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Global Electric Vehicle Value Chains: Paradigm Shifts and New Opportunities for Developing Economies

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3.1 Introduction

Since 2018, the global electric vehicle (EV) market has experienced rapid growth, with an average annual sales growth rate of 45.5%. By 2023, global EV sales reached 13.7 million units, accounting for 18% of total vehicle sales. With the continued decline in battery costs and the introduction of incentive policies in various economies, this share is expected to rise to 20% by 2024 (IEA, 2024a). The development of EVs is reshaping the traditional automotive industry ecosystem. The importance of engine manufacturing has diminished, while the roles of EV batteries, electric motors, electronic control systems and automotive chips have been elevated (Safari, 2018; Rísquez Ramos and Ruiz-Gálvez, 2024). Moreover, EVs have driven the rapid growth of emerging sectors such as battery manufacturing, charging infrastructure, software integration and battery recycling, along with advancements in related technologies like smart grids, autonomous driving, vehicle connectivity and energy storage. This process not only injects new vitality into the global economy but also helps reduce fossil fuel consumption in the transportation sector, supporting progress towards achieving carbon neutrality in transport (Li et al., 2024; Song et al., 2025).

The production centres of internal combustion engine vehicles (ICEVs) remain relatively fixed, primarily in the United States (US), Germany and Japan, where these countries have

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maintained production advantages for many years (Dowlah, 2018). Developing economies have generally only been able to participate in automotive production networks through assembly or by engaging in peripheral processing activities, such as the manufacture of car interiors, tyres and glass. However, the EV production network has been extended due to the complexity of battery manufacturing and now encompasses the entire supply chain – from critical mineral extraction to the installation of charging infrastructure and automotive chip development. As a result, the EV industry has fostered cross-sectoral development, as evidenced by companies such as consumer electronics companies Xiaomi and Huawei entering the automobile market, and vehicle maker BYD also producing mobile phones.

EVs, owing to their structural advantages in batteries and automotive chips, are inherently more conducive to deep integration with the digital economy (Liu et al., 2024). On the one hand, their high-efficiency and large-capacity power batteries free them from the energy efficiency bottlenecks and mechanical constraints of internal combustion engines. On the other, the number of onboard chips has risen substantially – 1,600 to 3,000 per EV, compared with 600 to 700 in per ICEV (IBE, 2024) – providing the hardware foundation for high-speed network access, real-time big data processing and other applications such as autonomous driving. Higher-level autonomous driving and intelligent cockpit technologies are also quickly advancing in EVs thanks to ongoing improvements in chip precision and processing power. Consequently, vehicles are evolving from means of transportation into lifestyle platforms more akin to smart terminals, which are deeply interconnected with personal data and digital services. This trend not only reshapes the structure of the automotive industry but also drives the digital transformation of global production and consumption (Llopis-Albert et al., 2021).

The EV-related production process creates significant value added but also places additional emissions reduction pressures on participants, particularly developing economies that supply raw materials and those that manufacture batteries (Franzò and Nasca, 2021; Hu et al., 2024). Research consistently shows that EVs generate higher carbon emissions during the production phase compared to ICEVs (ICCT, 2021). However, from a lifecycle perspective, EVs begin to demonstrate clear carbon reduction advantages after reaching a certain mileage. These advantages become increasingly pronounced with longer driving distances and the transition to cleaner energy sources (Qiao et al., 2020; Chen et al., 2024). For example, Farzaneh and Jung (2023) indicate that the life cycle carbon footprint of EVs in the US is approximately 22.6% lower than that of ICEVs. Mapping carbon emission flows and the carbon footprint distribution in EV production is crucial for fostering low-carbon EV manufacturing through international collaboration and unlocking their full emissions reduction potential.

The production of electric vehicles, particularly EV batteries, is highly dependent on critical raw materials such as lithium, cobalt and nickel. This creates unprecedented development opportunities for resource-rich developing economies. By directly engaging in or indirectly participating through foreign direct investment (FDI) in the mining, smelting and processing of these key minerals, these economies can not only integrate

into core segments of the global EV supply chain but also leverage this opportunity to drive domestic industrial upgrading and technological advancement. Companies from developed economies can also actively pursue collaboration with resource-rich economies through FDI, technology partnerships and other means to secure supply chains and tap into emerging markets. Such EV supply chain-driven cooperation models can help reduce global EV production costs, promote the inclusive development of clean energy technologies and foster a more inclusive global value chain.

In the next section, we first provide an overview of the current development of EVs, as well as the production and trade of core EV components and raw materials. In Section 3, we construct an EV-ICIO (inter-country input-output) model that distinguishes between EVs and ICEVs, which enables us to illustrate the differences in the creation, transfer and distribution of value added and carbon emissions along global EV and ICEV supply chains. Based on life cycle emissions, this section also estimates the emissions reduction potential of EVs relative to ICEVs. In Section 4, drawing on the product space model, we analyse the development pathways of different segments of the EV supply chain and discuss how developing economies can leverage their comparative advantages to seize new opportunities for participating in global EV supply chains. Finally, we review the main findings of this chapter and offer some policy recommendations.

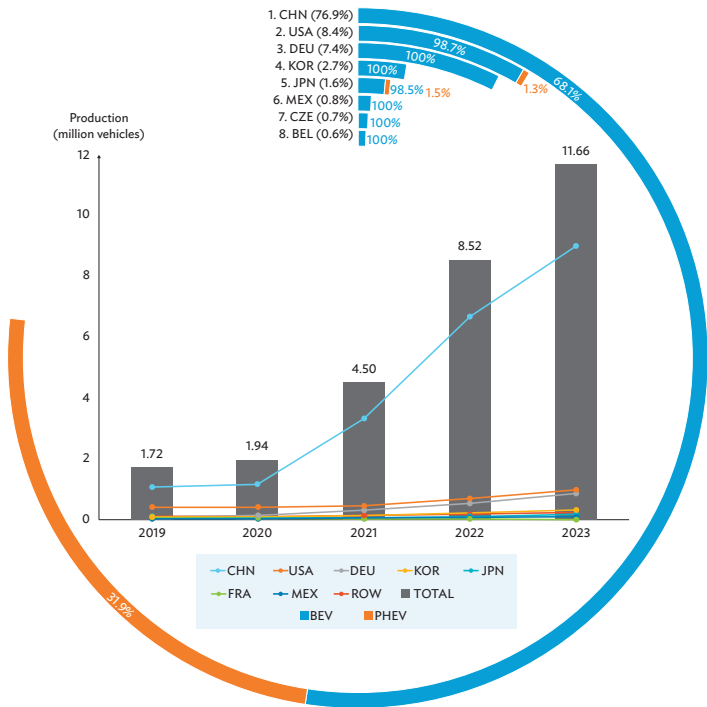
3.2 Overview of the Electric Vehicle Supply Chain

3.2.1 The Production and Trade of Electric Vehicles

From 2019 to 2023, China maintained its position as the world's largest producer of EVs, accounting for 76.9% of the global total in 2023 – far exceeding the US, Germany and South Korea (Figure 3.1). While China maintained steady growth from an already high base, South Korea and Germany experienced the fastest growth in EV production, with average annual growth rates of 130% and 119% respectively over the period. In terms of EV types produced, in 2023, 68.1% of China's output comprised battery electric vehicles (BEVs), and 31.9% were plug-in hybrid electric vehicles (PHEVs). In contrast, other economies focused almost exclusively on BEVs, with 98.7% of EV production in the US being BEVs and 1.3% PHEVs, while 98.5% of Japan's production was BEVs and 1.5% PHEVs.

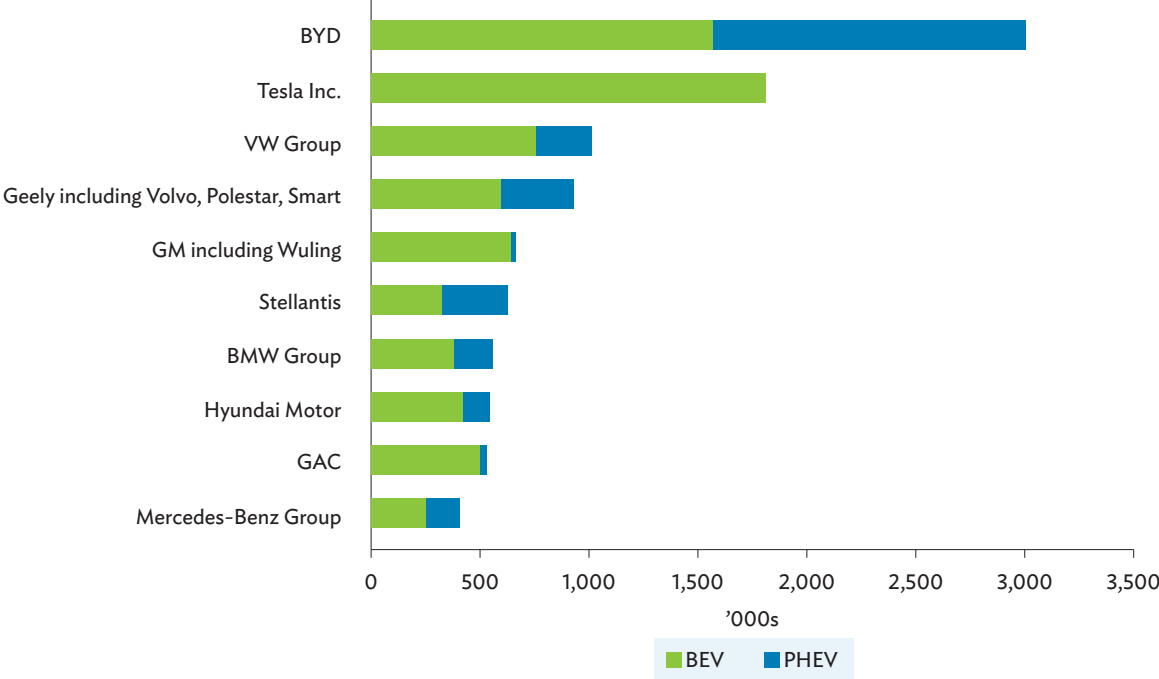
By automaker, BYD and Tesla led the global EV market by a significant margin in 2023 (Figure 3.2). BYD ranked first worldwide with nearly 3 million units sold, showing particularly strong performance in the PHEV segment. Meanwhile, Tesla focused exclusively on BEVs, with its Model Y achieving 1.2 million units in sales, making it the best-selling vehicle globally. Other Chinese automakers – including Geely, which also owns Volvo, Polestar and Smart; General Motors (GM), including Wuling; and Guangzhou Automobile Group Motor Co., Ltd (GAC) – also ranked among the top 10, highlighting the rapid rise of Chinese firms in the global EV sector. Germany had four companies on the list – VW Group, Stellantis, BMW Group and Mercedes-Benz Group – while South Korea's Hyundai Motor also emerged as a notable player in the EV industry.

Figure 3.1: Production of Electric Vehicles, 2019-2023



Note: This result is based on a territory-based principle. For example, EVs produced by Tesla’s factory located in China are counted as China’s domestic production.
 Source: Global Vehicles Production in Global NEVS (2024)

Figure 3.2: Top 10 EV firms by Global Sales in 2023 (in thousands)



Source: Global EV Sales for 2023 in EV Volumes (2024)

The global EV export landscape in 2023 exhibited a hierarchically structured network centred around a few dominant economies, which function either as global or regional export hubs (Figure 3.3). Using export value (in USD) as the primary measure of centrality, we classify economies into global hubs, regional hubs and peripheral nodes based on both the magnitude and geographical breadth of their EV exports, with China and Germany considered as the two main global hubs. China emerged as a top global player with EV exports totalling \$34.1 billion, corresponding to 1.6 million units. Its export destinations spanned Europe, Southeast Asia, Latin America and Australia, reflecting a highly diversified and global reach. China's central position in the network is bolstered not only by its dominant output but also by its expanding influence in emerging markets through competitively priced models (about \$21,313 per unit) from automakers like BYD and SAIC Motor. Germany, with an even higher EV export value of \$40.1 billion (approximately 786,000 units), also qualifies as a global hub. Despite a slightly lower volume, Germany's exports unit price for EVs is more than twice as high as China's (about \$51,020 per unit), attributed to its premium vehicle brands such as BMW, Mercedes-Benz and Audi. Major destinations included the Netherlands, France, the United Kingdom (UK) and the US – reflecting both intra-European strength and transatlantic ties. Together, China and Germany accounted for over 49% of global EV export value in 2023 and formed the dual cores of the global EV trade network, which is characterized by high outflows and extensive connectivity across continents.

South Korea, Japan and Belgium could be regarded as regional hubs. South Korea exported EVs worth \$11.98 billion (418,881 units) in 2023, predominantly to the US, Canada and parts of Europe. Its position as a regional hub stems from strong North American linkages, driven by Hyundai and Kia's strategic positioning in the SUV segment, and while the geographic coverage was narrower than that of China or Germany, the export scale was regionally significant. Japan exported EVs valued at \$5.74 billion (approximately 149,091 units), marking a sharp 246% increase on previous years. Key markets for Japan included the US, Australia, China and Thailand, and although Japan's EV exports remain modest in absolute terms, the diversification of its destinations indicates potential to evolve into a more global node. Meanwhile Belgium, with \$8.09 billion in EV exports (157,306 units), plays a unique role as not only a producer but also a logistics re-export hub. It acts as a key distribution node within Europe, re-exporting vehicles manufactured in neighbouring Germany and France to other European markets such as the Netherlands and the UK.

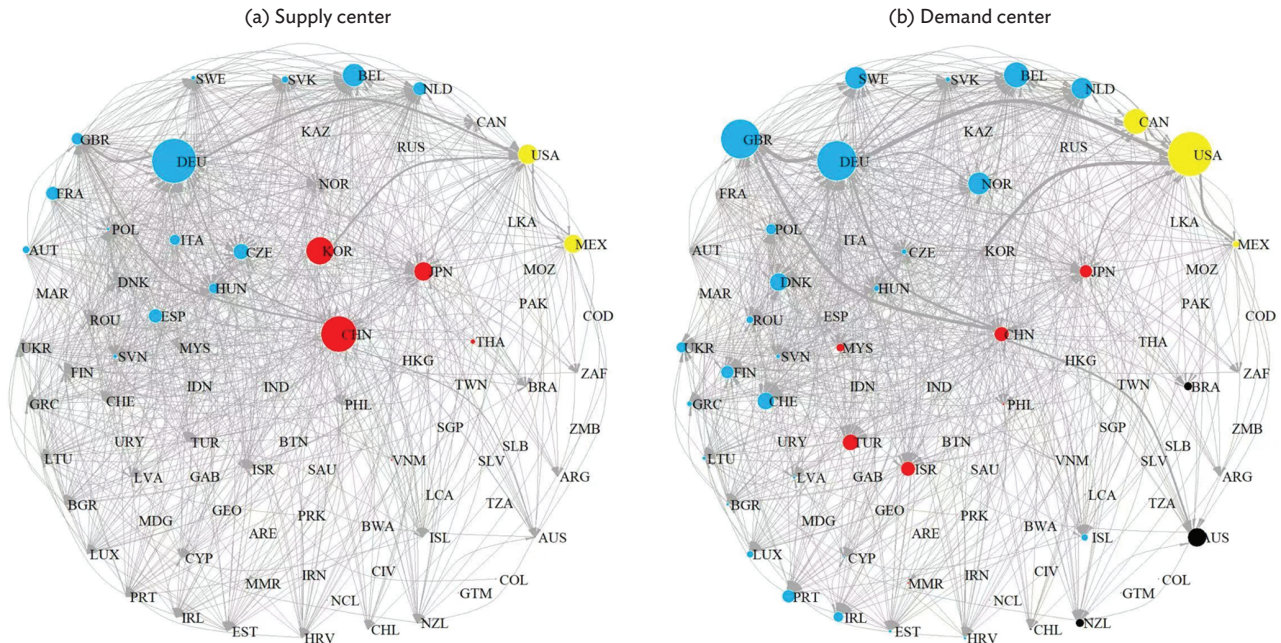
The US, despite being a major EV manufacturer, exported only \$6.27 billion worth of EVs (approximately 129,546 units) in 2023, with Canada and Mexico as its dominant destinations. Its export network remains regionally confined within North America, constrained by domestic consumption focus and regulatory complexity. Mexico, while lacking detailed EV-specific export breakdowns, functioned as a manufacturing node for global brands like Tesla and BMW. Estimated EV exports reached \$5.51 billion (137,750 units), primarily to the US and Latin America. As part of North American

value chains, Mexico’s network role is more embedded and original equipment manufacturer (OEM)-dependent, rather than autonomous.

In 2023, the global EV import network revealed a strongly asymmetrical and regionally layered structure, with a few dominant consumer markets absorbing the bulk of global EV exports. The US emerged as the world’s largest EV importer, with an import value of approximately \$19.00 billion, sourcing primarily from Germany, South Korea and Japan. Germany itself, while being a major exporter, also stood out as a substantial importer with \$15.27 billion in EV imports, mainly from China and Korea. This dual role reflects Germany’s intricate supply chain integration within the European Union (EU) and its reliance on Asian suppliers for specific segments, particularly battery-driven models. Other significant importers included the UK (\$14.79 billion), Belgium (\$6.42 billion) and Canada (\$6.40 billion), with each playing critical roles within the intra-European trade system and often functioning as logistical hubs or regional redistribution centres.

The import network, when mapped by trade value, displays a pattern of dense bilateral flows between a handful of high-income demand centres and a smaller group of producer economies. It is more consumption-centric than the export network and less centralized, with a relatively wider spread of mid-tier importers. However, most import links converge on key suppliers such as China, underscoring the growing concentration

Figure 3.3: Electric Vehicle Trade Network in 2023



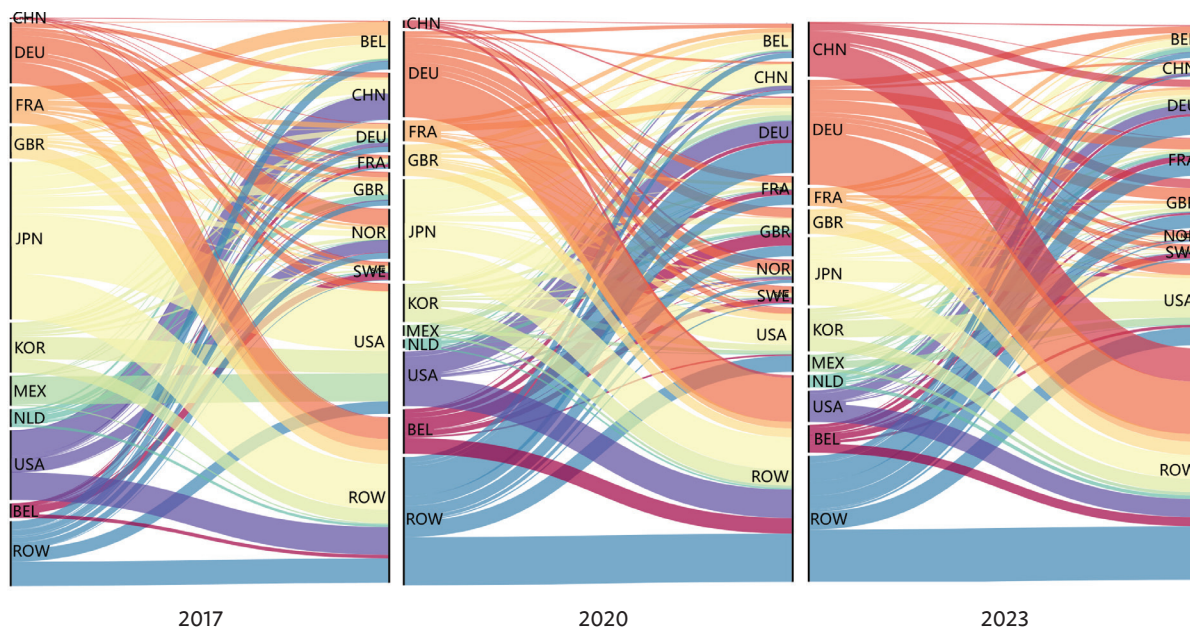
Notes: The network consists of nodes (countries or regions) and edges (trade flows). The node colors represent different regions, where red indicates Asia, blue represents Europe, yellow denotes North America, and black signifies other regions. The size of each node indicates its relative importance in terms of supply and demand, and the direction and size of edges (trade flows) indicate the trade direction and relationship strength, respectively. The topology of the network reveals core-periphery structures, hubs and linkages, which define the dynamics of global trade of EVs and their key parts.

Source: Meng et al. (2025) based on the OECD BTDixE (2023) and IDE-JETRO’s GVC Visualization Database.

in EV manufacturing. Regional clusters – such as Western Europe and North America – exhibit high internal connectivity and diversified sourcing, while regions like ASEAN remain more peripherally connected with asymmetric dependencies. These structural patterns are also driven by a mix of policy incentives (such as subsidies and emissions targets), industrial readiness and consumer market maturity, revealing how global EV trade is increasingly shaped by geopolitical alignment, regional integration and the evolving economics of decarbonization.

The export structure of EVs (passenger cars) by country from 2017 to 2023 is illustrated in Figure 3.4. China's share in the global EV market has progressively risen, with its share of global EV exports increasing from 0.2% to 10.4% over the period. Germany's share also increased from 11.4% to 19.9%. However, market shares of both Japan and the US both declined, with Japan's share falling from 29.5% to 12.9%, and the US from 13.0% to 5.8%, indicating a significant weakening in their competitiveness in EV exports. This is primarily due to the development of the EV industries in China and Germany, which squeezed Japan's market in other economies and reducing their demand for imports. For instance, from 2017 to 2023, the proportion of EVs imported by Germany from Japan decreased from 11.6% to 5.5%. Meanwhile, in the rest of the world, the shares of imports from China and Germany increased by 14% and 10%, respectively, while those from Japan and the US declined by 17% and 9%, respectively.

Figure 3.4: Trade Structure of Major Electric Vehicles-Exporting Countries from 2017 to 2023

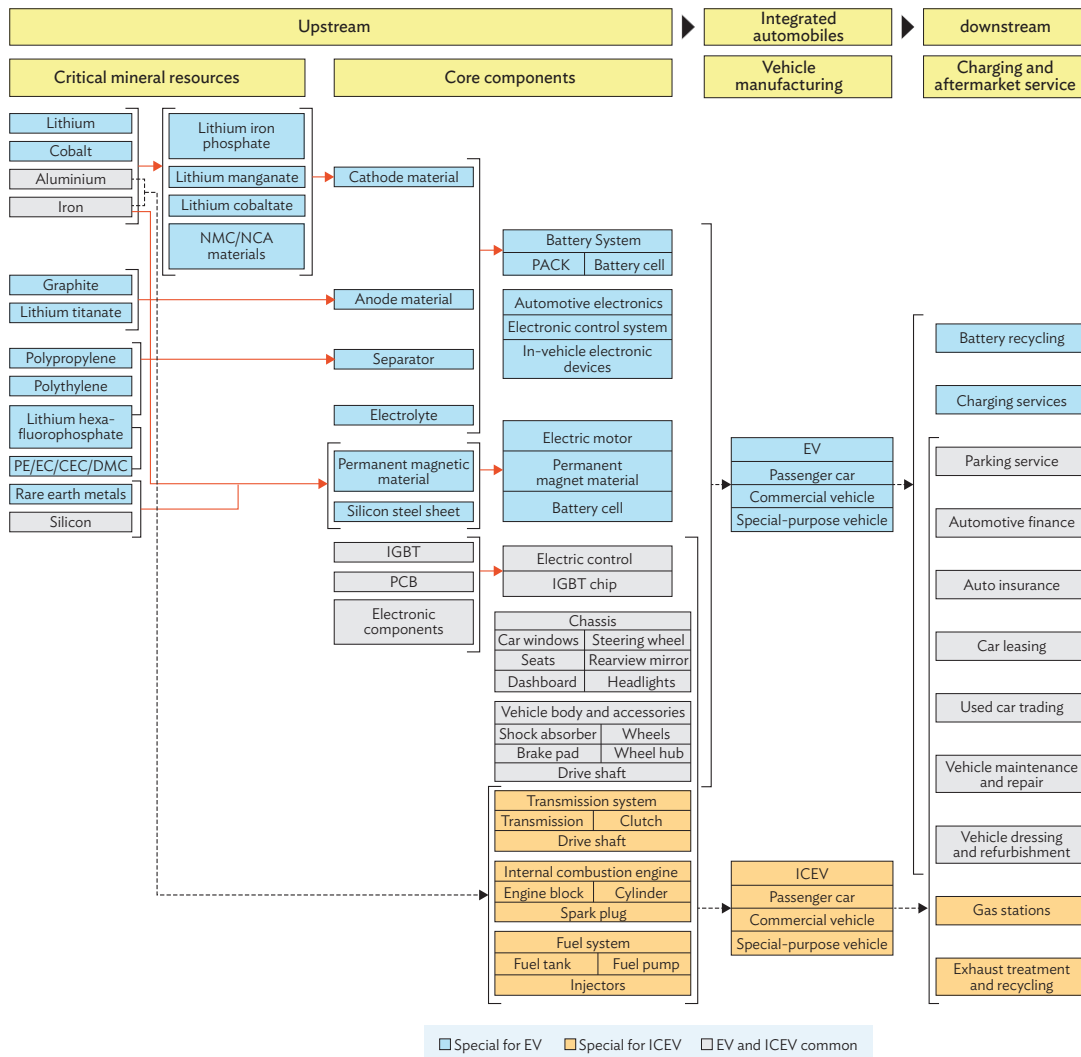


Notes: BEV (HS 870380), PHEV (870360 and 870370).
Source: UN Comtrade

3.2.2 The Production and Trade of Electric Vehicle-Related Minerals and Components

The EV supply chain can be divided into three main segments: upstream, integrated automobiles and downstream (Figure 3.5). At the upstream stage, the industry relies on a variety of critical mineral resources, including silicon, graphite, rare earth metals, magnesium, copper and cobalt, which are fundamental to the production of key components such as batteries and motors. At the same time, key chemical materials – including cathode and anode materials, magnetic materials and other functional chemicals, as well as a range of metallic materials used in vehicle bodies and battery structures – are also essential. Auxiliary materials, such as rubber, plastics, glass fibres and adhesives, provide important support for the manufacturing and assembly of various components.

Figure 3.5: Diagram of EV and ICEV Supply Chains



Source: Authors

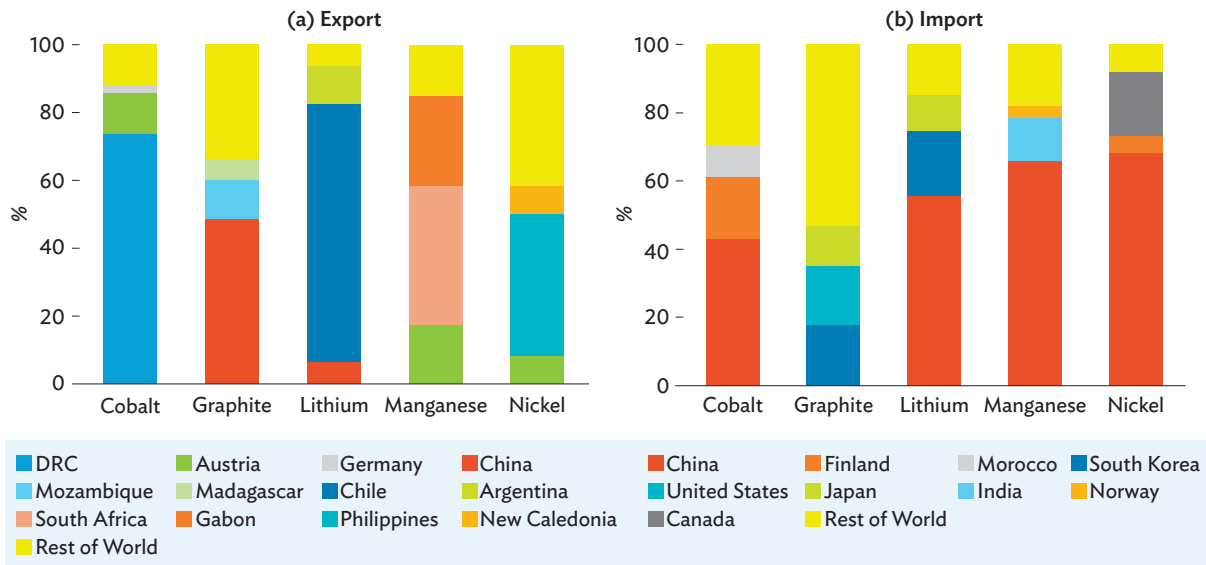
Moving into the core components segment, the supply chain covers automotive chips, various electronic parts, electric control systems, motors, battery systems and body and assembly modules. Automotive chips and electronic devices lay the technological foundation for EV intelligence and power control, while electric control and motor systems ensure power output and operational safety. The battery system serves as the core energy source and is crucial to vehicle performance, while the body and assembly relate to the structural integrity and functional realization of the vehicle. In the integrated automobiles segment, the focus is on vehicle manufacturing, which includes different types such as BEV and PHEV. This segment is responsible for the integration of all upstream components into a complete vehicle, ready for the market. The downstream segment centres on charging infrastructure and battery recycling. The development of charging facilities supports the large-scale adoption of EVs, while the recycling and cascade utilization of used batteries not only promotes resource circulation and environmental protection but also provides strong momentum for the industry's sustainable development.

Driven by high levels of investment in the previous five years, in 2024, annual battery demand surpassed 1 terawatt-hour (TWh) (IEA, 2025b). More batteries mean extracting and refining greater quantities of critical raw materials, particularly lithium, cobalt and nickel. Battery demand for lithium stood at around 140 kiloton (kt) in 2023, accounting for 85% of total lithium demand, while for cobalt, demand for batteries was up 15% to 150 kt, marking 70% of the total demand. Battery demand for nickel stood at almost 370 kt in 2023, accounting for over 10% of total demand (IEA, 2024b).

Figure 3.6a illustrates the export distribution of five key minerals closely associated with EVs in 2023: cobalt, graphite, lithium, manganese and nickel. Cobalt exports are highly concentrated, with the Democratic Republic of the Congo (DRC) holding a dominant position. Graphite exports are highly controlled by China and lithium exports are predominantly concentrated in Chile, while manganese exports mainly originate from South Africa, Gabon and other countries. Nickel exports are more widely distributed, with the Philippines being the primary supplier. In general, the key minerals essential for EV production exhibit significant regional concentration within the global supply chain, particularly for resources such as cobalt, graphite and lithium. This concentration might lead to supply vulnerability, leaving the global EV industry highly dependent on specific regions.

As shown in Figure 3.6b, China is the primary importer of key minerals for EVs, with the exception of graphite. This is largely because China serves as both the world's largest processing hub for raw materials and a major producer of both electric vehicles and EV batteries. Other significant importing countries, such as the US, Japan and Germany, also play crucial roles in EV production. As demand for EVs continues to rise, the need for raw materials in these countries has similarly increased. Consequently, these nations must be vigilant about potential risks to the supply of key minerals and consider strategies such as diversifying import sources to enhance the resilience of their raw material supply chains.

Figure 3.6: Trade of EV-Related Key Minerals in 2023

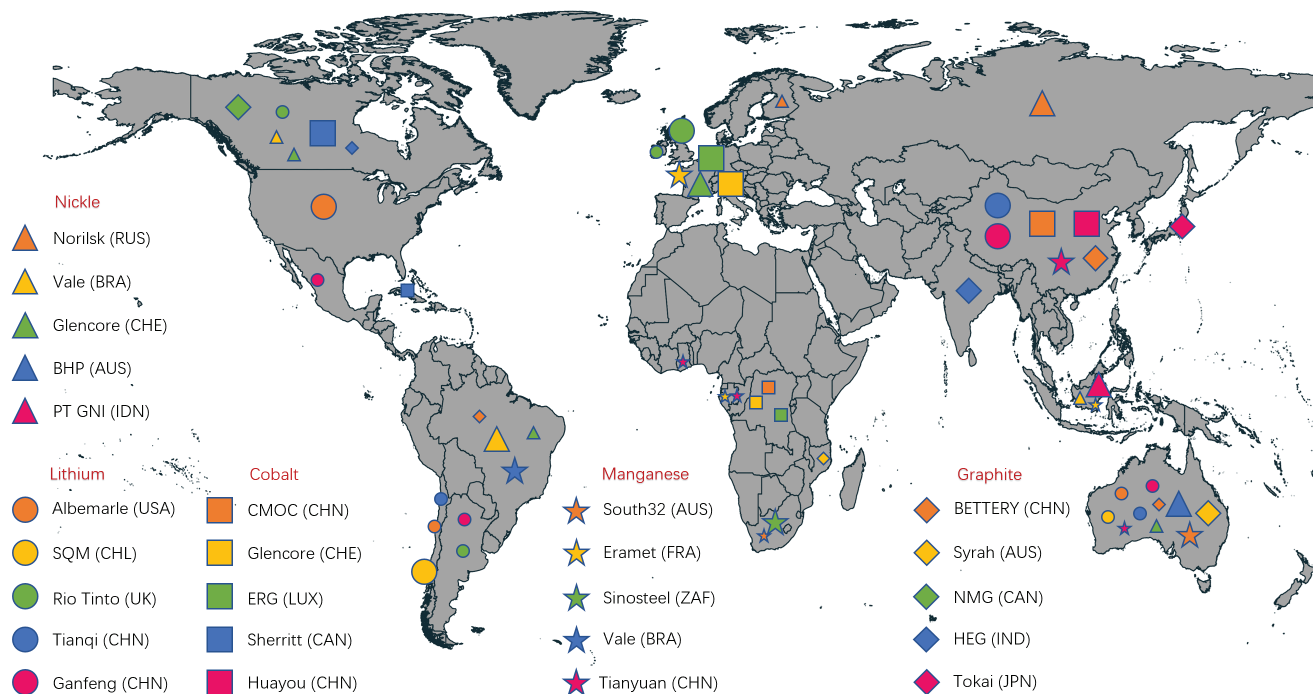


Notes: Cobalt (HS 260500), graphite (HS 250410, 250490), lithium (HS 283691), manganese (HS 260200), and nickel (HS 260400). DRC=Democratic Republic of Congo. For each mineral, the top three exporting/importing economies are shown, while all other regions are aggregated as the rest of the world.
 Source: CEPII BACI database

Although critical mineral resources are controlled by only a few countries, the origins of multinational enterprises (MNEs) engaged in related industries are widely distributed, which reduces the risks associated with EV battery production (Figure 3.7). Regionally, Australia has a comprehensive endowment across nearly all critical minerals; Chinese firms demonstrate strong global competitiveness and extensive control, particularly in lithium, cobalt and graphite; European companies, despite having limited domestic reserves, leverage their globally distributed extraction networks; Africa is rich in cobalt and manganese, though extraction activities are largely dominated by foreign firms; South American lithium is concentrated in Chile and Argentina and primarily developed by external actors; and North America, while resource diverse, lacks a dominant position in any single mineral. At the mineral level, lithium is concentrated in South America and Australia; cobalt centred in the DRC; manganese in Africa; and graphite primarily controlled by China and Japan, while nickel is more widely distributed.

The EV battery accounts for approximately 30% of the total vehicle cost, yet manufacturing of such batteries is concentrated in only a few countries (Figure 3.8). China contributed over 80% of the global EV battery production capacity in 2023, with a total capacity of 1,783 gigawatt-hour (GWh), followed by Europe (7.5%), the US (6.6%), South Korea (2.4%) and Japan (1.9%). From the perspective of the national origin of production capacity, Chinese manufacturers dominate with a total capacity of 1,600 GWh, which is 3.9 times that of the second-ranked South Korean manufacturers. However, South Korean manufacturers have a more globally distributed production footprint, accounting for 74% of total EV battery production capacity in Europe, 29% in the US and 10% in China. In contrast, Chinese manufacturers predominantly concentrate their production domestically, with only a small proportion located in Japan and Europe.

Figure 3.7: Distribution of Multinational Enterprises Engaged in the Extraction of Critical Minerals



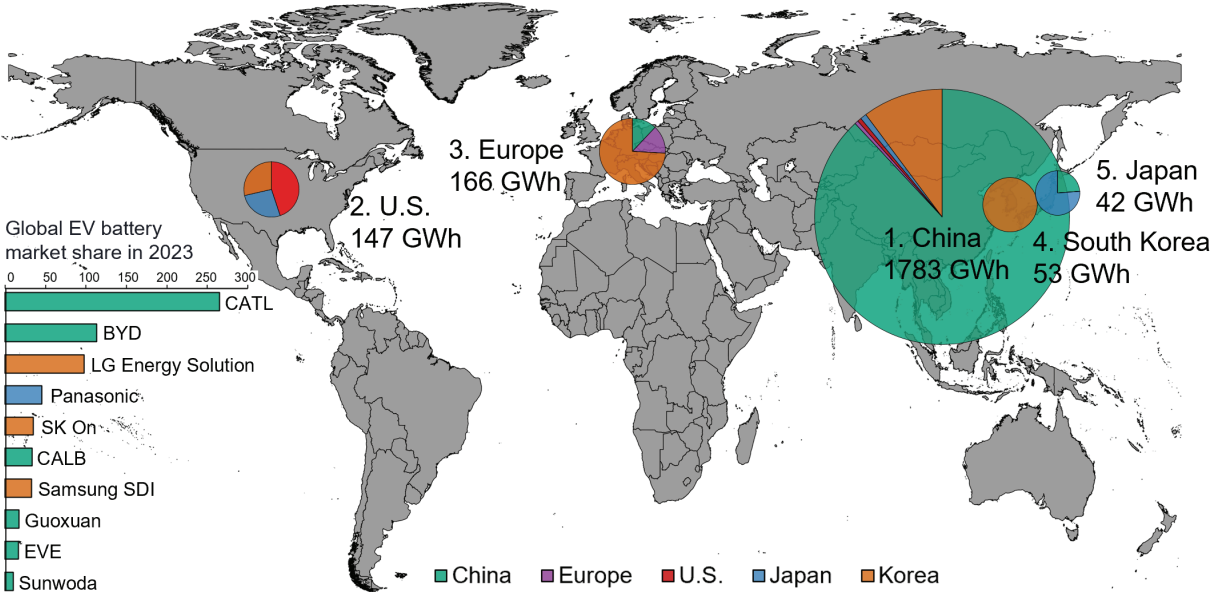
Notes: Different shapes and colours represent specific minerals and firms, with larger symbols indicating company headquarters and smaller ones denoting major mining sites.

Source: Data collected by the author from online news articles.

This concentration of production capacity mirrors the market's consolidation, where a few leading companies dominate. In 2023, 10 manufacturers collectively accounted for 93% of the global EV battery market share. China's dominance is underpinned by its technological leadership, large-scale production capabilities and robust government support for EV policies. Among the top 10 manufacturers, six are Chinese companies, with Contemporary Amperex Technology Co. Ltd. (CATL) commanding the largest market share at 36.8%. Meanwhile, leveraging advanced technology and global market strategies, South Korea's LG Energy Solution, SK On and Samsung SDI ranked third, fifth and seventh, respectively. Japan's Panasonic also secured a position in the global top 10 EV battery suppliers, placing fourth.

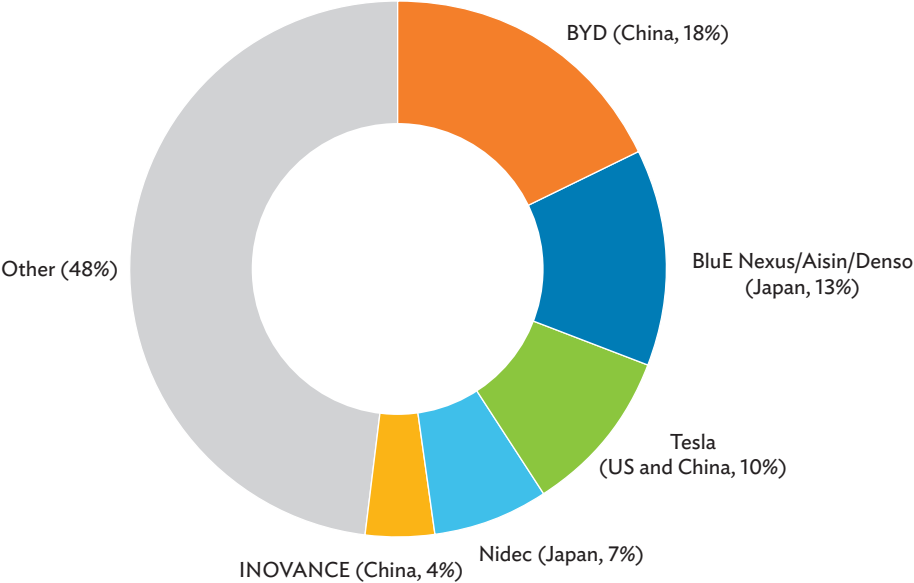
Compared to the EV battery sector, the electric motor market exhibits a more diversified competitive landscape (Figure 3.9). BYD leads the market, ranking first with an 18% share. The Japanese consortium of BluE Nexus, Aisin and Denso collectively holds a 13% share, securing second place. Tesla's electric motor production across its factories in the US and China accounts for 10% of the global market, placing it third. Japan's Nidec commands 7% of the market, followed closely by China's Inovance Technology (Inovance), which holds a 4% share. Other companies collectively account for the remaining 48% of the market.

Figure 3.8: Regional EV Battery Manufacturing Capacity By Manufacturer Headquarters and Global EV Battery Market Share in 2023



Source: IEA (2024a) and Annual Cumulative Global Battery Usage for EV in SNE (2024)

Figure 3.9: Global EV Electric Motor Market Share in 2022



Source: Analysis Report: EV/HV Drive Motor in Marklines (2024)

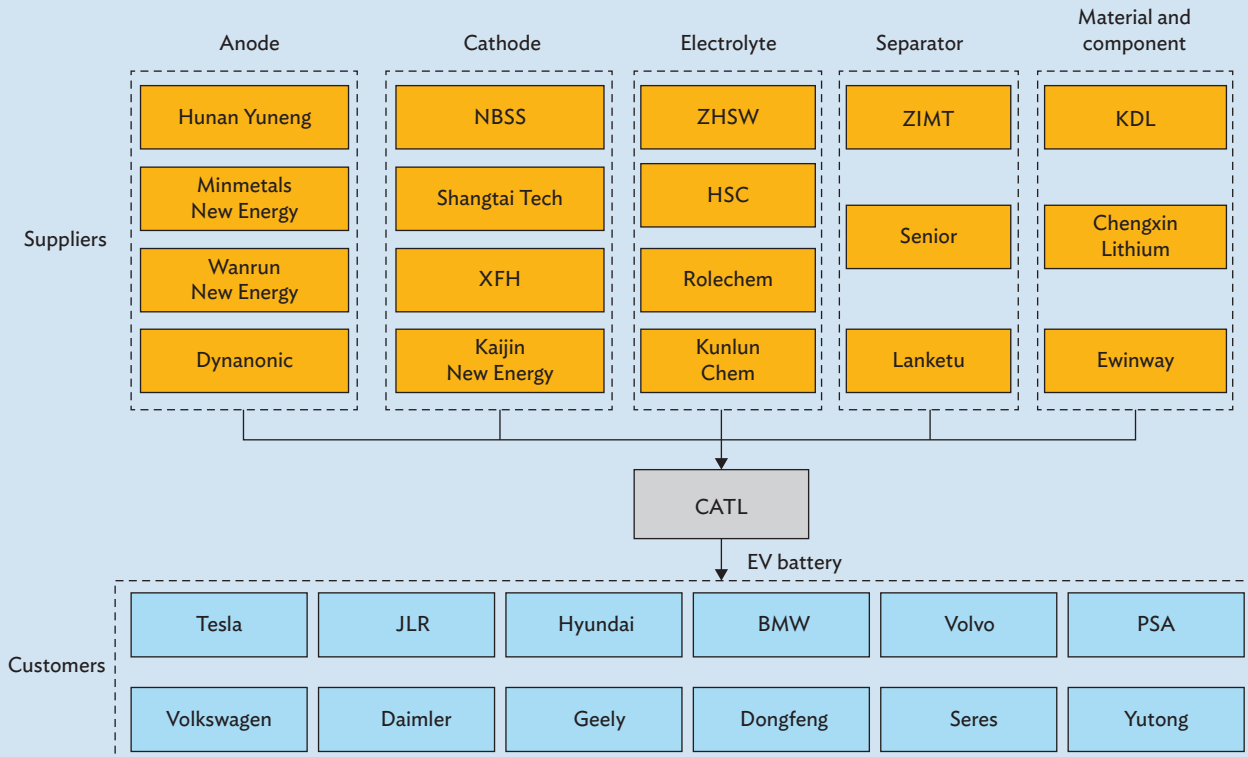
Box 3.1: Global Leader in the EV Battery Industry: CATL

Contemporary Amperex Technology Co., Ltd. (CATL) is the global leader in the production of EV batteries. According to SNE Research, the company held a 36.8% share in the EV battery market in 2023, maintaining its position as the leader for the seventh consecutive year. From 2017 to 2023, its annual average growth rate of EV battery sales reached 60.5%, driven by its continuous technological innovation and policies aimed at building a resilient supply chain.

CATL engages in deep collaboration with suppliers in crucial upstream areas such as cathode, anode, separator and electrolyte, as well as key components through mechanisms like technology licensing, long-term agreements and joint ventures. This strategy ensures the security of supply for critical raw materials and equipment while keeping costs under control. Additionally, the company collaborates with its suppliers to advance technological research and development (R&D), creating a supply chain system with sustained global competitiveness.

CATL's clientele includes numerous domestic Chinese automakers such as SAIC, Geely, Yutong, BAIC, Dongfeng, XPeng and Seres. Internationally, CATL has established partnerships with prominent global automotive brands, supplying EV battery products to BMW, Daimler, Hyundai, Jaguar Land Rover, PSA, Volkswagen and Volvo. This extensive customer base strategy effectively mitigates the negative impact of market demand fluctuations on the company's sales revenue, enhancing its stability and competitiveness in the global EV market.

Figure B 3.1.1: The Industrial Chain Distribution of CATL



Notes: NBSS: Ningbo Shanshan Co., Ltd. XFH: Shanghai XFH Technology Co., Ltd. ZHSW: Zhuhai Smoothway Electronic Materials Co., Ltd. HSC: Jiangsu Hsc New Energy Materials Co., Ltd. ZIMT: Shenzhen ZTE New Materials Technology Co., Ltd. Senior: Shenzhen Senior Technology Material Co., Ltd. Lanketu: Qingdao Lanketu Membrane Materials Co., Ltd. KDL: Shenzhen Kedali Industry Co., Ltd. Ewinway: Jiangxi Yunwei New Material Co., Ltd.

Source: Wind, annual report of CATL 2024

3.3 Structure Change of Value Added Creation and Carbon Emissions Along Global EV and ICEV Supply Chains

Drawing on the EV-ICIO model developed by Meng et al. (2025)¹, this section analyses how value added and carbon emissions are created and distributed along global supply chains in response to the production of EVs and ICEVs across six key automotive-producing countries: China, Germany, Japan, South Korea, Mexico and the US, which together accounted for 66.4% of global automotive production in 2023 (OICA, 2025).

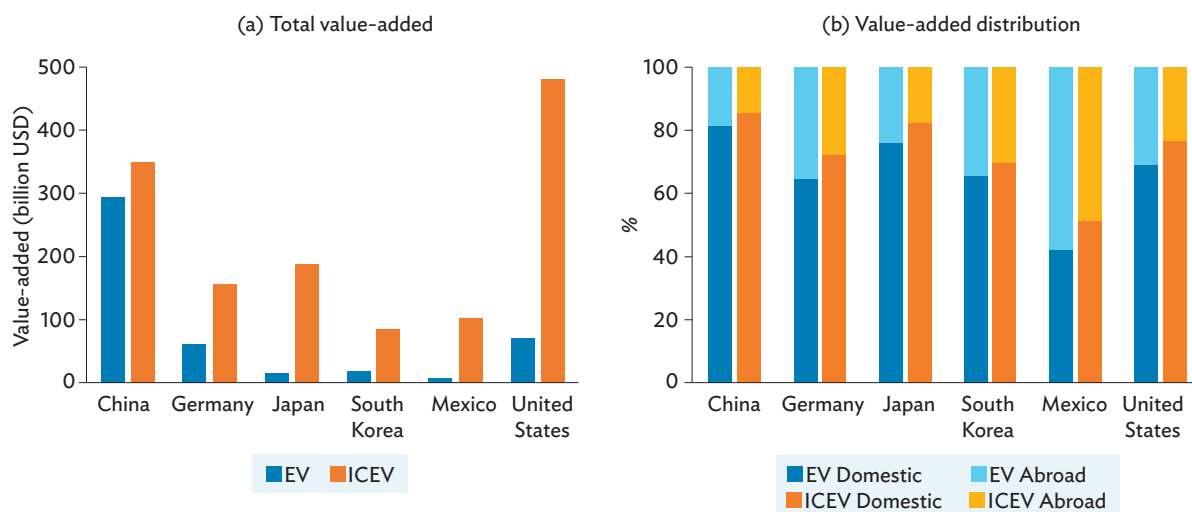
3.3.1 Value-Added Induced By the Production of EV and ICEV

Figure 3.10a presents the absolute level of value added embedded in the production of EVs and ICEVs. In 2023, China and the US were the largest automobile-producing countries, manufacturing 30.2 million and 10.6 million vehicles (OICA, 2025), respectively, thereby generating the highest levels of value added. However, the gap in value added between the two countries was relatively modest, with China generating \$643 billion and the US making \$552 billion. This narrower gap primarily results from the higher domestic value added coefficient of automotive-related sectors within the US, and the average vehicle price in the US is roughly 2.3 times that of China.

Driven by vertically integrated battery production, vehicle assembly and material refining capacity, China holds a commanding lead in the EV sector. EV production in China generated \$294 billion in value added. Benefiting from a large internal market and accelerating investment in domestic EV manufacturing infrastructure, the US (\$70 billion) and Germany (\$61 billion) ranked just behind China in terms of EV-related value added, though substantial gap remains compared with the ICEV-related value added. For example, in the US, the former accounted for only 14.6% of the latter. This reflects that traditional automotive manufacturing powerhouses may not necessarily be able to maintain their comparative advantages, given the significant differences in intermediate inputs and required production technologies between EVs and ICEVs. EVs impose higher demands on R&D capabilities and supply chain integration, especially in batteries, electronics and electric motors.

¹ The EV-ICIO model disaggregates the automotive sector in the OECD ICIO system into three subsectors: EVs, ICEVs and vehicle parts and components. The development of this model is based on the latest OECD ICIO tables (Yamano et al. 2023) as the control total, the OECD BTDIxE, detailed product level merchandise trade statistics (UN Comtrade), and the information of structural differences in technological input requirements between EVs and ICEVs estimated using a combination of firm-level surveys, expert interviews (for details, see Meng et al. 2025).

Figure 3.10: Value Added Induced By EV and ICEV Production, 2023



Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025).

Japan and South Korea possess advantages in battery and semiconductor technologies. However, the scale of their EV assembly remains relatively limited, resulting in a comparatively modest level of value added. Meanwhile, Mexico – traditionally a major assembly base for ICEVs – has yet to transition to large-scale EVs assembly, reflecting constraints in EVs demand, supply chain integration and technology adaptation.

Figure 3.10b illustrates the proportion of domestic and foreign value added, highlighting the more inclusive and globalized nature of EV supply chains. Compared with ICEVs, EVs involve more cross-border stages and external inputs, resulting in a higher share of foreign value added and enabling a wider range of economies to participate in the EV supply chains by leveraging their comparative advantages. For example, resource-rich economies such as the DRC have become important global suppliers of raw materials for EV batteries due to their abundant cobalt reserves – a role they can scarcely play in the ICEVs value chain. Similarly, countries like Indonesia and Chile, which are endowed with significant nickel and lithium resources, have emerged as key links in the EV supply chains.

The completeness of a country's domestic supply chain determines the share of value added that is retained domestically. China, Japan and the US all lead in terms of domestic value added shares. For China, 81.5% of the value added in EV production is retained domestically – only four percentage points lower than for ICEVs – mainly due to China's strong capabilities in battery manufacturing and vehicle assembly. However, it is worth noting that China still depends on foreign suppliers for automotive chips and critical minerals required for battery production. The US shows the inverse profile: relatively strong retention in ICEVs (76.6%) and a moderately lower share in EVs (68.9%). Although the US maintains significant control over chip manufacturing, vehicle design and vehicle assembly, it relies heavily on the Chinese supply chain

for EV batteries and critical mineral processing. This structural asymmetry results in a significantly lower share of domestic value added captured by the US in the EV production compared to ICEVs.

Germany and South Korea retain domestic value added shares of approximately 64.7% and 65.5% in EV production, respectively. Germany demonstrates strong capabilities in mechanical components but is highly reliant on battery supplies from Asia. South Korea has robust production capacities in batteries and semiconductors, yet still imports processed mineral products for battery manufacturing. Mexico exhibits the lowest domestic value added share, with only 42.3% for EVs and 51.5% for ICEVs, further highlighting its downstream position in the automotive supply chain and its limited control over high-value components.

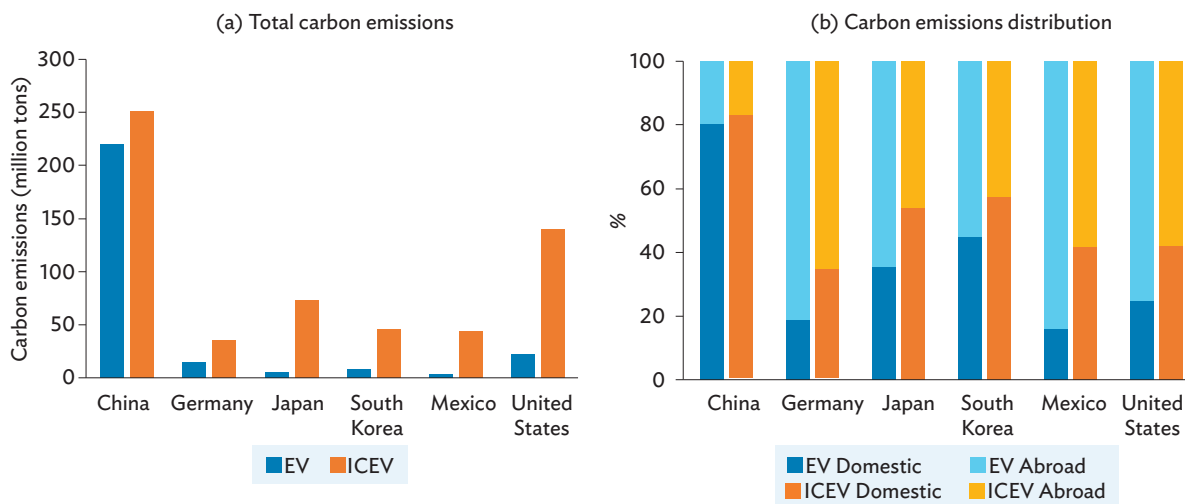
3.3.2 Carbon Emissions Induced by the Production of EVs and ICEVs

Based on the EV-ICIO model, it is also possible to quantify the differences in carbon emissions from the production of EV and ICEV across selected economies. Figure 3.11a illustrates the total carbon emissions generated from the production of EV and ICEV by economy. Owing to higher production volumes and ongoing reliance on carbon-intensive internal combustion engine manufacturing, ICEV production is associated with greater overall emissions. Meanwhile, the total emissions associated with EV production should not be overlooked either, as the battery supply chain generates substantial emissions.

At the national level, China's high degree of localization in the automotive supply chains, combined with its coal-dependent energy mix, results in the country leading the world in carbon emissions from both EV and ICEV production, reaching 220 million tons and 251 million tons, respectively. In contrast, the US benefits from a relatively cleaner domestic energy mix, with an average carbon intensity that is just 23% of China's (World Bank, 2025). Consequently, carbon emissions from ICEV production in the US are only 55.7% of those in China, totalling 162 million tons.

Figure 3.11b presents the share of carbon emissions between domestic and foreign sources. Similar to value added, the more open and globalized EV supply chains lead to a greater share of foreign carbon emissions, though this proportion varies significantly across economies. In China, strong domestic supply chains and high carbon intensity result in 80.2% of EV-related and 83.2% of ICEV-related carbon emissions remaining within the country. Although South Korea and Japan are also major producers of EV batteries, a large share of the upstream mineral processing required for their battery production is imported from China. As a result, their domestic carbon emissions embodied in EV production are higher than in the US and Germany, but lower than in China.

Figure 3.11: Carbon Emissions Induced By EV and ICEV Production, 2023



Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025). The carbon emissions information is derived and estimated from sectoral production-related emissions (Yamano et al., 2024).

The US and Germany have relatively limited domestic capacity for EV battery production and primarily rely on imports from countries like South Korea, Japan and China, while participating less in carbon-intensive battery manufacturing. According to estimates, battery supply chains account for roughly 60% of total EV production emissions (McKinsey, 2023). Consequently, in both economies, over 70% of carbon emissions associated with EV production originate from abroad.

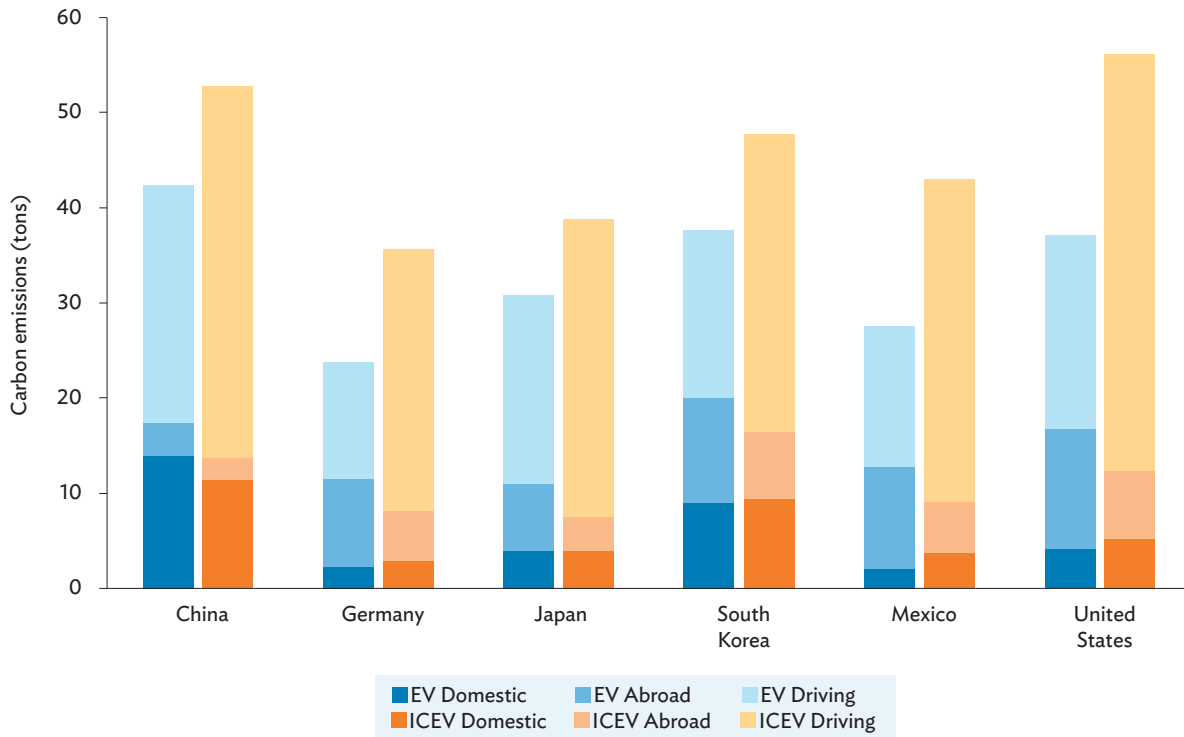
For ICEV production, traditional manufacturing economies typically have established stable global supply chains. Most ICEV-related industries in China are concentrated domestically. Partly because developed economies such as Germany, Japan, South Korea and the US have adopted relatively strict emissions regulations, they often outsource carbon-intensive production processes, resulting in a larger share of their carbon emissions occurring abroad. Notably, Germany records the highest share of ICEV-related carbon emissions occurring abroad – 65.0% – reflecting its deep integration within the EU's internal production network. As a country primarily focused on vehicle assembly, Mexico exhibits relatively low shares of foreign carbon emissions in the EV and ICEV production.

3.3.3 Life Cycle Carbon Emissions of EVs and ICEVs

As the primary pathway for decarbonizing the transport sector, EVs exhibit significantly lower life cycle emissions than ICEVs (TEI, 2022) (Figure 3.12). Emissions associated with the EV battery supply chain result in the production of an EV generating 2 to 4 tons more carbon emissions than an ICEV. For example, producing an EV in the US generates 16.8 tons of carbon dioxide (tCO₂) of carbon dioxide emissions, compared to only 12.3 tCO₂ emissions for an ICEV. However, over the vehicle's lifetime, EVs show

a clear advantage in emission reductions. In China, the driving emissions of an EV are about 25.1 tCO₂, while those of an ICEV reach 39.0 tCO₂. Similar trends are observed in other economies: in Germany, Japan and South Korea, the driving emissions for EVs are 12.3, 19.8 and 17.6 tCO₂, respectively, which are significantly lower than those of ICEVs (27.6, 31.4, and 31.3 tCO₂, respectively).

Figure 3.12: Life Cycle Carbon Emissions per EV and ICEV



Notes: The vehicle lifetime is set at 200,000 km (Nguyen-Tien et al., 2025).
 Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025). The carbon emissions information is derived and estimated from sectoral production-related emissions (Yamano et al., 2024).

The ongoing transition to cleaner electricity, combined with continued improvements in vehicle efficiency, will enable EVs to achieve even greater environmental benefits over their entire lifetime (Yang et al., 2021). We set up three scenarios to examine how improvements in the energy mix and advances in battery technology affect the time required for EVs to achieve net emission reductions relative to ICEVs. Scenario 1 assumes a cleaner national energy mix, characterized by a higher share of renewable energy (Table 3.1). Scenario 2 assumes more efficient electric driving system, meaning that less electricity is needed to drive the same distance (Table 3.2). Scenario 3 combines both factors – that is, assuming that the share of renewables and electric driving system efficiency is increased by the same proportion (Table 3.3).

Under the current energy mix and technological conditions, it takes only 1.7 years for EVs in the US to reach life cycle emission parity with ICEVs, while the corresponding periods are 5.7 years for China and 7.6 years for Japan. This outcome is mainly

determined by differences in average driving distances and the engine displacements of ICEVs. In the US, the average daily driving distance is 61 km, compared with only 25 km in China and 22 km in Japan. Moreover, ICEVs in the US have larger engine displacements compared to those in Japan and China, which means that switching from ICEVs to EVs results in greater annual emission reductions in the US, i.e., EVs in the US require less time to offset the higher production emissions through lower driving emissions.

Table 3.1: Simulation Results of Scenario 1 (cleaner energy mix)

	Baseline	5%	10%	15%	20%	25%	30%
China	5.7	5.5	5.4	5.2	5.1	4.9	4.7
Germany	3.7	3.6	3.5	3.3	3.2	3.1	3.0
Japan	7.6	7.3	7.1	6.9	6.6	6.4	6.1
South Korea	3.5	3.4	3.3	3.2	3.2	3.1	3.0
Mexico	3.3	3.2	3.1	3.0	2.9	2.8	2.7
United States	1.7	1.6	1.6	1.5	1.5	1.4	1.4

Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025).

Table 3.2: Simulation Results of Scenario 2 (more efficient electric driving system)

	Baseline	5%	10%	15%	20%	25%	30%
China	5.7	5.6	5.2	4.9	4.6	4.4	4.2
Germany	3.7	3.7	3.7	3.6	3.5	3.5	3.4
Japan	7.6	7.2	6.9	6.5	6.2	6.0	5.7
South Korea	3.5	3.4	3.2	3.0	2.9	2.8	2.6
Mexico	3.3	3.2	3.1	3.0	2.9	2.9	2.8
United States	1.7	1.6	1.6	1.6	1.5	1.5	1.4

Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025).

Table 3.3: Simulation Results of Scenario 3 (cleaner energy mix and more efficient electric driving system)

	Baseline	5%	10%	15%	20%	25%	30%
China	5.7	5.4	4.9	4.5	4.1	3.8	3.5
Germany	3.7	3.6	3.4	3.2	3.1	2.9	2.8
Japan	7.6	7.0	6.4	5.9	5.5	5.0	4.6
South Korea	3.5	3.3	3.1	2.8	2.6	2.5	2.3
Mexico	3.3	3.1	2.9	2.8	2.6	2.5	2.3
United States	1.7	1.6	1.5	1.4	1.3	1.3	1.2

Source: Authors' calculation using an EV-ICIO model based on the OECD ICIO data (Meng et al., 2025).

As the energy mix improves, the time required for EVs to achieve net emission reductions decreases significantly. For example, if the share of renewable energy increases by 15%, the payback period for EVs in Japan drops from 7.6 years to 6.9 years, and in China from 5.7 years to 5.2 years. In the US, only 1.5 years are needed to

achieve net emission reductions. This is because the expansion of renewable energy leads to a more substantial reduction in electricity-related emissions, benefiting both the production and driving phase of EVs, while the emissions associated with gasoline/diesel consumption in ICEVs remain unchanged.

Improvements in electric driving system efficiency help reduce the energy-related emissions of EVs during the operation phases. When electric driving system efficiency increases by 15%, the carbon payback period for EVs in Japan shortens from 7.6 years to 6.5 years, and in the US drops to 1.6 years. However, compared with improvements to the energy mix, increasing electric driving system efficiency poses greater technological challenges. When both the energy mix and electric drive efficiency improve by 15%, the emission reduction potential of EVs is further enhanced, with the carbon payback period for EVs in Japan declining to about 5.9 years to achieve life cycle emission parity with ICEVs.

Based on the above analysis, an efficient global EV supply chain design places low-emission, technologically advanced economies at the helm of battery and core-component manufacturing, as well as of end-of-life circular activities, while resource-rich developing economies supply critical minerals and undertake mineral processing. This specialization leverages comparative advantages, deepens technology–resource complementarities and accelerates the EV sector’s low-carbon transition worldwide.

3.4 New Opportunities for a More Inclusive Global EV Supply Chains: A Study Based on Product Space Evolution

The development of EV supply chains is profoundly redefining the landscape of the global automotive industry. EV-related industries have become a strategic priority not only for traditional automotive powerhouses but also for numerous emerging market and developing economies (EMDEs), which view the EV sector as a pivotal future development track and are exploring avenues for integration into the global supply chain. In 2024, EV sales in Asia, Africa and Latin America surged by 40% year-on-year, capturing a 4% market share. Notably, sales in Indonesia and Vietnam tripled and doubled, respectively, while Costa Rica and Uruguay achieved high penetration rates of 15% and 13% (IEA, 2025b). This growth opens new avenues for developing economies to enter the EV value chain, fostering economic growth through industrial upgrading and diversification.

3.4.1 Product Space Network of EV Supply Chains

The product space network is an outcome-based framework for measuring linkages between products (Hidalgo et al., 2007). Its core logic is that if the production of two

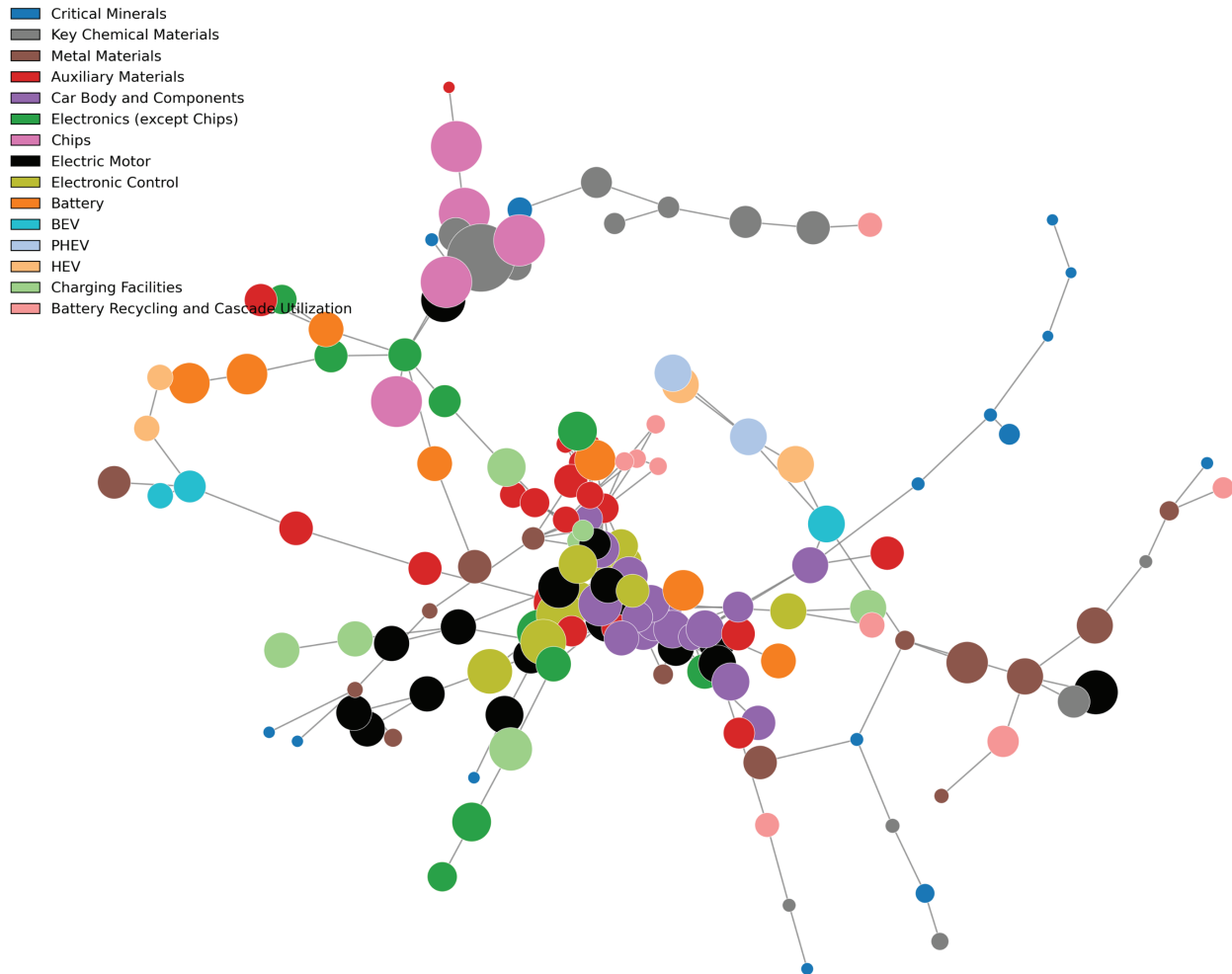
goods requires similar institutions, infrastructure, factor inputs or technology, etc., they are likely to be co-produced. This linkage is quantified as “proximity”, which formalizes the idea that a country’s ability to produce a product is dependent on its ability to produce other, related products. For instance, a country capable of exporting apples likely possesses most conditions needed for exporting pears (e.g., suitable soil, climate and cold-chain logistics), as the capabilities are highly transferable. In contrast, these capabilities would be largely irrelevant for producing goods like copper wires or home appliances.

Based on this logic, a product space network for EV supply chains was constructed. The network was developed by first identifying EV-related products according to industry classifications from the WTO (2024) and IEA (2024a), which categorize 155 products into four segments: raw materials, upstream, midstream and downstream. The raw materials category encompasses key chemical materials, metals and auxiliary materials. The upstream segment consists of six product groups: chips, other electronics, electronic control systems, electric motors and batteries, as well as car bodies and components. The midstream segment covers EV manufacturing, including both BEVs and PHEVs. The downstream segment includes charging infrastructure, battery recycling and cascade utilization.

The resulting EV product space exhibits a distinct core-periphery structure (Figure 3.13). Products located in the core demonstrate high technical versatility and complementarity. They are densely interconnected, enabling agglomeration effects and economies of scale through technology sharing and transfer. For instance, production factors related to electronic control systems (yellow), car bodies and components (purple) and auxiliary materials (red) can be readily applied across different EV subsystems. In contrast, peripheral products occupy relatively isolated positions in the product space. While their technological pathways are less extendable from existing products, they still fulfill indispensable roles within the EV supply chain.

Peripheral products can be broadly classified into two types. The first category comprises resource-intensive products, such as key mineral resources including lithium, cobalt and nickel. The development of these products is largely dependent on a country’s natural resource endowment. Although they involve relatively low levels of technological sophistication, they form the foundational support for EV manufacturing and represent the starting point of the supply chain. The second category consists of key components with high technical barriers, such as chips (pink) and batteries (orange). The R&D and manufacturing of these products rely heavily on original innovation and industrial ecosystems, presenting significant entry barriers and strong industrial control.

Figure 3.13: Global EV Supply Chain Product Space, 2017-2023



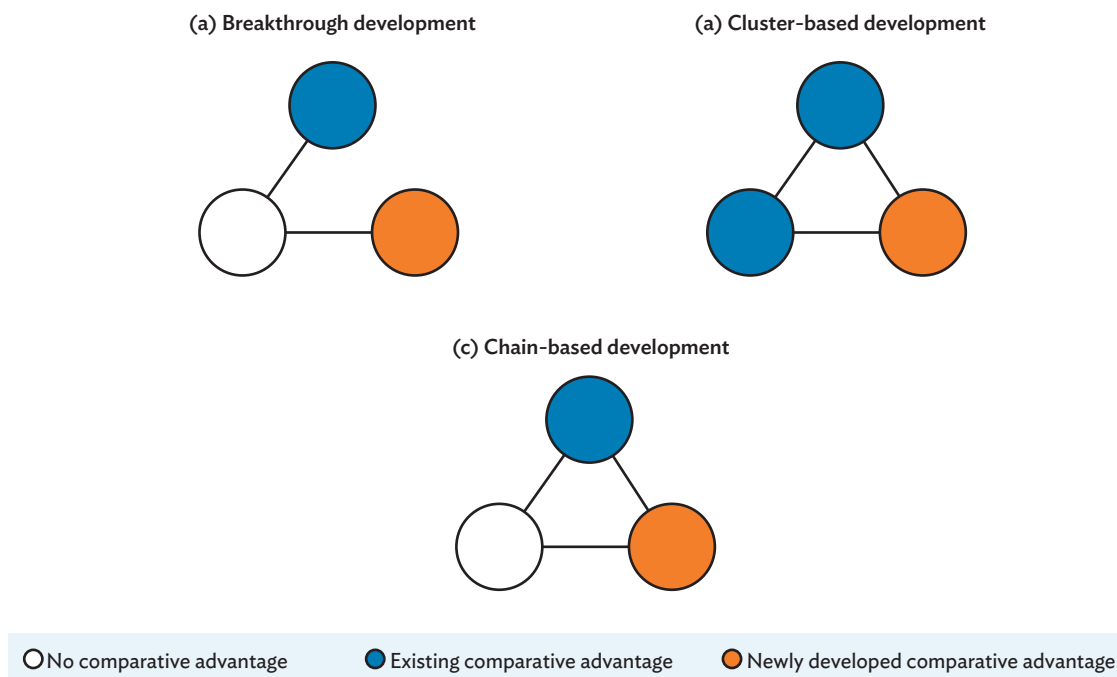
Note: The node size corresponds to the product complexity, node colour represents categories in the EV supply chain.
 Source: Authors' calculation based on UN Comtrade data (2017-2023)

3.4.2 Evolutionary Pattern of the Global EV Supply Chain

The evolutionary pathways of countries within the EV supply chain can be categorized into three types: breakthrough, cluster-based and chain-based. Using each country's set of competitive products in 2017 as the benchmark, we define any product newly added between 2018 and 2023 as a "new product".

A product is classified as following a breakthrough pattern if it has no direct network connection to any product in the benchmark (Figure 3.14a). It is considered cluster-based if the new product forms a triadic closure with existing products in the benchmark (Figure 3.14b). If it is connected to a benchmark product but does not form a triadic closure, the evolution is labelled 'chain based'. Both the chain-based and cluster-based patterns are considered path-dependent, as they build upon existing competitive products.

Figure 3.14: Schematic Diagram of Evolutionary Patterns



Source: Compiled by the author

The evolution diagram of the main countries in EV supply chains is shown in Figure 3.15. On the left side of this diagram are the evolutionary patterns of 15 EV supply chain categories. Raw materials categories mainly follow a breakthrough pattern, lacking links with pre-existing products. For example, among 22 new critical mineral products (2017–2023), 18 are breakthrough; in key chemical materials, 16 of 20; in metal materials, 18 of 30; and in auxiliary materials, 15 of 46.

Most upstream categories exhibit strong path dependencies: among 21 new electronics products, six are cluster-based and 10 chain-based; in electronic control, eight cluster-based and 11 chain-based (out of 23); in electric motors, eight cluster-based and 10 chain-based (out of 29); in batteries, three cluster-based and two chain-based (out of eight); and in body and components, 21 cluster-based and 11 chain-based (out of 37). An exception is chips, where three of six new products are breakthroughs.

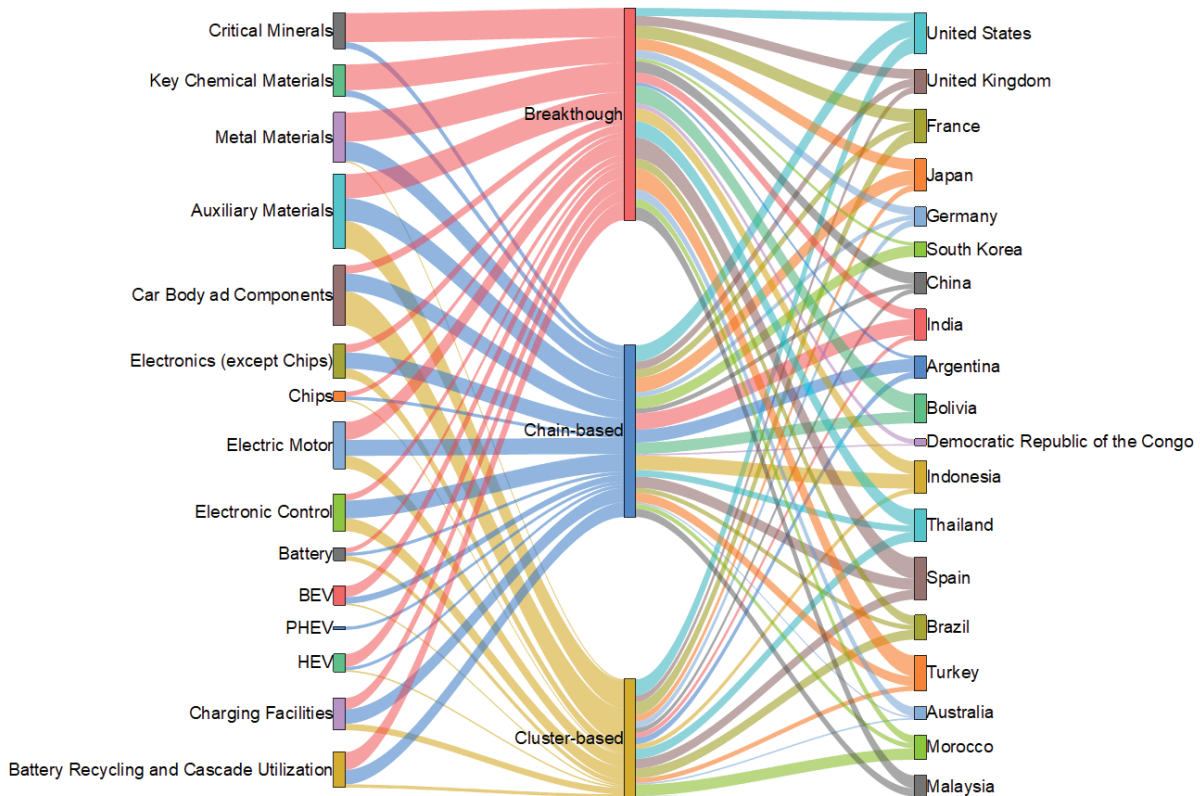
Most midstream categories also follow the breakthrough pattern, with 15 of 25 new BEV, PHEV and HEV products being breakthroughs. In downstream categories, half of the products (seven in charging facilities and 11 in battery recycling) are breakthroughs and half are chain-based.

The right side of Figure 3.15 allows for a cross-country comparison of evolutionary pathways within the EV supply chain. Most developed countries follow strong path dependencies, adopting chain-based or cluster-based patterns. In the US, 10 products

are cluster-based and 10 chain-based among 25 new products. The UK, Japan and South Korea mainly follow chain-based patterns with five, nine and seven products, respectively, while France and Germany lean towards cluster-based patterns with eight and four products. These developed economies build on existing technological strengths, particularly in electronics, electric motors and electronic control, leading to chain-based evolution without major shifts from traditional internal combustion engine industries, except in advanced technologies such as power batteries.

In contrast, developing economies display more varied patterns. China mainly follows a breakthrough pattern, with seven of 13 new products unrelated to existing ones. Thailand, Spain, and Türkiye also follow breakthrough patterns, whereas India shows a chain-based path dependency. Resource-rich countries such as Argentina (lithium) and Indonesia (nickel) mainly evolve in a chain-based manner. Bolivia presents a mixed case, with eight breakthrough and nine chain-based products. Brazil and Morocco, on the other hand, show a tendency towards cluster-based evolution.

Figure 3.15: Evolutionary Patterns of 15 Categories in the EV Supply Chain (Typical Economies)



Source: Authors' calculation based on UN Comtrade data (2017-2023)

3.4.3 Evolutionary Patterns of Typical Products in the EV Supply Chain

The evolution of six representative product categories within the EV supply chain was analysed at the product level, covering chips, electronics (excluding chips), electronic controls, electric motors, batteries and EV manufacturing. Their specific evolutionary pathways are illustrated in Figure 3.16.

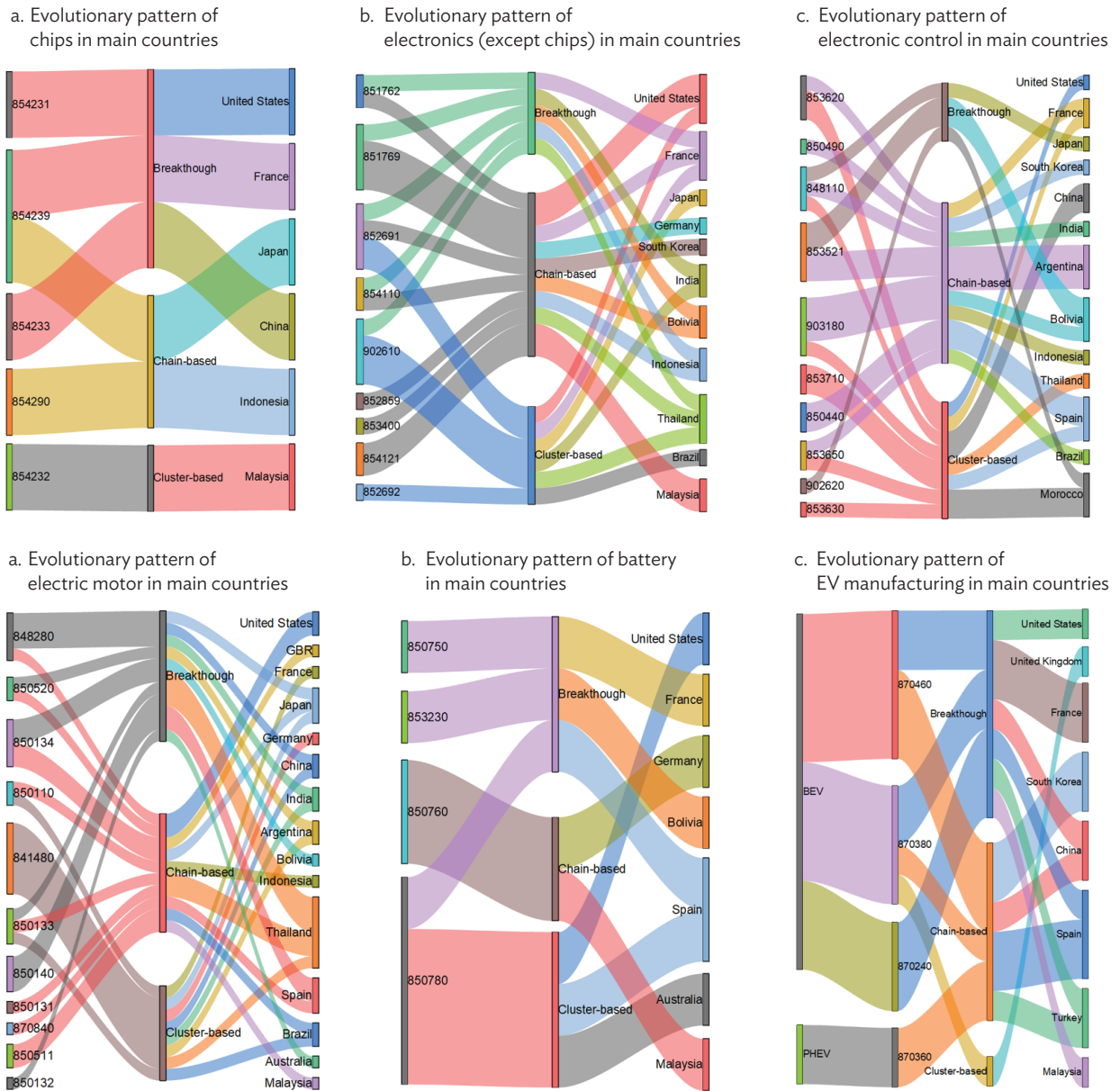
In the chips category, evolutionary patterns are highly diverse (Figure 3.16a). Processor and controller integrated circuits (HS 854231) and amplifier integrated circuits (HS 854233) predominantly follow a breakthrough pattern. In contrast, parts of integrated circuits (HS 854290) evolve in a chain-based manner, reflecting reliance on pre-existing electronic component industries. Memory integrated circuits (HS 854232) exhibit a cluster-based pattern, indicating strong linkages with existing products and the formation of triadic closures. Only six countries – the US, France, Japan, China, India and Malaysia – developed comparative advantages in new chip products and entered the global EV supply chain product space between 2017 and 2023, half of which followed the breakthrough pattern.

For electronics (excluding chips), the chain-based evolutionary pattern is dominant (Figure 3.16b). Among the 21 new electronic products that revealed comparative advantage (RCA) and entered the EV supply chain product space, 10 followed a chain-based pattern – including two products each from the US and Malaysia. Most electronic products, such as monitors other than cathode ray tubes (HS 852859), printed circuit boards (HS 853400), and unipolar transistors (HS 854121), follow the chain-based evolutionary patterns, indicating that they tend to develop based on existing technological and industrial foundations.

Electronic control products show strong path dependence, with most following chain-based or cluster-based patterns (Figure 3.16c). Of the 23 new electronic control products, 11 evolved in a chain-based manner – including three from Argentina and two from Spain – while eight followed a cluster-based pattern, with two products each from China and Morocco. Products such as automatic circuit breakers (HS 853620, HS 853521), static converters (HS 850440), electrical switches (HS 853650) and circuit protection devices (HS 853630) typically entered the EV product space via chain-based or cluster-based pathways, indicating reliance on technological extensibility or industrial agglomeration, indicating that electronic control products tend to develop based on their technological extensibility or technological clusters.

For electronic control, it displays evolutionary patterns across three paths (Figure 3.16d). Among 29 new electronic control products, eight are cluster-based, 10 are chain-based and 11 products follow the breakthrough evolutionary pattern. However, there are differences among products: the cluster-based evolutionary pattern is primarily concentrated in products such as micro motors (HS 850110), compressors

Figure 3.16: Evolutionary Pattern of Six Typical Products in the EV Supply Chain Across Selected Countries



Source: Authors' calculation based on UN Comtrade data (2017-2023)

(HS 841480) and DC motors/generators (HS 850133), while the products with chain-based and breakthrough evolutionary patterns are more widely distributed.

Battery evolution reveals significant technological lock-in effects (Figure 3.16e). Between 2017 and 2023, the US, France, Bolivia, Spain, Australia and Malaysia developed new RCA battery products, mostly following breakthrough or chain-based patterns. All power batteries (HS 850760) evolved in a chain-based manner, reflecting high dependence on existing lithium battery systems and manufacturing capabilities. In contrast, nickel-metal hydride (NiMH) batteries (HS 850750) and capacitors

(HS 853230) mainly followed breakthrough patterns, suggesting greater potential in alternative technology pathways. Other batteries (HS 850780) followed a cluster-based pattern, likely due to agglomeration in niche applications.

In EV manufacturing products, most countries follow the breakthrough evolutionary pattern (Figure 3.16f). Most BEV products (HS 870380, HS 870460, HS 870240) follow the breakthrough pattern, and their development requires policy incentives. In contrast, PHEVs (HS 870360) exhibit stronger path dependence, mainly following the chain-based pattern, due to their higher reliance on existing automotive industrial systems.

3.4.4 EV Product Space Network and Its Evolution in Typical Economies

The evolutionary patterns of countries within the EV supply chain can be visualized using a product space network diagram. We hold the product space of a country in 2023 fixed and studied the dynamics of products within it. To illustrate these patterns, seven representative countries have been selected, with their specialization evolution depicted in Figures 3.5-3.7. Products in which a country holds a revealed comparative advantage ($RCA > 1$) are represented by coloured circles.

Evolutionary Pattern of Traditional ICEV Economies

Figure 3.17 shows the evolutionary pattern of the traditional ICEV countries (the US, Japan and Germany) in the global EV supply chain product space.

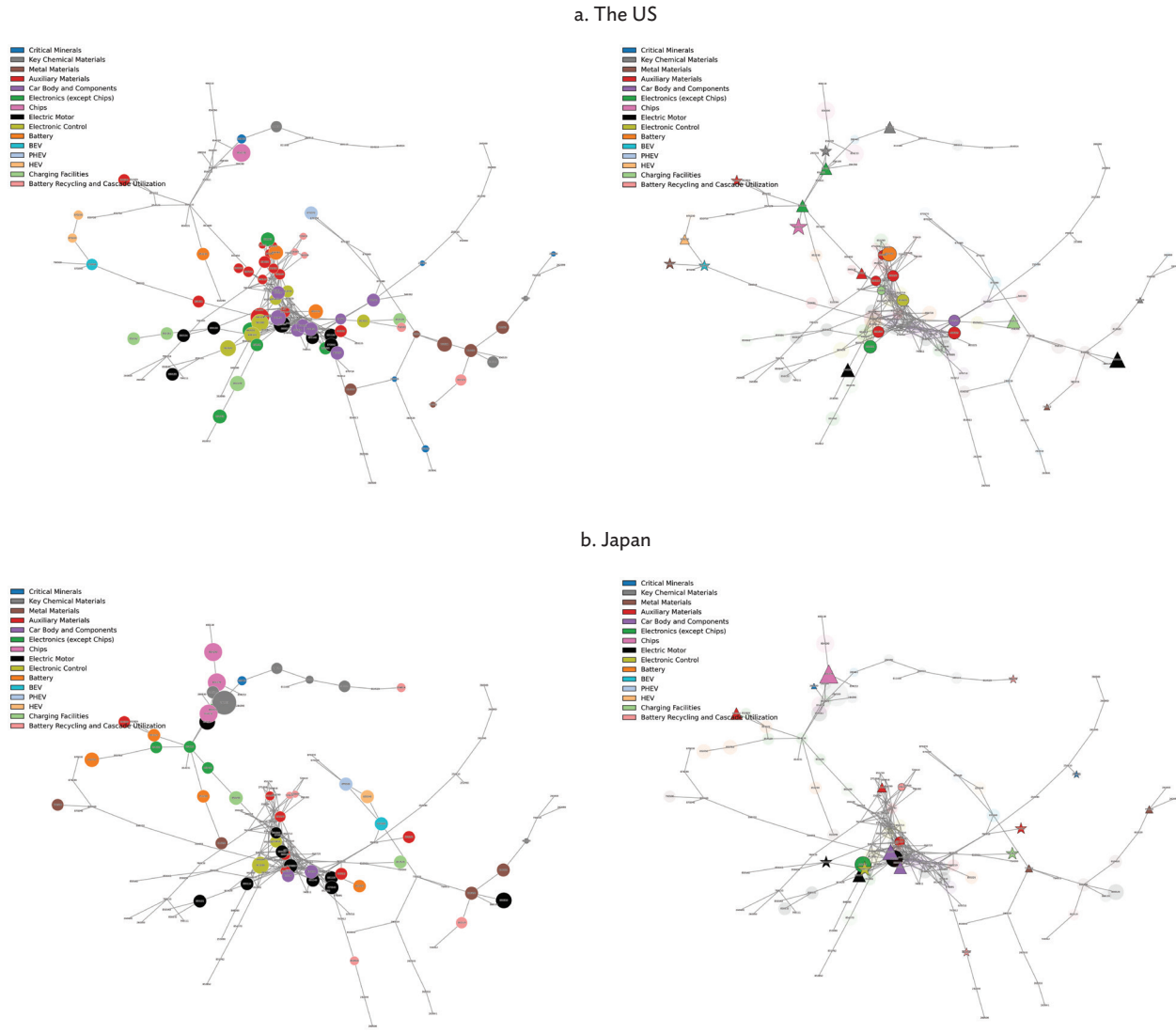
The US had an RCA in 71 EV supply chain products in 2023 (Figure 3.17a). It occupied the core cluster of the EV supply chain product space, primarily associated with products in electronic control, electric motors, body and components, and auxiliary materials. It also participated in 12 peripheral products, such as chips, metal materials and electronics. The evolutionary patterns of the US in the EV supply chain tend to be path-dependent. From 2017 to 2023, the US developed 25 new advantageous products, 10 of them following the cluster-based pattern and 10 following the chain-based pattern. Most products in the core cluster (such as polymers in auxiliary materials, NiMH batteries and circuit breakers in electric motors) followed the cluster-based pattern, and most products in the periphery (such as refined copper in metal materials, and diodes in electronics) followed the chain-based pattern.

Japan occupies both the core cluster and periphery of the EV supply chain product space (Figure 3.17b), and it has more products with comparative advantages in the periphery than the US. In the core cluster, Japan has RCA in electric motors (HS 850300, HS 850152, HS 851140, etc.), electronic control (HS 903180, HS 853580), body and components products. In the periphery, Japan has RCA in chips (HS 854232, HS 854239, HS 854290), batteries (HS 853222, HS 850750, HS 853230, HS 853225), electronics (HS 854129, HS 854110, HS 853400) and key chemical materials (HS 284169, HS 282690, HS 284690). The evolutionary pattern of Japan in the EV supply

chain product space tends towards chain-based and breakthrough patterns due to its technological advantage. From 2017 to 2023, Japan developed 20 new advantageous products, nine of them following the chain-based pattern, including other chips (HS 854239), heat exchangers (HS 841950), electric motors (HS 850110), polyvinyl chloride (HS 390330), and paints and varnishes (HS 321000), etc.

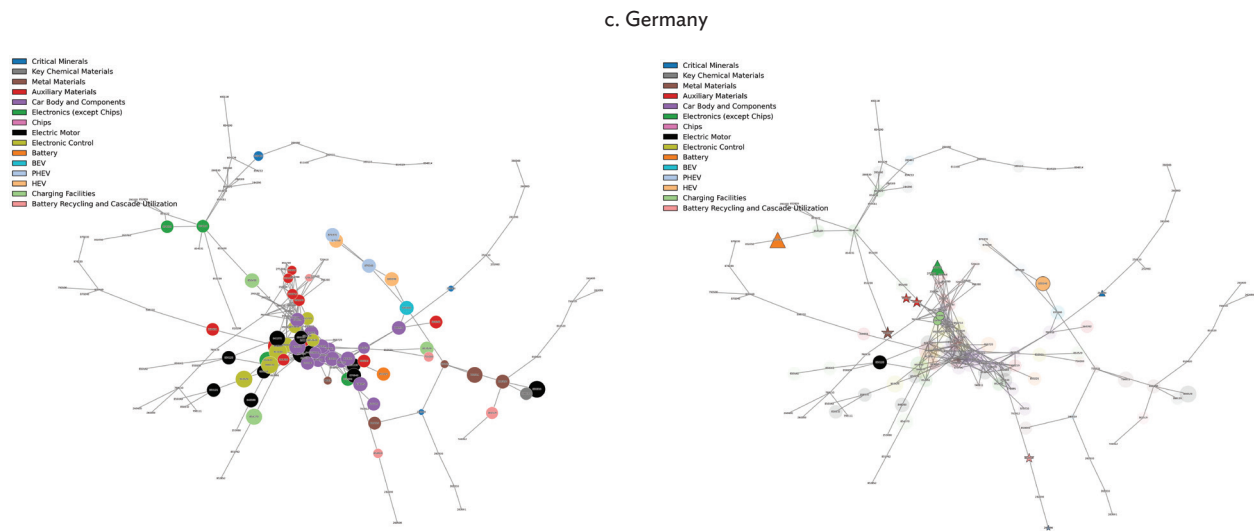
Germany mainly occupies the core cluster in the EV supply chain product space (Figure 3.17c), with products in the categories of body and components, electric motors and electronic control. In 2023, Germany had 71 RCA products, with 16 in body and components, 11 in electric motors, and seven in electronic control. Germany follows a cluster-based evolutionary pattern in the EV supply chain product space due to its scale advantage.

Figure 3.17: EV Supply Chain Product Space of the US, Japan and Germany in 2023 and their Evolutionary Patterns



continued on next page

Figure 3.17: continued



Notes: Left, the product space of countries in 2023. Right, the evolution between 2007 and 2023. The shapes of star, circle and triangle represent the evolutionary pattern of breakthrough, cluster-based and chain-based, respectively (the same below).

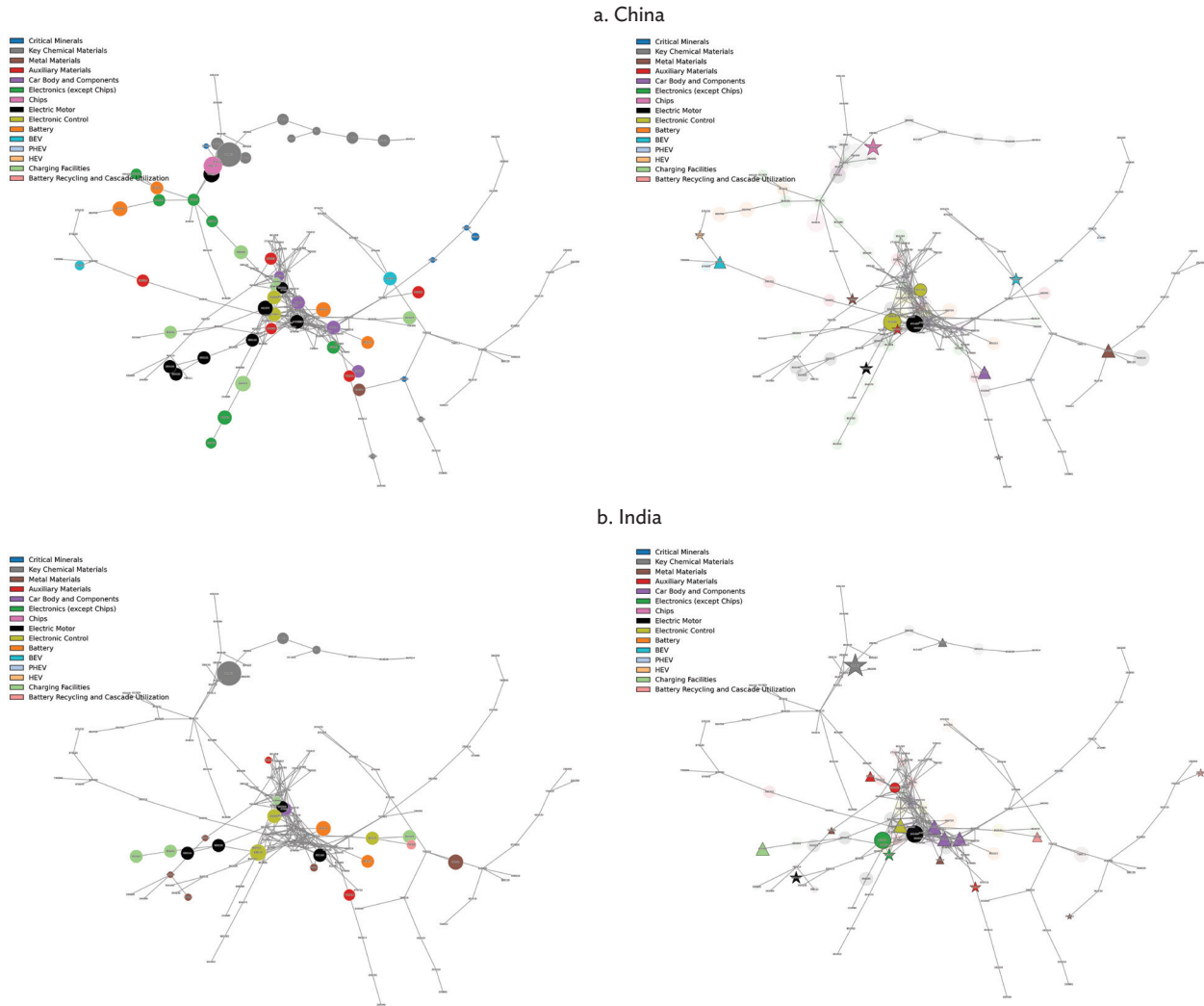
Source: Authors' calculation based on UN Comtrade data (2017-2023)

Evolutionary Pattern of Market-Driven Economies

China's products with RCA are distributed in the core cluster and the periphery of the EV supply chain product space (Figure 3.18a). In 2023, China had RCA in 56 EV supply chain products, 20 of them located in the core cluster of the EV supply chain product space and the others distributed in the periphery. China mainly follows the breakthrough evolutionary pattern in the EV supply chain product space. From 2017 to 2023, China developed 13 new advantageous products, seven of them following the breakthrough pattern. The breakthrough pattern indicates that China develops high-complexity products without establishing linkages with present products, which often rely on indigenous R&D, technology importation and industrial policy support.

India also has its RCA products in the core cluster and the periphery of the EV supply chain product space (Figure 3.18b). In 2023, India had 25 RCA products in the EV supply chain, most of them in the periphery. In the periphery, India has RCA in key chemical materials (HS 284169, HS 284690, HS 282010). In the core cluster, India has RCA in electric motors (HS 850134, HS 850133, HS 850300, HS 851140), batteries (HS 850720, HS 853225), and electronic control (HS 848110, HS 850490, HS 853521). India mainly follows the evolutionary pattern of breakthrough and chain-based development. From 2017 to 2023, India developed 19 new advantageous products, six of them following the breakthrough pattern and 10 of them following the chain-based pattern. India remains in the early development stage of the EV supply chain, with its advantageous products distributed in the periphery of the product space, which makes it hard to form an interconnected and complementary supply chain ecosystem.

Figure 3.18: EV Supply Chain Product Space of China and India in 2023, and Their Evolutionary Patterns

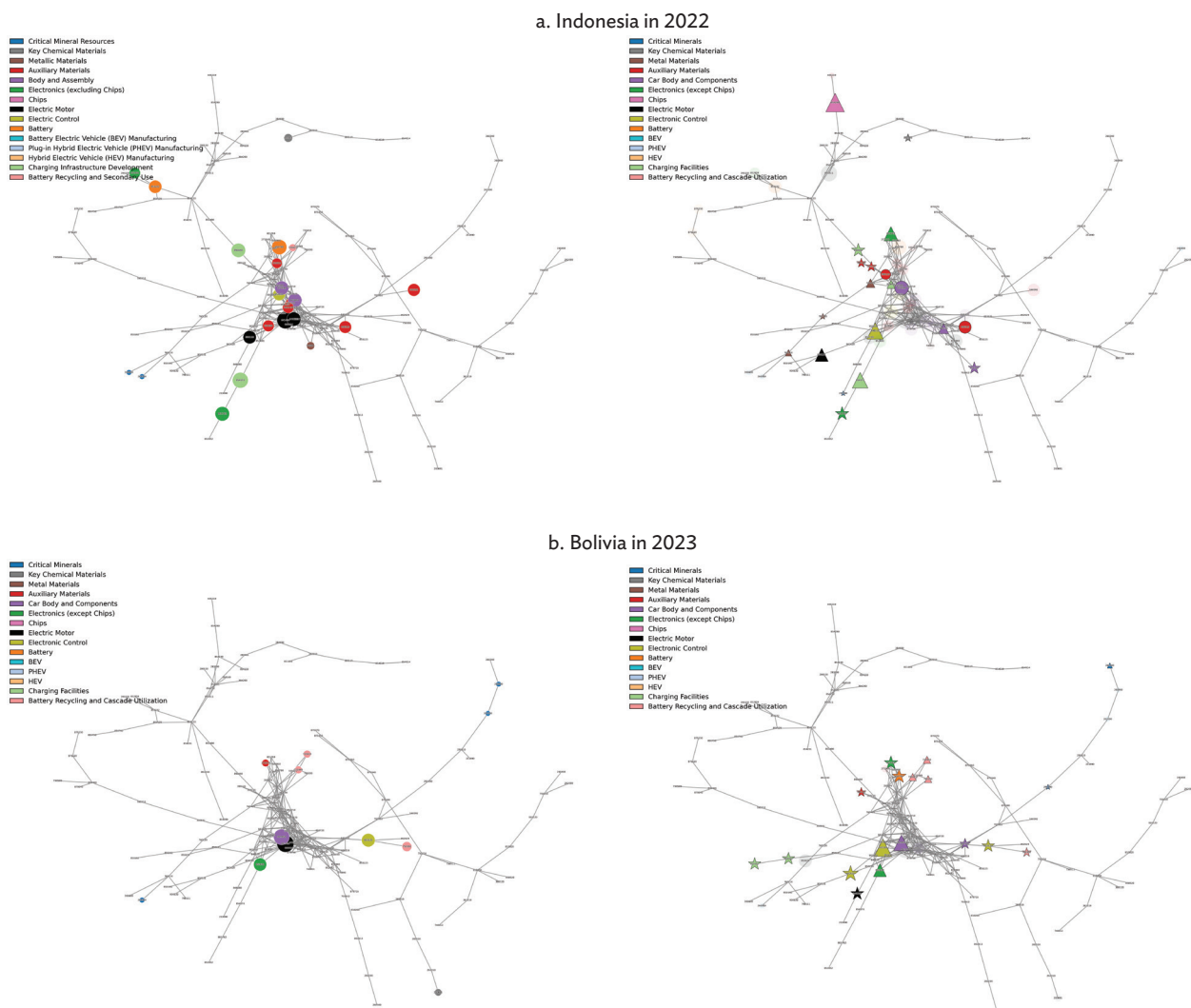


Source: Authors' calculation based on UN Comtrade data (2017-2023)

Evolutionary Patterns of Resource-Abundant Economies

Indonesia mainly occupies the core cluster of the EV supply chain product space (Figure 3.19a). In 2022, Indonesia had 23 RCA products, with two critical materials (HS 260300, HS 260600), one key chemical material (HS 811100) and one metal material (HS 740811). Indonesia follows the chain-based and breakthrough evolutionary patterns in the EV supply chain product space. From 2017 to 2022, Indonesia developed 20 new advantageous products, nine of them (HS 854290, HS 850131, HS 848110, HS 854370, HS 851769, HS 854442, HS 940120, HS 760410, HS 760110) following the chain-based pattern, eight following the breakthrough pattern and three following the cluster-based pattern. Indonesia holds the world's largest nickel reserves, but it lacks RCA in raw materials in the EV supply chain product space, due to the implementation of an export ban on unprocessed mineral ores (including bauxite and nickel) in 2014.

Figure 3.19: EV Supply Chain Product Space of Indonesia and Bolivia, and Their Evolutionary Patterns



Source: Authors' calculation based on UN Comtrade data (2017-2023)

Bolivia had 12 RCA products in the EV supply chain in 2023 (Figure 3.19b), with three of them being critical materials (HS 260900, HS 260300, HS 261590). From 2017 to 2023, Bolivia developed 18 new advantageous products, 11 of them following the breakthrough pattern. The South American country gained its advantage in the transition from ICEV vehicles to EVs due to its natural endowments. In the ICEV vehicles era, Bolivia's lithium-rich salt flats – characterized by high impurity levels and unfavourable locations – remained untapped. However, the global shift to EVs, coupled with rising lithium prices, has transformed these deposits into strategic assets and helped Bolivia enter the global EV supply chain.

3.4.5 Opportunities for Different Economies

For economies with established technological or scale advantages in ICEV manufacturing, it is crucial to leverage their traditional strengths while embracing new EV technology trends. By enhancing innovation in core components such as batteries and chips, these countries can occupy a high value added position in the EV supply chain. Given the significant similarities in production factors, technology and institutional frameworks between EVs and ICEVs, countries with a strong ICEV base should adopt a cluster-based development model to systematically build EV supply chain capabilities rooted in their existing ICEV foundation.

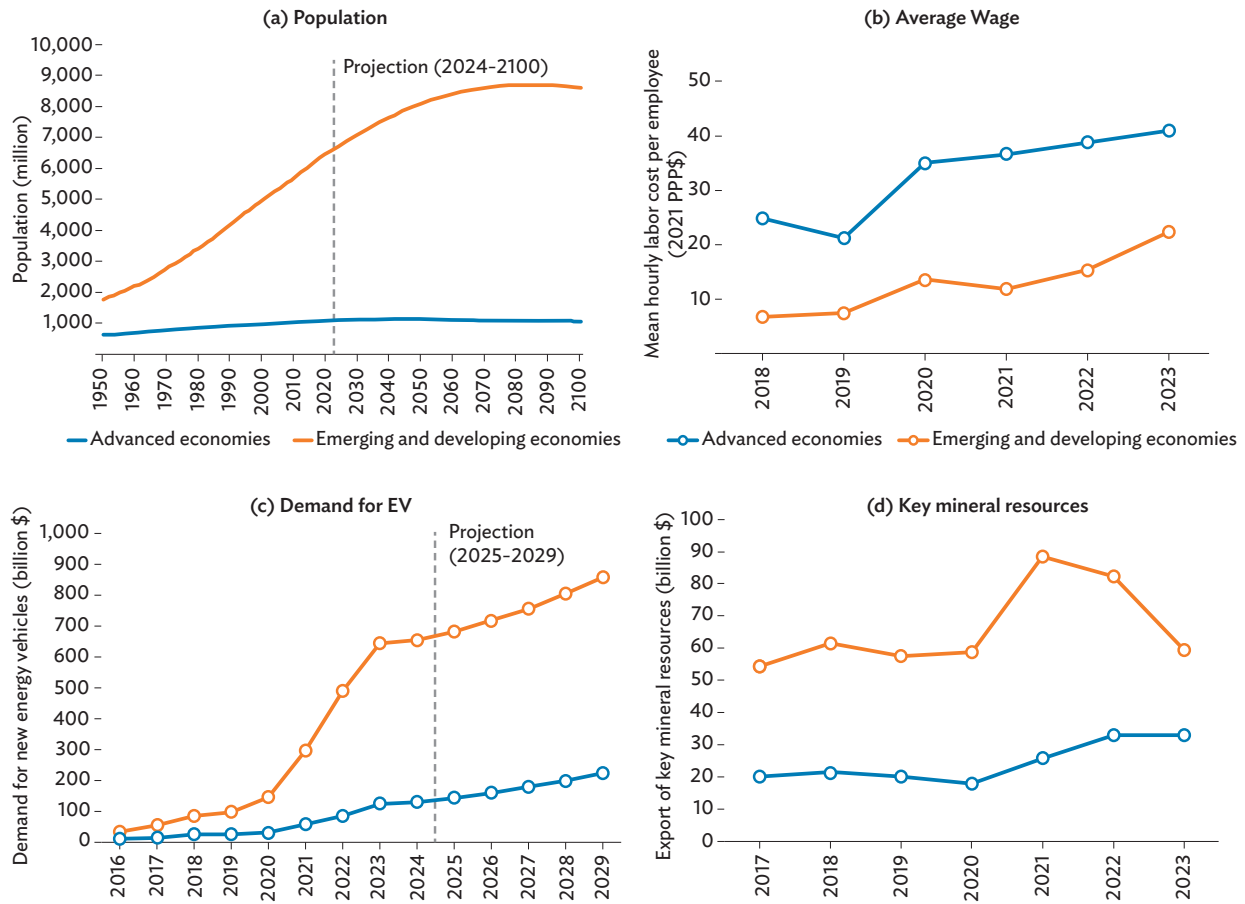
For economies with market advantages in the EV supply chains, it is important that they combine incentives with localization, construct special economic zones and use “market for technology” to attract foreign investment. A case in point is VinFast in Vietnam, which partnered with GM and LG Chem to license EV platforms and battery technology, capitalizing on local labour costs and market potential. Foreign enterprises with EV-related technologies can help these economies build an EV industry, which will help these economies foster a cluster-based and chain-based development ecosystem.

Resource-rich economies can draw lessons from Indonesia and Bolivia. Indonesia’s success hinges on policy coherence, forced localization and strategic FDI attraction. For example, Indonesia implemented a ban on unprocessed nickel ore exports in 2014 as part of a policy to promote greater domestic processing of mineral resources. This policy attracted giants such as CATL, LG Energy Solution and BYD to build smelters and battery plants. Estimates show that developing economies play a dominant role in the export of critical mineral resources, supplying more than 60% of global demand and consolidating their indispensable position in the production of EV batteries and the broader supply chain.

Beyond mineral reserves, developing economies also possess significant labour and market advantages (Figure 3.20). They account for more than 60% of the world’s working-age population, while labour costs are only about 39% of those in advanced economies, providing an unparalleled foundation for efficient, low-cost manufacturing and large-scale industrial expansion. These countries are not only key production centres but also the main drivers of demand growth, contributing nearly 80% of global EV market demand – a trend fuelled by rapid urbanization, rising disposable incomes and increasing acceptance of sustainable mobility solutions. As a result, developing economies are well-positioned to leverage their unique strengths to integrate into the global EV value chain, thereby achieving both economic growth and industrial upgrading.

The preceding sections have shown that the restructuring of global EV value chains is reflected in shifting trade patterns, evolving input-output linkages and dynamic product-space trajectories. But from the perspective of firms themselves, this transformation is not merely an aggregate pattern – it is an unfolding process taking place in real time

Figure 3.20: The Resource Advantages of Developing Economies



Source: Population data and average wage data are obtained from United Nations (1950-2100, medium scenario) and the International Labour Organization (ILO) separately (2018-2023). Data on EV demand is sourced from Statista Market Insights (2016-2029). Key mineral resources data is derived by the authors from UN Comtrade (2017-2023).

within firms and industries. Electrification, accelerated innovation cycles, rising capital requirements and increasingly interventionist policy environments are reshaping how automotive companies compete, organize production and manage risk. To complement the empirical evidence and analytical results presented in this chapter, the following box provides an industry-level, firm-side perspective on how global automotive companies interpret and navigate these structural shifts. This business viewpoint offers additional context for understanding the strategic and organizational adjustments that accompany the quantitative patterns documented above.

Box 3.2: The View from Global Business

Introduction – The New Architecture of Competition

The rise of EVs has triggered the most profound shake-up of the global automotive industry since Henry Ford first adopted the moving assembly line for mass production in 1913 (Nevins and Hill, 1954). What essentially began as a technological pivot towards electrification has evolved into a systemic transformation of the sector's economics, supply chains and organizational culture. The industry is being redrawn along new fault lines – not just between geographies, but between industrial models: old versus new, slow versus fast, linear versus integrated.

Across the world's major production hubs, the industry is confronting four major challenges defining this new phase of automotive globalization: 1) the reconfiguration of value chains, 2) the accelerating pace of innovation, 3) the escalating cost of the transition, and 4) the growing organizational gap between legacy and entrant firms. We discuss each in turn, particularly from the industry perspective. This box complements Chapter 3's quantitative analysis of EV value chain restructuring, critical mineral dependencies and opportunities for developing economies.

1. Value Chain Reconfiguration

The shift currently playing out, from ICEVs to EVs, has redistributed value creation across entirely new supply chains, altering both the geography and governance of the automotive industry. Batteries, semiconductors and software platforms have displaced engines, transmissions and exhaust systems as the principal nodes of competitive advantage (McKinsey, 2023; IEA, 2024). This transformation has empowered upstream actors – from mining firms in Australia, Chile and the DRC to battery giants such as CATL, LG Energy Solution and Panasonic – while leaving traditional OEMs increasingly dependent on suppliers they were previously in a position to dictate outcomes to (IEA, 2023; ICCT, 2023).

Some incumbents, such as Volkswagen and Stellantis, are responding through vertical integration, investing directly in cell manufacturing and critical mineral partnerships (Volkswagen AG, 2024; Stellantis, 2024). Others, including Hyundai and VinFast, are embedding entire EV ecosystems within national industrial strategies – leveraging state support and coordinated infrastructure investment to attract supply chain partners (OECD, 2024; UNCTAD, 2024; Vingroup, 2024).

2. Speed and Agility of Innovation

EV-first manufacturers have completely up-ended traditional automotive product development and iteration cycles. Whereas legacy OEMs would typically take up to five or even seven years to bring a new model to market, EV makers such as Tesla, BYD and NIO have successfully and dramatically compressed these cycles through the use of digital twins, software-defined vehicle architectures and over-the-air update capabilities (NIO, 2024; Jacobides et al., 2023; ISACA, 2023). Today, these digital design and simulation tools have enabled continuous product and design iterations, a much faster time-to-market, and tighter feedback loops between engineering, production and user experience.

As analyst Michael Dunne notes, “Chinese automakers develop new cars in half the time of traditional automakers in the West,” reflecting an organizational model optimized for speed and integration rather than sequential development (Dunne, 2024a). Firms like BYD illustrate this shift vividly: their 1,300-member smart driving R&D team is developing proprietary autonomous and connectivity systems “in double-quick time,” bypassing legacy dependencies on external suppliers (KR Asia, 2025).

In contrast, incumbent automakers remain constrained by functionally siloed structures and sequential engineering processes that make it difficult to achieve comparable agility. As Jacobides and colleagues observe, “incumbent OEMs have historically taken a function-by-function approach to developing software.. integrating across these functional silos is a difficult task” (Jacobides et al., 2023).

The result is a widening strategic gap. Traditional manufacturers such as Ford and Hyundai are experimenting with modular platforms and co-locating software and hardware teams to emulate digital-native competitors (Ramachandran, 2025; ISACA, 2023).

3. Cost and Capital Pressures

For most EV-focused firms, particularly newer entrants, profitability remains elusive and is often treated as a secondary objective. At this stage of the industry's evolution, the priority lies in capturing market share and establishing a defensible position within a fast-moving and capital-intensive ecosystem. Growth and scale, rather than short-term returns, have become the dominant strategic imperatives (IEA, 2024; Reuters, 2025).

Analysts estimate that the transition to EVs demands 30-50% more upfront investment per vehicle platform than comparable ICEV programmes, owing to the cost of battery plants, new software architectures and retooled manufacturing lines (McKinsey & Company, 2020; RMI, 2023). Despite record levels of investment, profitability remains elusive for most players; Ford's Model e division reported a \$4.7 billion operating loss in 2023, while China's hypercompetitive EV market continues to compress margins even for leading brands (IEA, 2024; Reuters, 2025).

Box 3.2: continued

Profitable entrants such as Tesla and BYD have achieved cost advantages through scale, vertical integration and proprietary battery production, whereas established automakers must reconfigure legacy assets – retooling factories, retraining workforces and maintaining dual ICEV and EV production systems during the transition (IEA, 2024; McKinsey & Company, 2020). This has led to a wave of strategic partnerships and joint ventures – including Ford–SK On (BlueOval SK) in Kentucky and Tennessee, Stellantis–Samsung SDI (StarPlus Energy) in Indiana, and Honda–LG Energy Solution in Ohio – designed to secure supply, share capital costs and localize production in line with evolving industrial policy frameworks (SK On, 2022; Stellantis, 2023; Honda, 2023).

Automakers are also seeking policy alignment, leveraging incentives under the US Inflation Reduction Act and the EU Battery Regulation (2023/1542) to offset transition costs and de-risk investment (CRS, 2024; European Commission, 2024; EUR-Lex, 2023).

4. Organizational Adaptation and Cultural Change

Perhaps the most subtle yet decisive challenge lies within the firms themselves. The shift to electrification demands not only new technologies but fundamental organizational transformation – embracing cross-functional decision-making, agile iteration and digital-first engineering cultures (McKinsey & Company, 2023; Deloitte, 2024). Automakers such as Hyundai and Volvo have restructured around software-defined vehicle (SDV) units to unify hardware and software development, enabling faster product cycles and over-the-air updates (Hyundai Motor Group, 2023; Volvo Cars, 2024).

In parallel, firms are expanding their internal technology capabilities, hiring large cohorts of software engineers, data scientists and systems architects. Volkswagen, for instance, now employs more than 6,000 software developers, while Ford has established a dedicated technology hub in Detroit in the US (Reuters, 2024).

Leading automakers are building in-house software capabilities, reducing reliance on suppliers and improving speed-to-market (McKinsey & Company, 2025). Scholarly studies also show that the most adaptive firms are integrating scaled agile methods across software and hardware domains, creating continuous feedback loops between design, testing and deployment (Ågren et al., 2022).

By contrast, traditional manufacturers including GM and Toyota continue to grapple with the complexity of managing overlapping ICEV and EV product lines and extensive legacy supplier relationships – issues that inevitably slow innovation and dilute strategic focus (IEA, 2024; Bain & Company, 2023). The contest is therefore no longer defined by geography – East versus West – but by organizational learning speed. Companies capable of simultaneously integrating digital, mechanical and cultural change are emerging as the true winners of the EV transition, while those constrained by inherited structures risk being left behind (Bain & Company, 2023; McKinsey & Company, 2023).

Conclusion – Adapting to Compete in an Era of Systemic Change

The transformation under way in the global automotive industry is neither cyclical nor incremental – rather it is profoundly systemic. Electrification has set off a once-in-a-century reconstruction of the industry's architecture, in which scale, speed and systems integration now define competitiveness more than brand heritage or existing market share. The companies that thrive will be those capable of reimagining themselves as technology platforms and ecosystem orchestrators, rather than as manufacturers alone.

In this new order, value creation no longer flows down linear supply chains but circulates within networks linking mining, software, batteries and mobility services. Financial endurance and strategic patience have become as important as engineering excellence. Governments are no longer neutral referees but active participants shaping outcomes through industrial policy and energy transition mandates.

For the business community, the implications are clear. Surviving this phase will require organizational agility, disciplined capital deployment and the ability to learn faster than technological change. Firms that can align product, policy and digital strategy within a coherent framework will not only endure the transition but define the next industrial paradigm – one where the boundaries between automaker, technology company and energy provider are dynamically intertwined.

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Box 3.2: continued

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Note: This box was authored by Simon Lacey (formerly with the World Economic Forum, currently with Belt Road Capital Management). The views expressed herein are those of the author and do not necessarily reflect those of the affiliated institutions.

3.5 Conclusion

The rapid expansion of EVs is fundamentally restructuring traditional automotive value chains. The importance of conventional ICE manufacturing has diminished, giving way to core EV components such as batteries, electric motors and electronic control systems. This transition has not only raised the overall technological complexity but also led to a concentration of manufacturing capacity – particularly in battery production, which is dominated by China, and in semiconductors, which are controlled by a limited number of economies. Such geographic and corporate concentration introduces vulnerabilities and potential disruptions, especially for key raw materials like lithium, cobalt and nickel, which are not only geographically scarce but also exposed to geopolitical uncertainties. Although EV production initially generates higher carbon emissions than conventional vehicles – mainly due to energy-intensive battery manufacturing – life cycle assessments confirm substantial carbon reduction benefits over time. These advantages are further amplified by the adoption of cleaner energy and ongoing technological progress. For resource-rich developing economies, the EV transition offers a pathway to integrate into higher-value segments of global supply chains, enabling industrial upgrading through targeted policies, strategic foreign investment and international cooperation. Ultimately, fostering inclusive and sustainable growth in the global EV market will depend on coordinated policy incentives, diversified supply chain partnerships and enhanced international collaboration.

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