA localization and FTA-partner sourcing.

C.4. India

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
Production-Linked Incentive (PLI) for Advanced Chemistry Cells (ACC)	Active; ₹18,100 crore for 50 GWh; 5-year performance window.	Anchors domestic gigafactories and R&D.	Opens India for cell/pack and upstream localization.
Electric Mobility Promotion Scheme (EMPS 2024)	Transitional scheme (Apr-Sep 2024) post-FAME II.	Maintains short-term EV demand while successor policy develops.	Supports local OEM sales momentum and supply chain planning.

C.5. The UK & Canada

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
UK | Zero-Emission Vehicle (ZEV) Mandate (VETS Order 2023)	Active 2024-2035 (22% → 80% → 100%).	Legally binding sales shares for cars and vans.	Ensures predictable demand and charger deployment.
Canada | EV Availability Standard	Finalized Dec 2023; 20% (2026) → 60% (2030) → 100% (2035).	Binding national ZEV supply targets.	Reinforces battery clusters in Ontario and Québec.

C.6. Asia-Pacific Emerging Markets

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
Thailand | EV 3.5 Incentive Package (2024-27)	Active; 2025 amendments enhanced export flexibility.	Links import relief to local production commitments.	Positions Thailand as ASEAN BEV export base.
Indonesia | Nickel Ore Export Ban & BEV Policy (PR 55/2019)	Export ban since Jan 2020; policy active.	Forces domestic processing and EV investment.	Anchors Ni → precursor and stainless value chains; raises ESG oversight.
Vietnam | Registration Fee Exemption for EVs (Decree 51/2025/ND-CP)	Full exemption of first-registration fees for battery EVs extended until 28 Feb 2027 (effective 1 Mar 2025).	Maintains affordability of EVs during early adoption phase.	Supports scale of domestic EV sales, which underpins supply-chain localization for components and chargers.
Vietnam | EV Charging Infrastructure Mandate (Notice 09/2024)	From 5 Oct 2024 new motorway rest-areas >5,000 m^2 must include EV-charging bays (10% of parking).	Signals infrastructure build-out commitment, reducing range anxiety.	Creates demand for charger hardware, software and grid management services in Vietnam.

Policy	Status & Key Dates	Significance	EV Supply-Chain Impact
Malaysia | Tax & Import/Excise Duty Incentives for EVs	Full exemption of import & excise duties for imported EVs until 31 Dec 2025; for domestically produced EVs until 31 Dec 2027. Road tax exemption until end 2025.	Reduces upfront cost of EVs, supports market uptake and domestic manufacturing.	Encourages localization of EV assembly, components, charger manufacturing and encourages investment.
Malaysia | EV Charging Infrastructure & Investment Incentives	Green Investment Tax Allowance (GITA) 100% for eligible charging-point operators; income-tax exemption for charging-equipment manufacturing (2023-2032). Target: 10,000 charging stations by 2025.	Strengthens the ecosystem (beyond just vehicles) for EV deployment.	Drives growth of charger hardware, installation services, battery testing/charging networks, localization.
Singapore | EV Incentives (VES & EEAI)	Rebates under the Vehicular Emissions Scheme (VES) and the EV Early Adoption Incentive (EEAI) extended to 31 Dec 2026. Band A1 rebate (EVs) SGD 25,000; ARF rebate up to SGD 15,000 under EEAI.	Maintains cost-gap support for EVs; indicates shift over time to structural/market support rather than large fiscal rebates.	Reinforces demand in a highly-priced market; supports charger, grid and service-industry investment in Singapore and regional HQ roles.
Philippines | Zero Tariff for EVs & Parts (EO 12 / RA 11697)	Under Executive Order 12 (Jan 2023) zero import duty on many EVs and parts until 2028; expanded tariff lines in May 2024.	Opens market access, lowers cost of EVs & imported components, and supports nascent domestic EV ecosystem.	Fosters import of EVs/parts; potential localization of assembly or battery-packs; part of resource-diversification in regional supply-chain.

Our Global Supply Chain Analysis by Industry

Electric Vehicle

Expansion and Diversification: Securing EV Supply Chains Amid Global Fragmentation

Solar PV

Where the Sun Shines: The Changing Landscape of the Global Solar Supply Chain

Apparel

Threading a Green and Intelligent Tapestry:
The Apparel Supply Chain Landscape in a Turbulent World

Medical Device

The Evolving Landscape of Global Medical Devices:
Supply Chain Resilience and Innovation

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