WORKING PAPER 25

SMALL AND ELECTRIC - THE INTERNATIONAL CASE TO MOVE AWAY FROM COMBUSTION SUVS

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Small and electric - The international case to move away from combustion SUVs

Opportunities from moving away from large, expensive combustion engine cars towards smaller, cheaper electric cars

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Executive summary

The global automotive industry is at a pivotal moment, facing industrial, environmental, and geopolitical pressures. This report examines the shift toward cleaner vehicle technologies and argues that small electric cars (EVs) are an underappreciated part of the solution—helping to address economic and supply chain challenges while delivering environmental, safety, and strategic benefits.

The report begins by analyzing the evolution of the global automotive market since 2005. It highlights how China has secured a competitive edge in EV technology, including in battery supply chains, as well as in manufacturing efficiency and the electronics sector, with the latter contributing more recently to its competitiveness in software-defined vehicle development. Increasing competition from Chinese manufacturers is now considered a significant challenge to legacy automotive manufacturing companies in high-income countries and emerging economies. The grip of China over battery supply chains has also led to perceptions of material dependency and supply chain risks.

The shift in regional power balance in the automotive market has also been accompanied by shifting market trends globally towards ever-larger vehicles like SUVs, which offer automakers higher profit margins. Electric vehicles sold in most markets outside China have predominantly targeted larger vehicle size segments. This shift towards SUVs and adoption of electric vehicles has resulted in increasing average vehicle purchase prices, which has contributed to stagnation in new vehicle sales in high-income markets and an aging of their vehicle fleets. In addition to the detrimental impact on vehicle affordability, the shift to larger cars has negative impacts on road safety and increased energy and material consumption, threatening environmental targets.

This report argues that a shift towards smaller EVs can serve as a strategic response to these challenges, offering automakers a way to adapt to economic and geopolitical pressures while accelerating decarbonization efforts. A shift to smaller EVs would have the following important benefits:

- **Smaller EVs improve vehicle affordability and therefore accelerate the uptake of electric mobility**, **reversing trends of stagnating vehicle sales and aging vehicle fleets**. Smaller and affordable EVs are crucial in enabling higher market shares of new EVs in low-and-middle income countries.
- **The economies of scale induced by smaller EVs can lower production costs, helping address industrial competitiveness challenges**. The greater scale of production can promote innovation in vehicle design and manufacturing technologies, helping narrow or reverse competitiveness gaps.
- **The scale enabled by smaller EVs can also help de-risk investments in EV and battery manufacturing facilities**, favoring more geographical diversification beyond China.

- **Smaller EVs can help reduce energy demand and pollutant emissions**, thanks to much lower energy use per km, less stress on the electricity system due to better energy efficiency and the opportunity for a synergistic integration with the generation of low-cost electricity from renewables.
- **Smaller EVs improve vehicle affordability and therefore accelerate the uptake of electric mobility**, **reversing trends of stagnating vehicle sales and aging vehicle fleets.** More affordable vehicles can also accelerate a shift in the composition of the fleet, over time, strengthening the pace of the delivery of road safety and energy efficiency benefits.
- **Smaller EVs can manage critical minerals demand from EVs.** They can reduce material needs to deliver low-emission energy-efficient mobility, in comparison with larger EVs, in case of supply chain bottlenecks, compared to larger vehicles, increasing resilience. Small EVs are also well suited, as they are likely to be turned over more rapidly than large EVs, for the build-up of significant stock of recyclable materials if supply bottlenecks are not an issue. In doing so, and thanks to lower energy demand, through circularity, they can also foster better competitiveness.
- **Smaller EVs can improve road safety** compared with the continued market shift towards SUVs.

Based on the analysis in this report we recommend governments and automotive manufacturers to **encourage a shift towards smaller vehicles and more affordable EVs, while also taking action to diversify battery supply chains**. To do this they should:

- **Introduce targeted incentives, taxation, pricing mechanisms and regulatory support** to shift the market towards smaller vehicles. Examples include differentiated taxation based on vehicle footprint, weight, and environmental performance, resulting in a more favorable economic case, from the perspective of manufacturers and car buyers alike, for smaller and more environmentally friendly vehicles. A similar differentiation can be applied to levers such as parking pricing or social leasing of EVs. Due to comparatively low purchase price, small EVs are also well suited to respond to the integration of equity-related features in these policy tools.
- **Promote investments in cost-effective, accessible and affordable charging infrastructure** to support a wider range of EV models. A greater availability of charging infrastructure would help make EVs with smaller batteries more attractive to consumers. These, in turn, could help increase frequency of use of infrastructure, reducing impacts of fixed costs for infrastructure users. Smaller EVs are particularly relevant in cities, in areas without easy access to home or workplace charging, and for low-income communities, where small EVs could play a significant role.

- **Scale up support for research and innovation** to help enhance the competitiveness of the sector in geographies that were slower than China to embrace e-mobility.
- **In geographies that are exposed to vulnerabilities** from supply disruptions (price risks) or interruptions in the supply of critical mineral supplies (quantity risks) and to a loss of competitiveness, **consider the use of other policy tools to support the diversification of EV and battery value chains**. These may include:
  - Specific conditionalities to access public support – including demand-side incentives for increased EV adoption and bankable incentives for more diverse supply chains (if they can be aligned with international trade rules)– and in the definition of regulatory requirements regarding EVs and their batteries.
  - Targeted requirements and incentives for the development of geographically diverse battery supply chains, including joint ventures between local companies and partners that have acquired a competitive technological advantage, and specific requirements on technology and intellectual property transfer.
  - Temporary trade tariffs and negotiated price undertakings in coordination with trading partners.
  - Policies stimulating strategic investments across relevant countries in the different steps of a more geographically diverse and secure battery supply chain, thanks to better and more secure access to raw, processed materials and battery components, with open trade.

Ultimately, the report argues that smaller EVs are not only a practical solution to industry challenges but also a strategic necessity. By embracing them, especially in a more challenging geopolitical context, automakers and policymakers can foster a more resilient, sustainable, and competitive global automotive industry.

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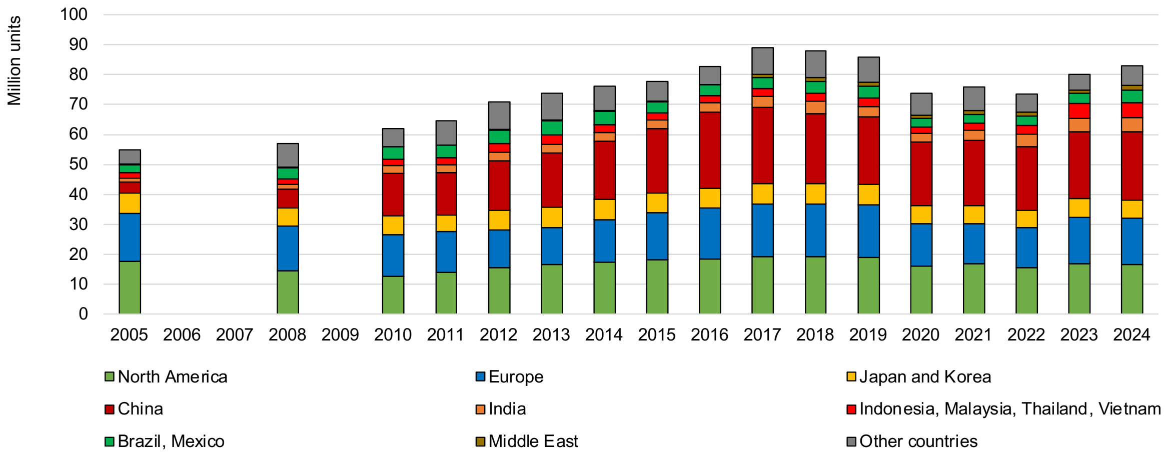
Table of Contents

1. Global automotive market developments

Figure 1 illustrates global light-duty vehicle sales in major countries and global regions, representing the majority (close to 90%) of the global market from 2005 to 2024. It shows total sales have generally increased, peaking around 2017-2018 before experiencing a decline in 2020, reflecting the impact of COVID-19 and subsequent supply chain disruptions. The figure shows a significant shift in the nature of demand across global regions.

Figure 1. Light-duty vehicle sales in major countries and global regions, 2005-2024



Note: Light-duty vehicle sales included in this analysis (and in this graph) are the same covered in FIA Foundation, 2023.[1] Europe includes all member countries of the European Economic Area (EEA) plus Switzerland and the United Kingdom. North America includes the United States and Canada but excludes Mexico, included in the same group as Brazil. Total sales for this set of countries exceed 90% of the global total of light-duty vehicle sales, based on data from Dejean and Kuhanathan, 2025 and about 85% of the total vehicle sales accounted by OICA (based on OICA, 2024), meaning that they represent the vast majority of light-duty vehicle sales globally.

Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025 and New Automotive, 2025

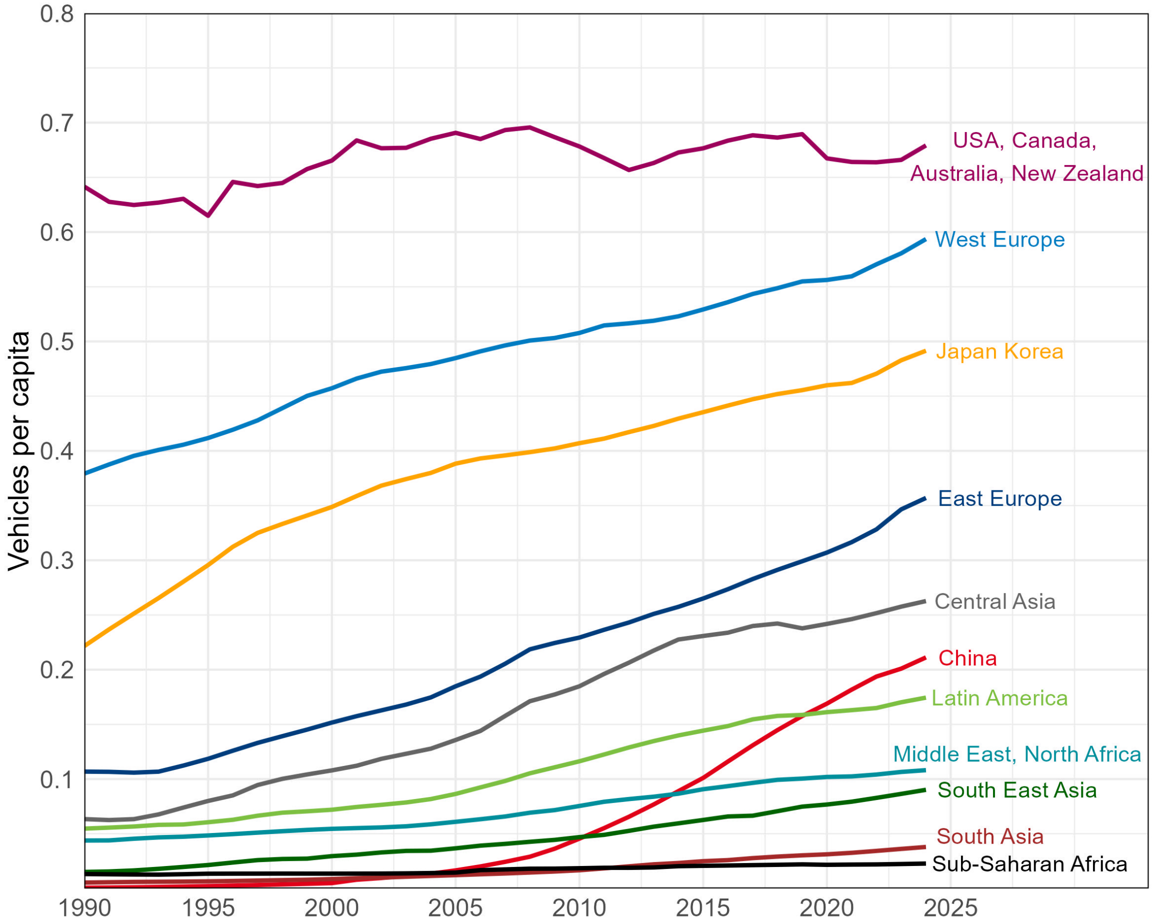
1.1 Developed economies have become replacement markets, and emerging economies – led by China – are driving growth

Developed economies, particularly those in North America, Europe, Korea and Japan, have in the past few decades stabilised in terms of sales volumes of new light-duty vehicles, effectively becoming replacement markets. In these regions, the majority of households already own cars, and the number of potential new car buyers has stagnated or even declined. Figure 1 shows that automotive sales in these economies have been

[1] These include Argentina, Australia, Belarus, Brazil, Canada, Chile, China, Colombia, European Economic Area, Egypt, India, Indonesia, Israel, Japan, Kazakhstan, Korea, Kuwait, Malaysia, Mexico, Myanmar, New Zealand, North Macedonia, Oman, Pakistan, Peru, Philippines, Puerto Rico, Russia, Saudi Arabia, Singapore, South Africa, Switzerland, Taiwan, Thailand, Turkey, United Arab Emirates, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan and Vietnam.

characterized by a long-lasting trend of limited growth, punctuated by a sharp decline with the COVID-19 pandemic, followed by a slow and uneven recovery.

Figure 2. Passenger cars per capita in major countries and global regions, 2005-2024



Note: West Europe includes Austria, Belgum, Czech Republic, Denmark, France, Germany, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland, United Kingdom. East Europe includes all other member countries of the European Economic Area, countries in the Balkans and Ukraine. Latin America includes all South and Central American countries plus Mexico. Central Asia includes Russia and former members of the Soviet Union located in Asia. South-East Asia includes all countries of the Association of South-Eastern Asian Nations (ASEAN). South Asia includes India, Afghanistan, Bangladesh and Pakistan. Middle East and North Africa includes Morocco, Algeria, Egypt, Tunisia, Israel, Lebanon, Iraq, Iran, Türkiye, Gulf countries, Syria, Palestine, Libya and Jordan.

Sources: Population data from UN World Population Prospects 2024. Vehicle stock data from various sources including Rozsai et al. 2024, ADB, 2024, ITF, 2024, IRF, 2024 and UNECE, 2025. Vehicle stock data from various sources including Rozsai et al. 2024, ADB, 2024, ITF, 2024 and IRF, 2024.

Meanwhile, emerging economies, and China in particular, have evolved from major growth markets for the automotive industry prior to COVID-19 to more measured growth in the past few years. However, growth in certain markets, such as India and ASEAN, show that significant margins remain for increases in vehicle ownership. The potential for continued growth in sales volumes is particularly evident when comparing per capita vehicle ownership of emerging economies with developed economies (Figure 2).

In China, rapid growth in car sales has been largely driven by rapid economic growth and rising disposable incomes (Linn and Shen, 2021), even if it was mitigated by major parallel investments in public transport and rail infrastructure (Lu et al., 2024 and Yan, 2022). The increase in size of the Chinese market was also coupled with substantial investments by international and local automakers, both driving and responding to market opportunities.

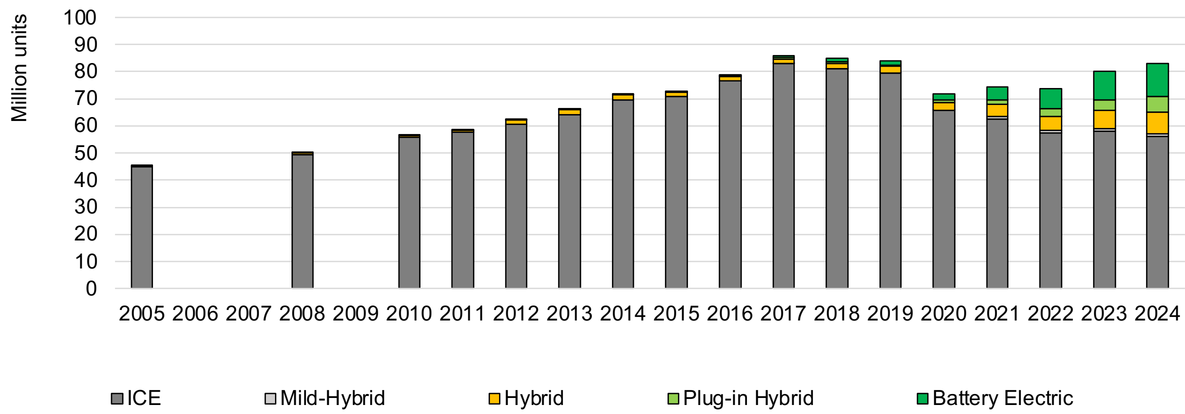
Today China is a major player in the automotive market. The Chinese market accounts for 28% of global passenger car sales and is the largest single market at the country or regional level (Figure 1). North America and Europe remain major markets, although their relative share in global LDV sales decreased from 73% in the year 2000 to 38% in 2023.

1.2 Electrification is gaining ground, to the detriment of internal combustion engine vehicle market shares

Figure 3 highlights a second major development characterizing the global automotive market: the rapid emergence of different forms of electrification technologies. In the broadest definition, "electrified" vehicle powertrain technologies include anything that uses batteries to store and electric motors to provide energy, and so include hybrid electric, plug-in hybrid and battery electric vehicles. These powertrains emerged at different points in time over the past two decades and their market grow evolved at different paces in various regions.

Hybrid electric vehicles (HEVs) saw a progressive increase in market shares, starting already in the early 2010s and then accelerating after 2020. Battery electric vehicles (BEVs) emerged more recently but also more rapidly, leveraging major developments in battery technologies and ambitious actions by market disruptors. Electric Vehicles (EVs – including BEVs and PHEVs) started gaining greater market shares in the late 2010s and overtook hybrid electric vehicles only after the COVID-19 pandemic more than doubling their sales in 2023 and 2024.

Figure 3. Global light-duty vehicle sales by powertrain, 2005-2024

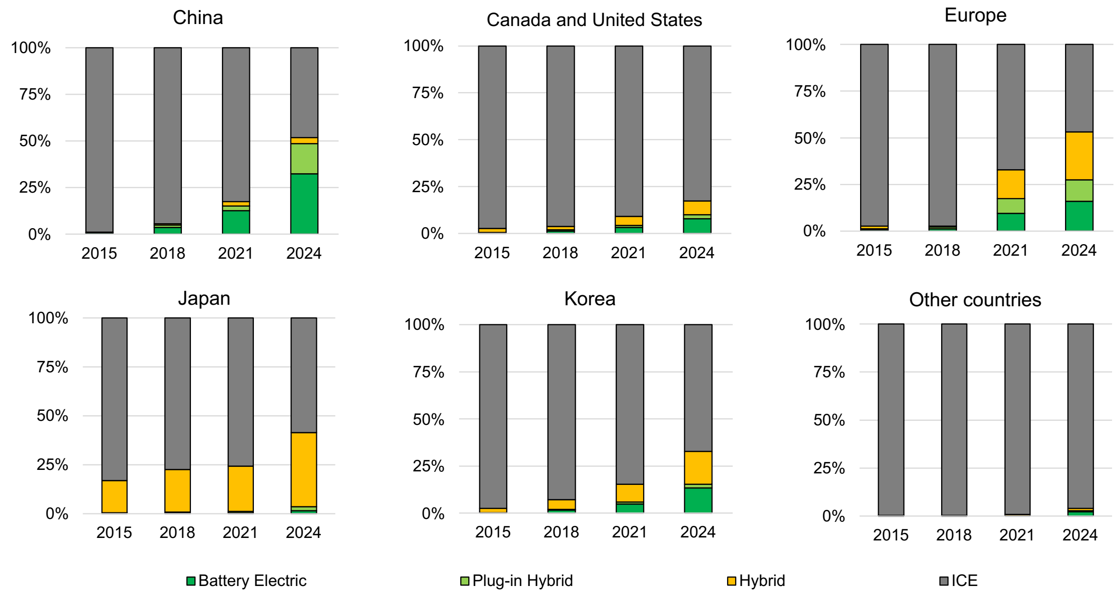


Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025 and New Automotive, 2025

Importantly, the growth of electrified vehicles coincided with the shock of the COVID-19 pandemic, which limited the increase of the car market and marked a peak in internal combustion engine (ICE) vehicle sales in the year 2017. Sales of "pure" ICE light-duty vehicles have continuously declined since the year 2017, and sales of vehicles equipped with ICEs (i.e. accounting for hybrids and plug-in hybrids) have stagnated since the beginning of the 2020s.

The path towards increased EV shares has not been uniform, with greater EV market share growth in China; followed by Europe (including the United Kingdom) and Korea, lower market penetration in Canada, the United States and Japan; and limited increases elsewhere (Figure 4).

Figure 4. Light-duty vehicle sales shares by powertrain, 2005-2024, by global region



Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025 and New Automotive, 2025

Japan's powertrain technology transition was unique in its strong focus on HEVs. Significant market adoption of HEVs also occurred in Europe and Korea, both of which are characterized by high fuel taxes, and hence by higher fuel prices, than other developed countries. PHEVs gained market shares mainly in the EU, already by 2021, and are primarily adopted in larger vehicles. More recently they also experienced a rapid growth in China, especially with the emergence of the extended range electric vehicles (EREV), a variant of PHEVs where the ICE is only used to run an electric generator to recharge the battery.

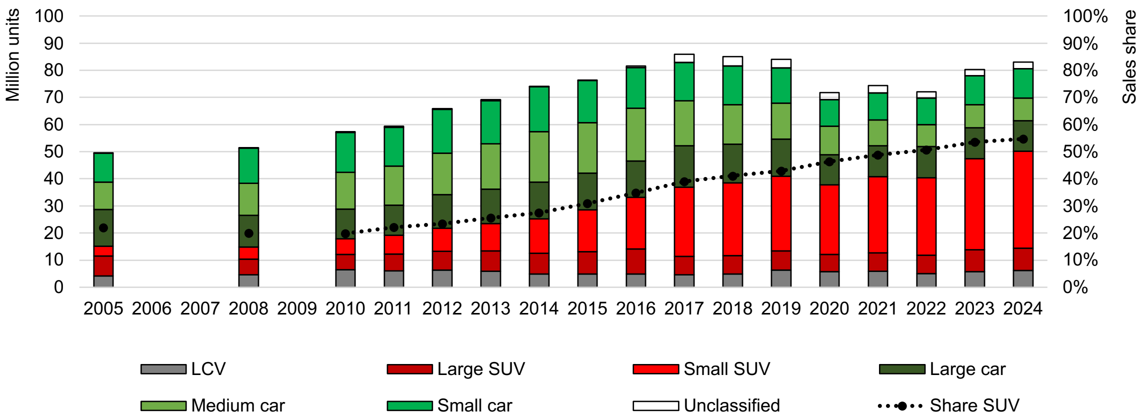
1.3 Vehicle size, weight and prices increased across all regional markets, being particularly strong in North America

The global stagnation, and in many cases net decline, of sales of light-duty vehicles equipped with internal combustion engines, marks a structural change from the trend of light-duty vehicle sales increases that took place before the COVID-19 pandemic.

This structural change took place in a context that had already seen automakers pursuing greater profitability by increasing reliance on selling larger vehicles (as shown in Figure 5), thanks to higher margins available in SUVs, as compared with small and medium cars (FIA Foundation, 2023, ITF, 2021 and IEA, 2019). These higher margins partly offset the shift in sales at a global level toward emerging economies, where vehicle sales prices are generally lower, compared with developed economies.

The supply chain disruptions between 2020 and 2023, particularly in semiconductors and chips, had significant impacts on the automotive industry contributing to a drop in production and increase in vehicle sales prices. Faced with a limited availability of components, such as chips, many automakers prioritised larger vehicles with higher profit margins (Caranalytics, 2024).

Figure 5. Global light-duty vehicle sales by segment, 2005-2024



Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025, Marklines, n.d. and New Automotive, 2025.

The shift towards larger, heavier and more expensive cars may have also been driven by the need for resources to invest in innovation. Part of this was related with major changes in the powertrain mix. Another part could relate with other major technological developments: the increased adoption of digitally enabled technologies for automated driving capabilities and, more broadly, the advent of so-called "software-defined vehicles" (SDVs). Investments in software focus on centralized electronic architecture and are designed to enable over-the-air (OTA) updates, real-time diagnostics, and facilitate and interact with ride hailing services, which are also enabled by digital technologies (BCG, 2023).

Figure 6 shows that the shift towards larger, heavier and more expensive cars took place in all global markets. Despite important region-specific differences, small SUVs were the market segment that experienced the greatest increase in sales share. Canada and the United States saw penetrations of large SUVs (including pick-up trucks) far higher than those elsewhere, with large SUV sales shares driven by long-lasting policies that attempted to maintain domestic production in North America, and in particular in the United States.

Key instruments include:

- Different technical safety and environmental regulations (although they are not limited to large vehicles) with respect to other markets.[2]
- A 25% import tariff on light trucks,[3] first established in 1964 – applicable to countries that do not have a free trade agreement (FTA) with the United States, including China, Europe, Japan, India and Thailand, amongst others[4]—and very recently overlaid with another 25% tariff, also applicable to cars (White House, 2025).
- The development of separate regulatory frameworks on fuel economy under the Corporate Average Fuel Economy (CAFE) standards for cars and light trucks, with more lenient requirements historically (National Research Council, 1992), with less stringent fuel economy standards for light trucks, which has led to gradually increasing shares of light trucks in LDV sales in both Canada and the United States, and also implicitly removes incentives on vehicle weight and size reduction as a compliance strategy.

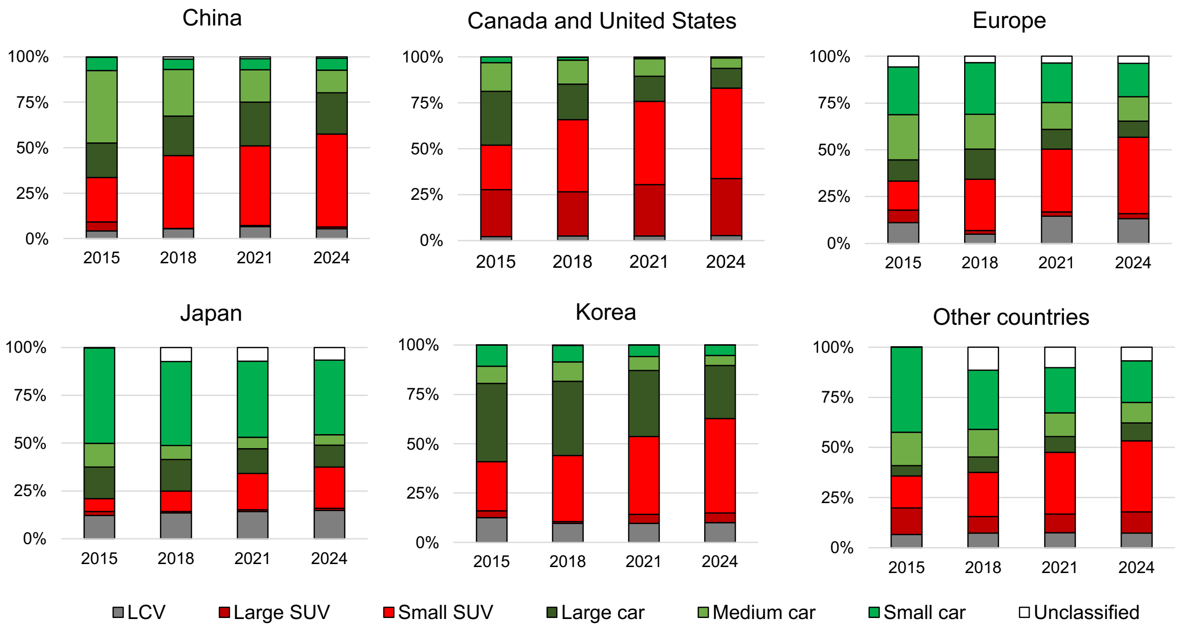
Despite shifts away from smaller size classes, Japan, Europe and emerging economies retained relatively high market shares of small and medium vehicles (44% of total sales in Japan, and 31% in Europe and emerging economies, excluding China) in 2024. Taken together, small cars sold in these countries account for 84% of those sold globally, and medium cars for 54%.

[2] Most Eurasian countries – including those in the European Union, non-EU Eastern Europe, Central Asia, Japan and the United Kingdon, and collectively accounting for around 40% of light-duty vehicle sales in 2024 – adopt technical standards developed in the context of the 1958 UN agreement on the mutual recognition of type approvals of vehicles and vehicle parts (United Nations, n.d.a). China is not a Party to the 1958 UN agreement. However, China adopts domestic regulations that are more closely aligned with the UN Regulations, e.g. with respect to measurement and limit values for the emissions of local pollutants (Dieselnet, n.d.).

[3] These are vehicles with a gross vehicle weight rating of up to 8,500 pounds (4.25 t) and a payload capacity of up to 4,000 pounds (2 t).

[4] The tariff does not apply to Korea, following the signature of the US-Korea Free Trade Agreement (KORUS) in 2021, nor to Australia due Australia-United States to the Free Trade Agreement (AUSFTA), nor to Canada and Mexico, due to the United States-Mexico-Canada Agreement.

Figure 6. Light-duty vehicle sales shares by market segment, 2005-2024, by global region



Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025 and New Automotive, 2025, considering (for 2023/24) continued growth of the SUV share based on historical trends, based on 2022 shares and 2023/24 market volumes.

1.4 China exerts increasing influence in automotive market developments

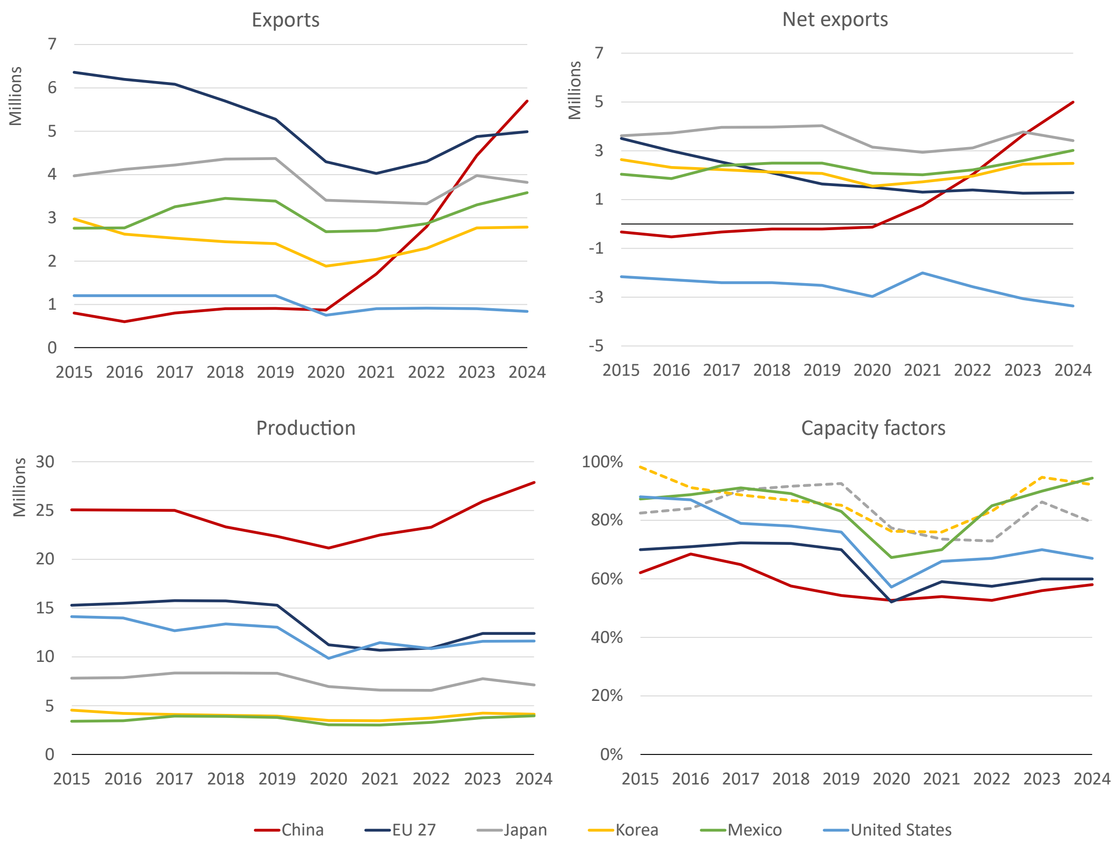
China played a pivotal role in automotive market developments. Its domestic market grew from 3.5 million sales in the year 2005, representing only 7% of global light-duty vehicle sales (values are even lower in earlier years), to nearly 23 million sales in 2024. At more than one-quarter of the global market, China grew to become the single largest global automotive market over the course of a decade.

The transformation of China's automotive landscape was accelerated by the country's accession to the World Trade Organization (WTO) at the end of 2001. This move opened the door for foreign automakers to enter the Chinese market and establish joint ventures with local manufacturers.

With sales volumes increasing rapidly in the 2010s (until the COVID-19 pandemic), the Chinese car market became a key driver of demand increases in the global automotive sector.

The Chinese car market developed with similar sales shares by segment to Europe, Korea, Japan and other countries (Figure 6). This similarity in market structure can help China gain access to export markets with similar features (and vice-versa). All these markets are notably different from North America (Canada and the United States in particular), which are characterized by a far greater penetration of very large SUVs. This is a feature that prevents alignment with environmental and safety-related technical regulations followed by most countries, and it serves to differentiate these markets from the rest of the world.[5]

Figure 7. Exports, net exports, production and capacity factors for the main light-duty vehicle exporting countries, 2015-2024



Note: dashed lines reflect estimates based on limited data points, corroborated by indications pointing towards high capacity utilization in the manufacturing sector, both for Korea and Japan. Values labelled as EU-27 exclude intra-EU trade. Net exports are exports minus imports.

Sources: estimates based on sources used for vehicle sales estimates above, complemented by Auto in China, 2023, ML trucks, 2025, Trading Economics, n.d.a, Trading economics n.d.b for China; Eurostat, n.d. for production and trade in the EU, IER, 2024 for EU capacity factors; AMIA, n.d.a, AMIA, n.d.b, AMIA, 2024 for Mexico; JAMA, 2024, JAMA, n.d., Wards, 2000 (combined with indications on restructuring plans of Japanese automotive manufacturers (to assess evolution in production capacities, estimated at 9.5 million units in 2015 and at 9 million as of 2019); KAMA, n.d., GlobalFleet, 2024 and Marklines, 2019 for Korea; and AAI, 2025 and Federal Reserve Bank, 2025 for the United States.

[5] Elements of alignment that exist are enabled by Global Technical Regulations developed in the context of the related United Nations 1998 Agreement (United Nations, n.d.b), but these have a far lower integration than UN Regulations, applicable to Parties of the 1958 UN Agreement on the mutual recognition of type approvals (United Nations, n.d.a).

China also evolved from a net importer of passenger cars before 2020 to the world's largest net exporter (Figure 7). This took place at a time when:

- Capacity factors were heavily impacted across all major markets by the COVID-19 pandemic, particularly in 2020 and 2021.
- Europe saw its net exports decline and its domestic production struggle to recover from the plummeting demand and supply chain issues brought by the pandemic, which led to reduced capacity factors, and with negative implications for its competitiveness.
- US production and exports declined similarly.
- Production, exports and net exports in major car exporting countries – including Japan, Korea and Mexico – were less impacted, and their capacity factors recovered more than those of other major car producing countries or regions.

The persistent declines in capacity factors in the EU—although values are heterogeneous across manufacturers (IER, 2024)—and the US is an indicator of an increased stress on the competitiveness of the industry. Low capacity factors, including in the case of China (and not only the EU and the US), point towards a pressure to increase vehicle production to gain competitiveness or risks of factory closures, in the absence of changes in production.

1.4.1 How China tapped its burgeoning middle class as a strategic lever to catalyse technological and industrial development

China's rise as a dominant player in the global automotive sector reflects opportunities available from China's rapidly expanding middle class and urban population, as they both represented massive and growing consumer base for both international and domestic automakers. China's success in developing its domestic automotive industry also follows:

- Choices to increase openness to investments from foreign capital.
- A dynamic response dictated by large return on capital investments, thanks to lower production costs, favored by lower labor costs, material availability and economies of scale, also due to dynamic developments in other economic sectors.
- Incentives for domestic production through higher tariffs rates on vehicles with lower local content.
- Conditionality of access to the Chinese market, with obligations to establish joint ventures with the domestic partner maintaining majority control, and to stimulate industrial development and to transfer technology locally (Oh, 2021).

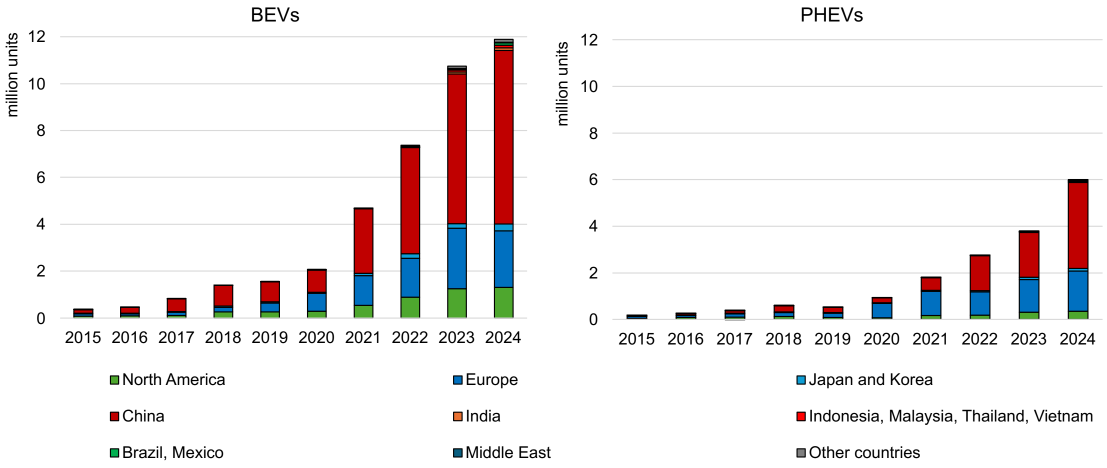
It is also on this basis that China became a key production base for international companies, not limited to vehicle manufacturers by also including parts suppliers (Liu, 2020, Oh, 2021).

These drivers were both key enablers of a growth in demand and in industrial capacity. The construction of the factories enabling this productive capacity was supported by development of technical expertise and further bolstered it.

1.4.2 China first as an early innovator, and then the global fulcrum of electric mobility and battery growth, through scale, public support and investment in new industrial capacity

The Chinese car market has clearly seen major increases in EV adoption, beyond those of all other major markets, enabling China to become the largest market for EVs globally (Figure 8). The combined sales volumes of BEVs and PHEVs in China are now comparable to the total new car market, including conventional vehicles, in the EU or United States.

Figure 8. Electric light duty vehicle sales in major countries and global regions, 2005-2024



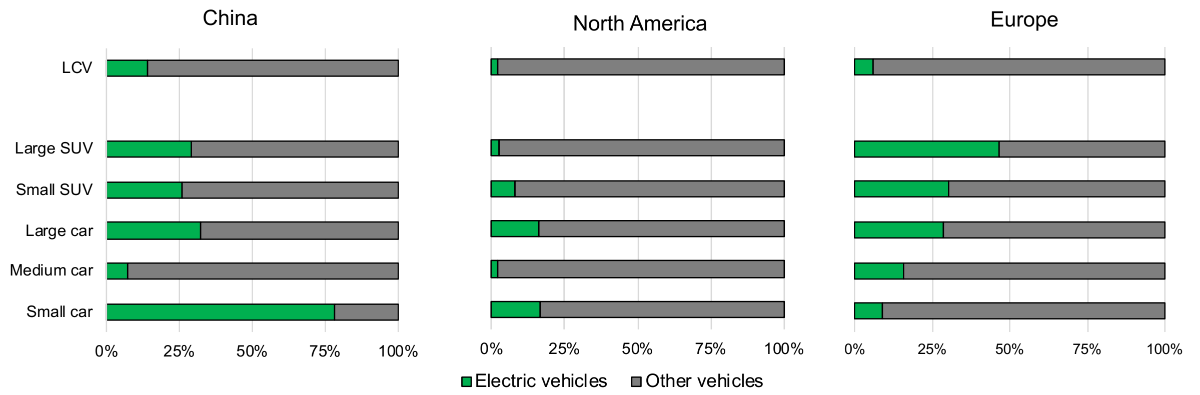
Sources: estimates based on FIA Foundation, 2023, EEA, 2023, ACEA, 2022, IEA, 2024a, IEA, 2024b, Kuhanathan et al., 2024, Dejean and Kuhanathan, 2025 and New Automotive, 2025

China is also the only major global market to have achieved significant EV sales shares in small market segments (Figure 9),[6] and the only market where EV purchase prices managed to fall below those of ICEVs (IEA, 2024).[7]

[6] India also has market shares of small EVs that are comparatively high with respect to the EU and the EU (ICCT, 2025), but its market is still characterized by a small market size for EVs, and high sales numbers for a few models.

[7] In other markets, however, there is an expanding range of use cases and fuel/electricity pricing and taxation frameworks enabling EVs to have a lower total cost of ownership than ICEVs.

Figure 9. Electric vehicle sales share by vehicle segment in key automotive markets, 2022



Source: FIA Foundation, 2023.

China's primacy in the EV value chain has not been limited to vehicles. Battery industries, with companies like CATL and BYD, have established themselves as global leaders, and China's domestic battery industry supplies both China's own EV demand and international markets, driving global cost reductions.

China's success in lithium-ion battery production builds on its long-standing track record of government support for technological innovation, including industrialization. China's cultivation of the domestic battery industry has also benefitted from other forms of policy steering, dictated at least in part by the country's strategic imperative to reduce its dependency on energy (mainly oil and gas) imports.

Policy instruments used in China to support the e-mobility transition include a series of specific and general environmental, energy/mineral security, industrial and trade-related measures:

- Tax rebates amounting to 10% of the purchase price for new energy vehicles (NEVs)[8] were first put in place in September 2014. In recent years, these were capped at 30,000 RMB, and they were recently extended to the year 2027, but will be cut in half from 2026 on (Interesse, 2023, Chinese Ministry of Finance, 2023).
- EV purchase incentives were first deployed, alongside public procurement infrastructure deployment support, in 2009, in pilot cities. By 2015, a new energy vehicle subsidy was applied nationwide. In 2016 the subsidy amounts were linked with performance requirements, including battery energy density, power output, and all-electric range (ICCT, 2021). Incentives were renewed in following years, and integrated specific provisions for rural areas, via the NEVs to the Countryside programs (ICCT, 2023) – nationwide subsides were, however, phased out in 2023 (ICCT, 2023) .

[8] NEVs include BEVs, PHEVs, and fuel-cell electric vehicles

- Low, ultra-low and zero emission zones in cities have also been in place for more than a decade in first tier cities, with smaller second and third tier cities adopting them more recently. China is also the only country (with the exception of a city-state like Singapore) where most major cities have implemented annual quota systems for license plates at the city level. Preferential treatment for EVs in these frameworks have resulted in clear and substantial acceleration of EV market share growth in the cities that have set up these quotas (ICCT, 2023).
- A country-wide new energy vehicle (NEV) credit mandate was first developed in 2017 (ICCT, 2018), then renewed in 2021 (ICCT, 2021, Government of China, 2021).
- National standards (GB/T) for charging interfaces (conducting systems and connectors) and communication protocols for electric vehicles date back to 2001 (general requirements) and 2011 (connection set) (State Grid Corporation of China, 2013). They were updated in 2015 (Tridens, n.d.) and then again in 2023 and they are also recognised by the International Electrotechnical Commission (IEC 61851 for conductive EV charging systems and 62196 standards, for EV charging interfaces: plugs, socket-outlets, vehicle connectors and vehicle inlets). The GB/T standard was also aligned with the ISO 15118 standard, for communication protocols, first released in 2013.[9] The 2023 update integrates the ChaoJi high-power DC charging coupler and protocols (CHADeMo, 2023). Battery swapping GB/T standards were also updated in China as of 2021 (Ibold, 2022).[10]
- More recently, China has also provided investment support for pilot installations of battery swapping systems, across cars and trucks (Ibold, 2022, ICCT, 2023).

Taxes on road transport fuels in China have consistently remained at levels that imply effective carbon tax rates higher than the United States, but still significantly lower than those in place in EU countries (OECD, 2023). For residential and commercial electricity, China applies lower taxes than the EU, resulting in a higher difference between electricity and road transport fuel prices (OECD, 2023), which provides stronger economic incentives favouring the a transition to EVs.

Chinese policies have also included implicit and explicit production subsidies at the national and provincial level and other types of measures and incentives promoting first industry development, and later consolidation, of the domestic EV and battery industry, and their supply chain (ICCT, 2021, Oh, 2021, Jiang and Xu, 2023). Similar efforts were also mirrored, on the electricity supply side, by measures that promoted the rapid

[9] In 2022, the ISO 15118 standard integrated an extension enabling bidirectional charging and stronger cybersecurity requirements (ISO, 2022). China has not yet decided how bidirectional charging will be implemented, though it is expected that China's technical standard system for vehicle to grid (V2G) interaction will be defined by 2025 (Pionix, 2024).

[10] Battery swapping is also integrated in the international IEC 62840 standard (State Grid Corporation of China, 2013).

deployment and scale-up of manufacturing capacity of solar panels and wind turbines and other related components.

Internationally, China is engaged in in international standardisation organisations, including the IEC and the ISO. These are instrumental to enable the international adoption of EV charging standards and can have positive spillovers for export opportunities by domestic manufacturers in cases where these standards are adopted elsewhere, thanks to economies of scale and lower costs of adapting vehicles also produced for the domestic market to international standards.

China is part of global trade facilitation fora, including the World Trade Organisation, and it is also engaged in specific fora focused on automotive trade rules. In particular, China is part of the World Forum on the Harmonisation of Vehicle Regulations (WP.29). Its involvement in the Forum is only as a member of its 1998 Agreement on Global Technical Regulations, and not the 1958 agreement on the mutual recognition of type approvals. This enables China to adopt technical regulations that are closely aligned with those developed in the 1958 Agreement, without being part of the same open trade framework. The means that China can apply targeted technical barriers to car imports, e.g. by deviating from regulatory texts established under the 1958 Agreement, while still enabling its manufacturers to develop and scale up the technologies needed to comply with the technical standards established under the Agreement. Importantly, this does not only apply EVs, but also to ICEVs.

China has also been an assertive investor in material supply and refinement, becoming a key producer of all battery materials and intermediate products (Box 1).

Box 1. The leadership of China in battery raw materials as a competitive edge in EV manufacturing

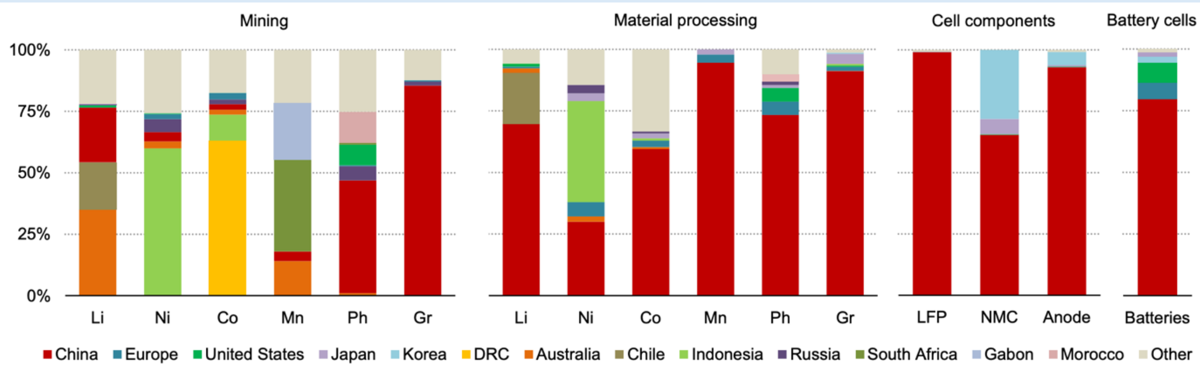
China's remarkable ascent as a global leader in electric vehicles (EVs) and battery technology has also been closely tied to its strategic investments in extractive industries and mineral processing. This approach has ensured a steady and cost-effective supply of critical raw materials, enabling the rapid growth of its domestic industries and drawing in foreign investors, including Tesla (Pistilli, 2025).

The leadership of China in battery raw materials is clearly underscored by shares of annual manufacturing capacity of batteries and components that far exceed those of other regions (Figure 10).

At the core of China's strategy has been its strategic support of corporate acquisition of essential mineral resources and existing mines in foreign countries. Resources that Chinese companies have acquired include lithium, cobalt, and nickel—key inputs for lithium-ion batteries. Chinese companies have heavily invested in mining operations worldwide, including in resource-rich regions like Africa, South America, and Australia.

Chinese firms control significant cobalt production in the Democratic Republic of Congo (DRC) (World Bank, 2021). Similarly, China has expanded its influence in lithium production in countries like Chile and Argentina through joint ventures and direct investments (Licata, 2024).

Figure 10. Geographical Distribution of EV Battery and Material Supply Chains, 2024



Note: Li lithium, Ni nickel, Co cobalt, Mn manganese, Ph phosphate and Gr graphite.

Source: IEA, 2025a, reproduced based on the Creative Commons Attribution 4.0 International License

China's advance extends beyond raw materials to mineral processing and battery recycling, underscoring that World EV battery supply is currently vulnerable to disruptions in China, for all relevant chemistries (Cheng et al., 2024). Chinese companies not only account for the majority of each step of the lithium-ion battery supply chain, but are also global leaders in cobalt refining and prominent players in nickel processing (IEA, 2025a, IEA, 2021, IEA, 2022, IEA, 2024c, Deberdt and Di Carlo, 2024). For battery recycling, China has already an installed capacity that exceeds what is available in the EU and the US by more than a factor 5 (CAS and Deloitte, 2025). It is also expected to realize full circularity more than ten years earlier than Europe and the US for lithium and nickel and seven years earlier for cobalt (Wesselkämper et al., 2024, IEA, 2024c and Deberdt and Di Carlo, 2024).

China's automotive sector was not developed in isolation but followed a similar trajectory to other key technological areas, most notably electronics, as China became a global manufacturing hub and a major net exporter of smartphones, computers, and other appliances (OEC, n.d.).

Drawing upon this strong presence in electronics, China's automotive industry has embraced its integration into vehicles, including for battery management systems, vehicle connectivity and self-driving technology. This helped put Chinese OEMs at the forefront of the ongoing transition towards software-defined vehicles. It is now being followed by similar development in the realm of artificial intelligence, where China already has a leadership position, globally, alongside the US (ITIF, 2024).

The synergy between automotive and electronics helped China to reduce dependency on foreign suppliers while promoting domestic innovation. By now, companies like BYD are prime examples of how Chinese firms integrated advanced electronics, software and battery technology into their vehicles.

1.5 The role of new entrants as market disruptors

The rise of new entrants, including pure-play EV makers – in China and beyond – was a key determinant of the profound transformation of the automotive market. The success of new entrants was crucial to mobilize a growing response from legacy automakers, fueled by the threat of losing market share.

A range of innovations is occurring across the whole value chain. These recent innovations are only the latest chapter in the story of the automotive sector, which has always been a leading investor in R&D, especially in Europe (European Commission, Joint Research Center, 2024).

Table 1. Innovations driven by new entrants in the automotive sector

Area of innovation	Key developments
Battery supply chains	Battery materials have been added to the mix of resources that were already needed for ICEV manufacture, mainly iron and steel, aluminium, rubber, glass and plastics. The EV battery supply chain comprises many steps: mineral mining, processing, precursor and cell component (cathode, anode, electrolyte) production. The expansion of the battery supply chain has stimulated new industrial approaches, novel design and business practices, helping lower EV battery costs, net of the effect of commodity price variations (BNEF, 2024). These include: • Scaling battery manufacturing, with "gigafactories', to reduce unit costs, an approach pioneered by Tesla and now common to all battery makers. • Developing new battery designs – such as BYD's blade battery, boosting the energy density of lithium iron phosphate technologies, cheaper and less constrained in terms of critical mineral supplies. • Increasing reliance on the vertical integration in battery supply chains (Naor et al., 2021, Qu, 2023), as this allows to reduce dependency on external suppliers. • Developing joint ventures between automakers and battery producers (Gulati et al., 2023), as this helps pool capital and mitigate risks, for all parties. • Developing strengthened and direct partnerships between battery and EV makers and upstream material suppliers (IEA, 2024d) for EV manufacturers, providing better access to the resources.

Area of innovation	Key developments
Vehicle design and architectures	Vehicle design architectures evolved, integrating modularity (Luccarelli et al., 2013, Sun et al., 2024), despite remaining relevance of system integration capabilities of automotive manufacturers (Murmann, 2023). High voltage BEV designs can limit energy losses, reduce motor and wiring sizes due to lower currents, and enable faster charging (Aghabali et al. 2024). The adoption of a skateboard architecture enabled EVs to integrate new components, in particular large battery packs. Electric motors removed the need to incorporate ICEs, opening opportunities for aerodynamic improvements and reduced the number of moving parts. These developments enabled savings in maintenance costs.
Vehicle manufacturing processes	Vehicle manufacturing processes were also simplified and accelerated through novel cost-cutting approaches. These include high-pressure die casting for large single-piece vehicle structures, which reduce the number of parts and does away with the need for welding (Yang et al., 2025).
Semiconductors	The higher value and dynamic growth for the semiconductor-based products used in EVs and vehicles using ADAS increases the reliance on advanced semiconductors. This supports new value creation and investments in increased hardware supplies (Morgan Stanley, 2024), with competitive advantages for industrial clusters also serving the electronics industry (similar to the case of batteries).
Integration of digital technologies and data science	Digital technologies and data science favoured greater optimization across the automotive industry, including in manufacturing, logistics, supply chain management and enabled predictive maintenance (Hofmann et al. 2017). Via direct-to-consumer (D2C) sales, they also contributed to enable downstream cost savings in the automotive sector (Levin et al., 2024).

Some of the new market entrants that managed to combine multiple innovations in vehicle electrification and digital technologies catalyzed a virtuous cycle of demand growth, technology learning and cost reduction. This helped deliver cost cuts and enabled consistent growth in revenue, bridging the need to offset the outlays needed to support investments and enabling these players to grow.

New entrants tended to focus on more expensive models, especially in the early phases of commercialization of their technologies. This is consistent with earlier cycles of technological diffusion in the automotive market.[11] This strategy is generally adopted to recuperate investment cost increases in early phases of market developments, when volumes of production and/or adoption are still comparatively small. This explains the

[11] Key examples, in this respect, include Anti-lock Braking System (ABS), turbochargers, Electronic Stability Control (ESC), Adaptive Cruise Control (ACC), LED headlights and direct fuel injection.

focus of EVs and advanced driving assistance features on premium segments and, as innovations came with greater disruptive potential for existing assets (unlike earlier incremental innovation cycles), it also provided an impetus for a supply-driven market transformation oriented towards vehicles with higher margins. This market dynamic, matched by legacy automakers seeking greater margins on each vehicle sold to respond to risks of losing market share, contributed to the global trends of vehicle size, weight and price increases.

Aside from companies headquartered in China such as BYD and CATL, the success of new market entrants with high disruptive potential is best illustrated by the case of Tesla, where a focus on innovation and higher margins from premium branding came with increasing sales, revenues, earnings, and therefore also with growing market capitalization, at least until 2022/23 (Companiesmartketcap, n.d.).[12]

2. Impacts of the structural changes taking place in the global automotive sector

2.1 Road safety

The progressive shift towards larger and heavier vehicles comes with relevant implications from a road safety perspective.

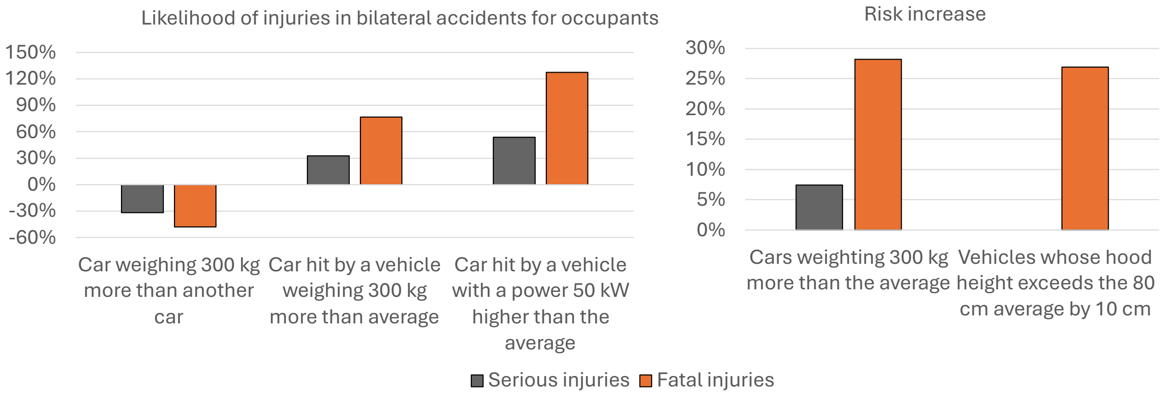
An analysis of accidents on Belgian roads between 2017 and 2021 (considered to be representative of conditions observed in Europe), shows that the occupants of car weighing 300 kg more than another car are more than 30% less likely to suffer serious injuries and nearly half as likely to be fatally injured, in two-vehicle collisions (Figure 11). The same analysis shows that the occupants of a car hit by a vehicle weighing 300 kg more than average are 37% more likely to suffer serious injuries and more than 75% more likely to suffer fatal injuries (Nuyttens and Ben Messaoud, 2023). Vehicle mass is a key determinant of the severity of the injuries of vulnerable users hit by a car: for cars weighing 300 kg more than a car with a reference mass of 1.4 tonnes (slightly below the 1.5 t assessed as average for Belgium in the analysis, for 2021), the risk of serious and fatal injuries increases, respectively, by 7% and 28%.

Similar indications also arise from the analysis of risks of injuries in accidents involving vehicles with higher power; occupants of a car hit by a vehicle with a power 50 kW higher than the average (roughly 100 kW, in Belgium, based on 2021 data) are more than 50% more likely to suffer serious injuries and more than 125% more likely to suffer fatal injuries.

[12] This pre-dates very recent drops for all these indicators, likely linked with political aspects (Anderson, 2025).

Higher hood heights are also implicated as a determinant of increased risks for vulnerable users, with fatal injury rates that are higher by more than 25% for vehicles whose hood height exceeds the 80 cm average by 10 cm.

Figure 11. Impact of vehicle weight, power and hood height on different injury risks in case of accident



Source: compiled from Nuyttens and Ben Messaoud, 2023

Higher hood height, heavier weight and greater power are all characteristics of SUVs and pick-ups. These vehicles therefore pose greater serious or fatal injuries risks for occupants of conventional cars and vulnerable road users.

Similar findings arise from assessments made in the United States, already decades ago (Simms and O'Neill, 2006) and also confirmed over the years (Anderson and Auffhammer, 2011, Jehle et al., 2021, Edwards and Leonard, 2022, IIHS, 2022, RTZ/NSC, 2024, Tyndall, 2024). Other recent examples also exist in Canada (Joncas, 2024) and in Australia (Newstead et al., 2024), which are also characterized – like the United States – by very high market shares of large SUVs.

Risks of disproportionate impacts on other car occupants, cyclists and pedestrians may be exacerbated with EVs, as they have higher vehicle mass compared to ICEVs having the same footprint (AP, 2023). A recent analysis looking at EVs on Belgian roads and reviewing international assessments finds no evidence of increased accident risks[13] and severity[14] with a switch to EVs (Feys et al., 2025). The same analysis also indicates that vulnerable

[13] The risk of an accident involving an electric car is lower than with a gasoline or diesel car. This can be explained by the age and segment of electric vehicles, as these are often newer vehicles equipped with more safety systems. The driver's profile may also play a role (Feys et al., 2025).

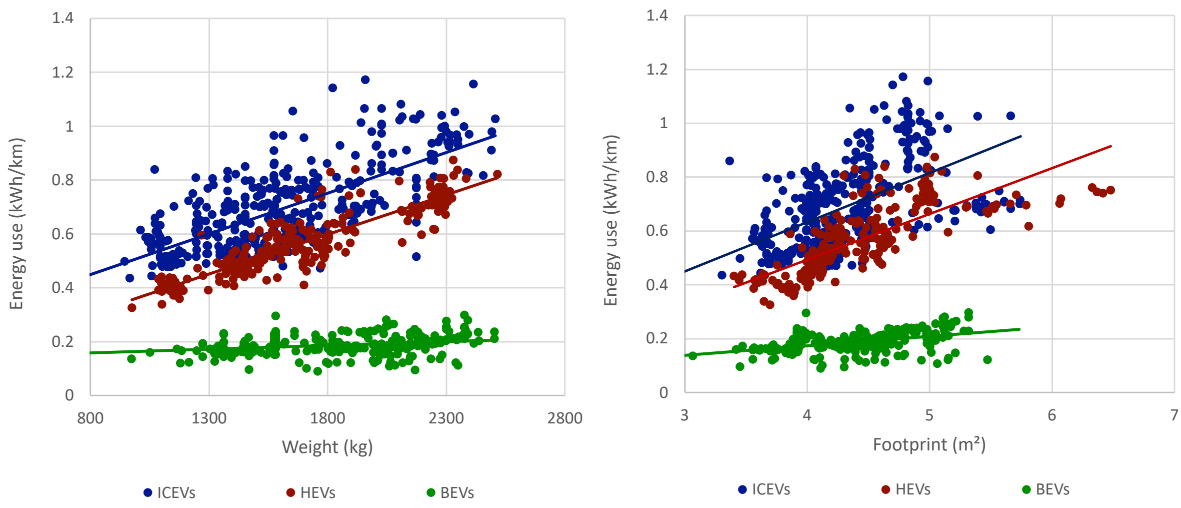
[14] The severity of accidents with vulnerable road users as opponents in accidents with passenger cars is not significantly different for electric cars. However, the severity for the opponent in accidents between two cars is significantly greater with electric cars. When corrected for the factors age, weight, and power of the vehicle, the influence of electric propulsion dissolves. Weight, power and a higher speed limit most strongly influence the severity of injuries to the opponent. The severity for the occupants of accidents between two cars is significantly lower in electric cars. The influence of electric propulsion dissolves when vehicle characteristics are considered: age, weight, and acceleration explain the lower severity for occupants of electric cars (Feys et al., 2025).

road users tend to be more frequently involved in accidents with electric cars (even if they are not reported to be subject to more severe injuries), possibly due to the combination of lower noise and more frequent use in urban areas, for EVs.[15] These results underscore the importance to ensure that the transition towards EVs is not accompanied with an increase in vehicle size, from a road safety perspective. A size increase would entail weight increases exceeding those arising from the switch from ICEs to batteries and electric motors, with negative impacts for third parties, unless accident rates with EVs can also be reduced.

2.2 Energy and material demand

Vehicle weight and size not only have implications for road safety but are also key determinants of energy demand. Figure 12 shows the relationships between energy use (in kWh/km) and two key vehicle attributes: weight (left) and footprint (right). The data is categorized by powertrain type, distinguishing between internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and battery electric vehicles (BEVs). Both plots show how energy consumption increases with vehicle weight and size, with the relationship being strongest for ICEVs and HEVs. This highlights the significant role that these physical attributes play in determining a vehicle's energy demand.

Figure 12. Energy use per km as a function of vehicle weight and footprint for ICEVs, HEVs and BEVs



Source: elaboration based on country-, powertrain- and segment-level data available in Cazzola et al., 2023

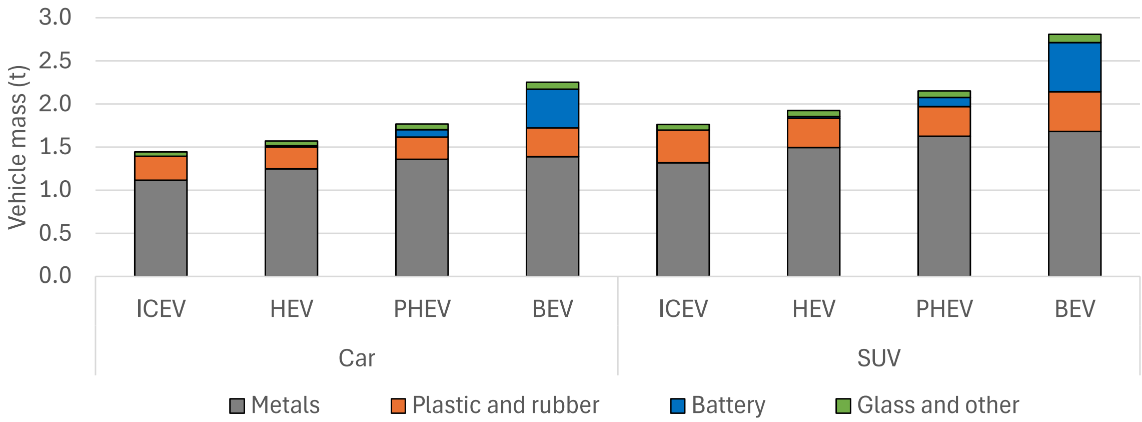
ICEs suffer from substantial heat losses and relatively low energy conversion efficiency, meaning that increases in vehicle mass and footprint exacerbate fuel consumption. In

[15] Vulnerable road users are relatively more frequently involved in accidents with electric cars (Feys et al., 2025). Feys et al., 2025 flag that it is also on the basis of similar evidence that the AVAS (Acoustic Vehicle Alerting System) has been introduced, in the EU (European Union, 2017), with an enforcement starting in 2021.

contrast, BEVs, which operate with highly efficient electric powertrains and have regenerative braking, exhibit much lower energy use, and are less impacted by weight and footprint increases. These energy savings during vehicle use also translate to reductions in life-cycle GHG emissions. The magnitude of these GHG benefits is less pronounced in regions where electricity is generated primarily from fossil fuels (Bieker, 2021).

Material demand is also dependent on vehicle size and powertrain. Figure 13 illustrates that larger vehicles, such as SUVs, require more metals, plastics and other materials than smaller cars, regardless of their powertrain. The figure also shows that BEVs – whether they are cars or SUVs – come with the highest material demand, primarily due to the significant contribution of battery materials.

Figure 13. Material requirements in cars and SUVs, across powertrains, by type of material



Source: elaboration focused on vehicles using conventional materials, based on default data available in the 2024 version of the R&D GREET model (ANL, 2024). The figure does not cover large SUVs, having weights that – as shown in Figure 12 – can exceed 2 t.

Sourcing materials that have traditionally been used in the automotive sector is relatively simple thanks to well established and diversified supply chains. Conversely, over-dependency and geopolitical risks exist for new supply chains, in particular EV batteries (Box 1).

The higher material needs of both larger vehicles and electric mobility, together with the high supply chain concentration for EV batteries, highlight the importance of sustainable sourcing, diversification and recycling strategies to mitigate environmental impacts and geopolitical challenges.

2.3 Vehicle affordability

Since small SUVs are priced above small and medium cars, and large SUVs are priced above large cars, on average, in all major global markets (IEA, 2019) – the shift towards larger vehicles resulted in upward pressure on vehicle prices. It was therefore part of the determinants of the contraction in sales volumes.

EVs generally incur lower energy costs, thanks to major energy efficiency gains vs. internal combustion engine vehicles (ICEVs). With fewer moving parts, EVs also incur lower maintenance costs, ultimately offering opportunities for lower total cost of ownership (TCO) with respect to ICEVs, across different global regions (Carello, 2024, Horesh et al., 2024, ERIA, 2023, IEA, 2024).[16] However, EVs are also paired with higher upfront costs – with the exception of small vehicles in China, thanks to batteries with comparative low capacities.

Some of the TCO advantage may be eroded by higher insurance costs for EVs, reflecting greater costs of repairs (Swiss Re, 2024), partly offset by the fact that EVs tend to cause less damage to other vehicles (GDV, 2023). Part of the TCO advantage is also conferred by fuel taxes, which are generally used to fund road construction and maintenance and are not paid by EVs. As countries shift to other ways to generate revenue from all vehicles (including EVs), this driver of TCO benefits for EVs will be phased out.[17] The residual value of electric vehicles has also decreased faster than ICE vehicles, negatively impacting the TCO. However, as the market matures, residual values are already improving (IEA, 2024a). This trend is expected to continue as battery technologies prove their durability, and innovation cycles begin to stabilize (Turrentine et al., 2018; Chakraborty et al., 2024). Moreover, the energy efficiency benefit of BEVs, paired with the possibility to access low-cost, low-carbon electricity, is hard to overcome and will remain in place (Chakraborty et al., 2024). Recent announcements by the CEO of Renault point to electric light commercial vehicles and small vehicles being cost competitive with internal combustion engine models in the near future (Verhelle, 2025).

The EV TCO advantage is most significant for high-utilization consumers, as they have higher operational costs, and hence are able to amortize the purchase price premium more quickly. Conversely, it narrows and may even reverse in markets with lower average driving distances and in cases where petroleum fuels are subject to very low taxation and where electricity is expensive.

While the TCO advantage is generally an incentive for EVs, the upfront investment needed for their purchase is a major barrier to widespread adoption. This is especially the case in regions – such as Europe and North America – where the EV model offer has remained focused on more expensive market segments (Sery and Le Marois, 2024, FIA Foundation, 2023). The upfront cost barrier is also more relevant in markets with high borrowing costs, especially for households and businesses for which access to affordable financing options or government incentives is constrained.

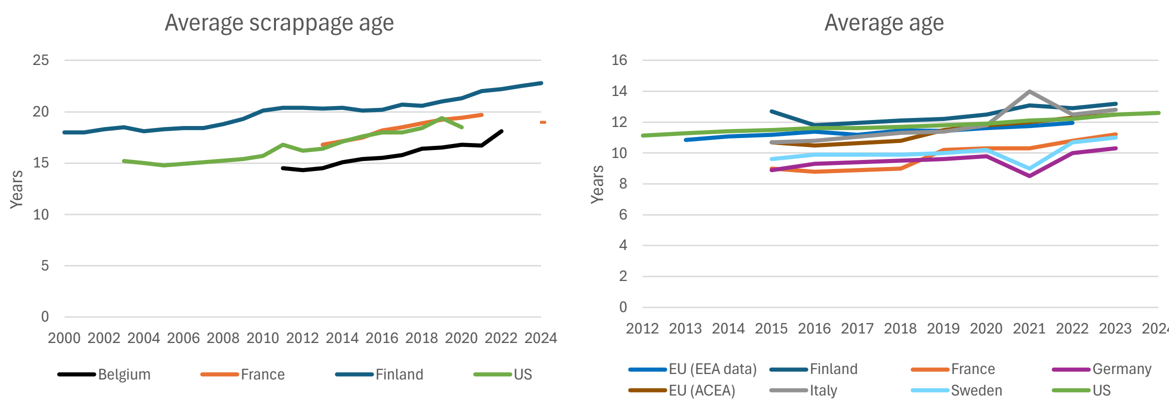
[16] An economic advantage – also in macroeconomic terms – can also arise from the integration of EVs in the electricity system, as discussed below.

[17] Some countries, such as Iceland (Island.is, n.d.) and New Zealand (NZ Transport Agency, n.d.), have already adopted policy frameworks aiming to respond to risks of shortfalls of government revenues.

Declining battery costs are expected to continue to drive down the costs of EV production, despite differences in production costs across global regions. Even at times of major geopolitical challenges, battery costs volatility has been limited (BNEF, 2024). While part of the cost reduction potential may be used to design vehicles with greater range, technological developments including battery chemistry diversification and design innovation have the capacity to structurally support reductions in EV upfront costs. Such cost cuts can be accelerated if vehicle size increases can be contained or reversed.

The two major trends in automotive markets – increasing size and weight and electrification, may have contributed to extending the useful life of cars. Increases in the cost of vehicle acquisition (in the case of EVs) and operation (in the case of SUVs), together with greater durability of the vehicles and their components, are likely to have led to vehicle owners holding on to their vehicles for longer (Jacobsen and Benthem, 2015; Bento et al., 2018; Greene and Leard, 2024). Increases in vehicle durability, in turn, may have contributed to a reduction in market size for new cars. Data on average scrappage age and average age of mature vehicle fleets in Figure 14, show that vehicle age increased consistently over the years, accelerating after 2010, when SUV shares also started growing.

Figure 14. Average scrappage age and average vehicle stock age in Europe and the United States



Sources for average scrappage age: Autoalan Tiedotuskeskus, n.d. for Finland, CE Monitor, n.d. for Belgium, Ministère de la transition écologique, 2025, ORD&EC, 2022, ORD&EC, 2021, Extenso Innovation Croissance, 2021, Deloitte Développement Durable, 2019, Henry, 2022, Murati, 2018 and ORDIF, 2014 for France and Greene and Leard, 2024 (using the average of cars and SUVs) for the United States. Sources for average age: EEA, 2025, ACEA, 2025, 2024, 2023, 2022, 2021, 2019, 2018 and 2017 for European countries, S&P Global, 2025 for the United States.

2.4 Industrial development challenges and jobs

The emergence and increased competitiveness of China and of new entrants in the EV market has resulted in a significant concentration of the EV battery value chain. China's competitive presence in the software-defined vehicles field is likely to strengthen this further, due to important synergies between software-defined vehicles and EVs.

The dynamics that led the current situation brought advantages through cost reduction for consumers, but they also carry overdependency risks, regarding battery supply chains, and other industrial risks, especially the potential for loss of competitiveness and the resulting long-term implications on economic activity and jobs.

These risks are not only perceived by economic actors whose market is being eroded, but also by national governments that see their domestic industrial base, and hence national interest, as negatively affected. In the case of governments, this consideration is exacerbated by the increasing tensions of the current geopolitical context.

Supply chain challenges were clearly exposed by the COVID-19 pandemic. In the automotive sector, these materialized in the form of shortages of semiconductors (partly induced by increasing demand for electronics, with greater profit margins available, partly due to suspensions of industrial activities in the production of semiconductors) and delayed car production (King et al, 2021, Chakraborty, 2023).

Threats are very significant for incumbent car manufacturers located in the EU, the US and elsewhere, as they struggle to contribute to the diversification of EV and battery supply chains globally. This is partly due to greater resistance to revamp legacy automotive production assets (due to losses not present in a strong growth market like China), partly due to differences in labour costs, and – especially in the EU – partly also due the need to manage the consequences of increased energy costs, following major geopolitical development like the Russian invasion of Ukraine (Draghi, 2024).[18]

Negative repercussions risk being more profound in cases where the protection of existing assets has been prioritized over timely investments to respond to this major technology shift. Key challenges relate to jobs, skillsets and the need for their rapid evolution, as well as increased systemic costs for social protection, which are hard to sustain without a robust economy. They also encompass tensions across geographies, especially if there are unbalances related with winners and losers from the transition. These challenges include a strategic dimension, as deindustrialization impacts automotive production facilities and technologies that have the potential to be used in both civil and military applications.

Competition amongst great global powers regarding clean energy technologies and related industrial capacity also underpins the focus of COVID-19 stimulus packages, not only on the deployment of infrastructure (a traditional focus of countercyclical policy-driven economic stimuli), but also on sectors specifically supporting the energy

[18] In some geographies (such as Italy, and to some extent also in France), this has also exacerbated competitiveness issues due to declining capacity utilization of legacy automotive factories (Hermine, 2024).

transition through EV charging. A key example of this is visible internationally, through the lens of technical standards for electric car chargers, as these can be instrumental to major global powers as a means to secure influence internationally and protect industrial production domestically. Technical standards differ across the main EV markets, globally. In North America for electric cars are based on the NACS and the CCS 1 connectors. The low-voltage part of the CCS 1 is also suitable for Japan, which has a 110 Volt system for household electricity – like North America – and is also home of the ChaDeMo connector. Europe uses the CCS 2 connector, combining DC charging with a low-voltage connector suitable for 220 V, for triphasic electricity. As in the case of other technical standards for vehicles, the European approach was also adopted in India. China has its own GB/T connector. Going forward, differences in technical standards for the electric car and charging infrastructure connectors are likely to become relevant insofar as they determine the degree of access that each global power has to international markets. For this reason, it is likely to become an area where competition, rather than international collaboration, will be given priority.

The need to invest to secure competitive niches in domestic industries in sectors that are characterized by efficient and resilient technologies (like EVs), especially but not only with climate-related drivers, explains other major policy packages: India's Production-Linked Incentives programme, the Inflation Reduction Act in the United States, several measures included in the EU COVID-19 recovery package (in particular the NextGenerationEU recovery and resilience facility, funded by joint debt), the Green Deal (including pricing and regulations) and, more recently, the more explicit industrial development measures that formed part of the Green Deal Industrial Plan.

Industrial challenges related with e-mobility and renewable energy also resulted recently, in the EU, in a clear call for increases in investments in infrastructure, research and industry to increase productivity, to levels unseen over the past half a century (Draghi, 2024, von der Leyen 2024).

These considerations show how EVs have become a key element of a major global competition for industrial growth (and – in developed markets – for the avoidance of de-growth[19]). They also underscore the relevance of a technology transition at scale in markets that did not transition as fast as others, and that were not successful in seizing opportunities to transform their economic fabric, as scale and technology learning can be key incentives to gain greater cost competitiveness.

[19] Risks of de-growth are higher in developed economies, due to greater exposure to asset stranding risks from the loss of economic competitiveness of existing industrial assets, as new technologies replace incumbent ones.

2.5 Geopolitical development and over-dependence risks

In China, competitive governmental support mechanisms were set up to foster industrial development (for state-owned enterprises, private companies and joint undertakings), and continued funding was conditional on technology improvement. Leveraging technology learning, vertical integration and economies of scale, funding proved effective to mobilize investments and reduce costs.

Additional pressure towards cost reductions also arose from a regulatory and market environment that, at least initially, did not rein in increases in production capacity (as shown in Figure 7), a condition that induces market players to seek export opportunities and market share increases to improve their competitiveness. Even today, the number of automotive manufacturers (and of EV makers in particular) operating in China is far higher than in most other countries, and consolidation is likely to result from intense price competition (Reuters, 2025; Bloomberg, 2025).

These dynamics, not only related with industrial developments but also integrating energy security and diversification drivers, have enabled China to achieve a leading position globally in many technology areas (European Commission: DG for Research and Innovation, 2024).

The automotive sector, with its key role as a mobilizer of investments and its importance to fund innovations, is one of the sectors at the center of a global struggle among regional powers to preserve or augment technology and industrial development, including clean energy and end-use electrification technologies that will be cornerstones of the industrial economy over the coming century.

While the current market concentration in EVs and digitally-defined vehicles reflects China's long-term investments, scale-up of industrial capacity, and strong competitiveness in these technologies, overreliance on any single source of supply introduces a range of risks, as these technologies will become essential to transportation, energy, and broader economic infrastructure. For instance, on the supply side, countries that are able to leverage natural resources and competitive advantages to secure industries along the EV battery value chain will establish new sectors that provide jobs and economic value-add. On the demand side, road transport electrification will reduce dependence on fossil-derived fuels and result in declining pollutant and GHG emissions, while also supporting the broader transition to renewables and low-emissions electricity generation.

As EVs become increasingly central to national economies and climate objectives and as the adoption of EVs and renewable electricity supply scales up globally, ensuring a diversified, transparent, and stable supply of battery technologies becomes critical not just for economic resilience, but also for long-term national security and policy autonomy (Bauerle Danzman, 2024). Diversification is also relevant for economic reasons, as low-cost, low-carbon technology options also result in increased economic competitiveness and reduced exposure to the volatility of fossil energy prices, especially for countries that are poor in these resources.

Potential vulnerabilities may arise from supply disruptions due to geopolitical tensions, trade restrictions, or unforeseen global events. Disruptions have the potential to affect regional or global prices (price risks), as well as to result in interruptions in the supply of critical minerals to specific countries (quantity risks).

Security concerns in EV battery supply chains are also further exacerbated by the consequences of unilateral restrictions to raw material exports from China (Kashyap, 2024), with clear headwinds for the development of battery producers located elsewhere – as illustrated by the case of graphite exports to Sweden (The Economist, 2023, Björling, 2024).

Moreover, control over critical battery inputs could be used as leverage in geopolitical conflicts (Bauerle Danzman, 2024). Overreliance on supplies from a single country may also limit the ability of other countries to set industrial standards, protect intellectual property and ensure that environmental and labor practices align with domestic expectations.

The relevance of these challenges is amongst the factors that contributed to trigger the application of trade tariffs on Chinese EVs by the US – first at 25% in 2018 (Swanson, 2018), then at 100% in 2024 (Associated Press, 2024), and now including a further 25% increase (White House, 2025) that also apply to other countries. Evidence of subsidies in China also provides the justification of the decision to apply countervailing duties on imports of new battery electric vehicles in the EU (European Union, 2024).

Concerns that China could use over-dependencies as geopolitical leverage and to stymie development of industrial capacity in EV batteries and other strategic and clean tech sectors in developed economies are not purely hypothetical. Export controls on raw materials needed for the manufacturing of dual-use technologies, including EV batteries and motors, are one example of how China has already limited supplies of critical minerals (Baskaran and Schwartz, 2024). Another example is the case of graphite, for which China is the global top producer. Long before it required in 2023 export permits, justified by national security considerations and as part of the tit-for-tat tariff and trade escalations with the US (Liu and Patton, 2023), as early as 2020, Chinese graphite exports to Sweden were prohibited raising costs for Swedish firm Northvolt – which filed for bankruptcy in 2025 (Northvolt, 2025) – at a pivotal moment in its development (Economist, 2023). China's large market share also gives it a capacity to manipulate (either lowering or raising) export prices of commodities at multiple steps of the EV battery supply chain (Toman and Gayatri Kannan, 2025).

These dynamics call for efforts to accelerate supply diversification along all stages of the EV battery supply chain (Bauerle Danzman, 2024). This cannot simply be grounded on unilateral trade tariffs, not only because these negatively impact the global economy, but also because they do not provide incentives for innovation and better productivity in the countries that adopt them. The capital costs of developing a geographically diverse mineral processing capacity would also be substantial, and would result in higher EV manufacturing costs that would be reflected in EV prices, except in cases where investments in supply chain diversification have received government support (Toman and Gayatri Kannan, 2025).

Measures aiming to stimulate greater supply chain diversification also need to consider the scale of total capital outlays required and related economic risks (Toman and Gayatri Kannan, 2025). Scaling domestic manufacturing therefore requires policies that endeavor to guarantee competitiveness, support the development of innovative technologies, secure demand, favor cost savings from economies of scale, and ultimately enable the diversification to be self-sustaining, from an economic perspective (European Commission: DG for Research and Innovation, 2024).

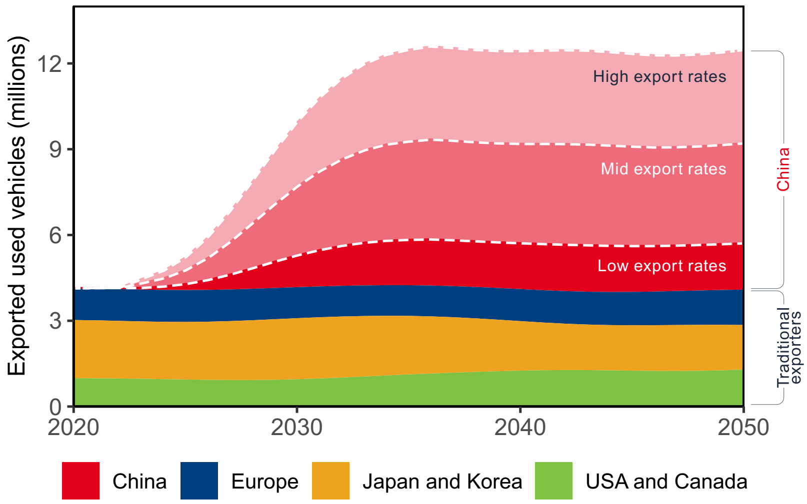
2.5.1 The specific channel of second-hand international vehicle trade

China's growth in vehicle ownership is not only occurring in new cars, but it is also expanding to the used car market, increasing the availability of second-hand vehicles (ITF, 2023).

To ensure the domestic availability of used vehicles to meet growing domestic demand, the export of used vehicles in China was prohibited until 2019. With this ban lifted in 2019, this is expected to result in China becoming a major global supplier of second-hand vehicles (Figure 15). This development could be fueled by a gradual evolution in China towards a replacement market, resulting in many used vehicles leaving the country in the coming years.

While not directly related to vehicle size, this transition has implications for EV market dynamics. Its primacy in terms of EV market share amongst the main global markets, combined with the greater EV penetration in cheaper market segments, may offer to China important opportunities to gain relevance as a clean and affordable road vehicle technology supplier for emerging economies. For example, importing significant volumes of used electric cars from China may increase the likelihood of locking in Chinese charger standards (GB/T) over European (CCS) or North American (ChaDeMo) alternatives. This shift can have very significant implications for global vehicle trade patterns, as affordable second-hand EVs can be particularly attractive for households and small businesses in emerging economies.

Figure 15. Modelled export of used vehicles by region of origin



Source: ITF, 2023

This transition may enhance China's geopolitical influence as a global technology provider, especially in countries that are net oil and oil products importers, as a transition to EVs can help these countries to relieve their trade balance. In practice, this is already well exemplified by recent policy decisions in Ethiopia, as the country became the first country to ban imports of internal combustion engine vehicles (US International Trade Administration, 2024, Mengiste, 2025). Signs of second-hand vehicle trading hubs – including EVs – are also emerging in Central Asia, as in the case of the Khorgos Gateway, a dry port located on the Kazakhstan/China border that facilitated trade of more than 400 thousand vehicles in 2024 (four times the volume of 100 thousand vehicles traded in 2023) (Business Standard, 2025).

3. Smaller, cheaper EVs can be part of a solution to overcome multiple challenges in the automotive industry

3.1 Key advantages of the EV transition

Wider EV adoption offers major opportunities to reduce emissions while also diversifying away from oil. Net of remaining differences associated with vehicle size and electricity generation mixes, a combined transition away from ICE vehicles and towards EVs is capable to offer compelling life-cycle emission savings, both in terms of local pollutants (Chang et al., 2023) and GHGs (Bieker, 2021).

Thanks to the greater energy diversification of electricity, this transition can also be paired with significant energy security advantages. Thanks to low costs of low-carbon electricity, in particular from renewable energy (due to low operational costs), the same transition can also be a significant market opportunity, both for consumers and industry stakeholders.

Additional benefits can also arise from the integration of EVs with the electricity grid (Heid et al., 2024, CEM, 2022 and Hildemeier and Kolokathis, 2019). These benefits can occur at the level of single households/businesses owning EVs, but also at the macroeconomic scale, as – with policy frameworks enabling time-variable electricity prices – improvements in the grid integration of EVs can trigger lower electricity costs. Exploiting alternative revenue streams – including from EV grid integration (Guille and Gross, 2009) – can also help strengthen the case for lower emissions in electricity generation by enabling greater penetration of variable renewables. In this case, cost-saving opportunities will need to be effectively shared with customers to enable stronger EV demand (Daina and Suel, 2023, Burger, 2023).

Focusing on EV adoption in highly utilised vehicles (such as those used for taxi and ride sharing services) can help to accelerate the payback period of the higher initial purchase price of EVs, while maximising the GHG benefits of batteries. Greater diversification towards smaller segments in the car market can also help ensure, thanks to greater accessibility in terms of cost of vehicle acquisition, that the same amounts of raw materials are used to enable e-mobility access to a broader spectrum of users.[20]

Circularity, and hence gradually increasing rates of material recycling (pending the availability of materials to be recycled) can also come with net advantages from an economic competitiveness perspective. These advantages are most pronounced when fossil energy prices are high and renewable electricity is cheap and abundant. Key reasons for this lie in the relevance of aluminium for battery production, on one hand, and in the much lower energy requirements of secondary (and hence recycled) aluminium, with respect to primary aluminium.[21]

As long as battery cost reductions from technology learning and low-cost options grow in the electricity mix, supporting the case for lower TCOs, a shift toward EVs can also contribute to alleviating global inflationary pressures.

Promoting EV adoption while rewarding lower carbon footprint and increased reliance on recycled materials can also support the EV battery supply chain diversification. This is because many emerging economies stand to benefit from a lower carbon intensity of electricity generation and of industrial production processes than China (the current leader across all the steps of the EV battery supply chain). Further opportunities come

[20] Further material savings can be achieved with a greater reliance on public transport and shared vehicles with high occupancy rates. This, however, is beyond the scope of this report.
[21] This is clearly shown by life-cycle analyses, such as those available in the GREET model (ANL, 2024)

from the lower carbon intensity of the circular economy, as is most evident in the cases of recycled aluminium and steel.

3.2 Opportunities (and risks) from small PHEVs and/or EREVs

An increased reliance on PHEVs – including extended range electric vehicles (EREVs), sales of which have rapidly grown in China in the recent past, including in smaller market segments (Ramsay, 2024), but with a primary focus on larger segments (IEA, 2025b) – could effectively reduce GHG and local pollutant emissions and also help manage challenges due to new material demand and related dependencies.

To effectively deliver these benefits, PHEVs need to be driven primarily on electricity.[22] Most daily car trips are relatively short – typically under 65 km, across all global regions, and with shorter distances in countries with denser urban areas (Bricka et al., 2024, UK Department for Transport, 2025 and European Commission: Directorate-General for Mobility and Transport et al., 2022, Gupta, 2018, Qu et al., 2019). This means that appropriately designed PHEVs with moderately sized batteries – large enough to cover typical daily driving in electric mode, but with much lower capacity than BEVs are typically equipped with – can enable operations reliant on electricity as the primary form of energy for the majority of trips.

When well-designed and well-used (i.e. when frequently charged), PHEVs could represent a practical and scalable tool for decarbonizing transport, replacing ICEVs while managing resource constraints during the global EV transition. PHEVs (and/or EREVs) could also be instrumental to meet the preferences of consumers that are particularly opposed to a switch to BEVs, supporting overall reductions of energy use, increased energy diversification and emission reductions. However, available data points regarding the real-world usage of PHEVs indicates that realizing this potential requires addressing issues of PHEV design, use, and regulation.

Figure 16 shows results of on-road monitoring of real-world performance in the European Union (the only global region where reporting of on-board fuel consumption data is not only technically feasible, but also mandatory). The figure highlights that in real-world conditions, PHEVs have not been driven frequently in all-electric driving modes.[23] The average gap between the real-world specific fuel consumption of PHEVs registered in the

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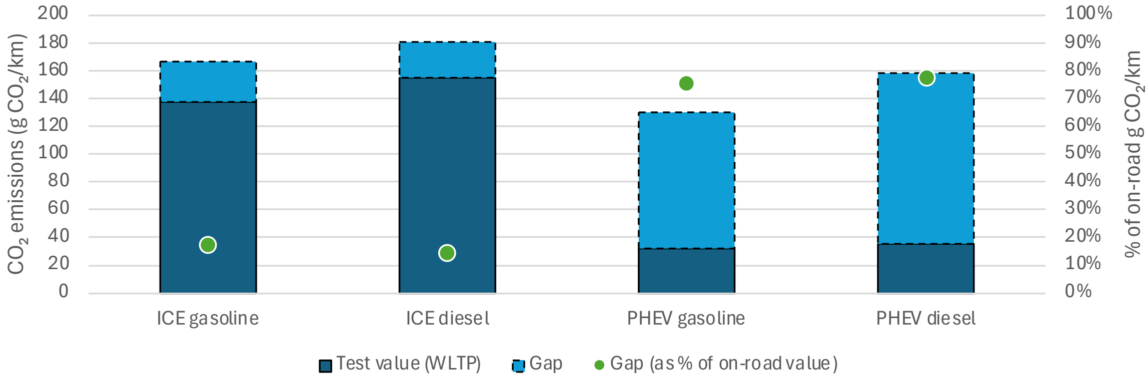
[22] While the remaining travel would still benefit from lower energy use and emissions than on ICEVs, as PHEVs would work in a more energy efficient hybrid mode, significant energy savings, energy diversification and emission cuts require large shares of all-electric driving. While smaller batteries used in hybrid vehicles can deliver energy savings with a reduced dependence on large quantities of minerals, larger batteries are needed to enable the all-electric driving mode needed to support greater energy diversification, and not only energy efficiency savings.

[23] It is also for this reason that the EU introduced policy revisions to the initial estimates of PHEV utility factors – which define the shares of all-electric driving used to determine the CO_2 emissions during the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) type-approval test used for regulatory purposes.

European Union in 2022 exceeded 300% (European Commission, 2024, EEA, n.d.). The share of all-electric driving in PHEVs was estimated to be about 40% lower than values used for type approval (Plötz et al., 2021), before the revision of the type approval methods in 2023 (European Union, 2023).

Figure 16. Tested vs. on-road emission factors in the EU for ICE, HEV, PHEV and BEVs (2022)



Note : while data are for 2022, year-on-year variations between 2021 and 2022 (both available in the source data) are minimal: the result can therefore be generalized beyond the specific year considered.

Source: EEA, n.d.

Other assessments focused on China also point towards on-road energy use and emission intensity gaps for PHEVs (including EREVs), even without considering changes from test values of all-electric driving shares. A recent study found that the on-road fuel consumption of top-selling PHEVs in China ranged from 3 to 6 times the NEDC rated fuel consumption,[24] showing that the issue of the on-road vs. test gap is not specific to the EU (Deng et al., 2024). While an official assessment of real-world charging behaviour is not enabled by mandatory reporting, available sources from scientific literature regarding all-electric driving shares for PHEVs in Chinese cities suggest shares of all-electric driving for PHEVs that range from around 25% to 50% lower than those used in test procedures (Hao et al, 2021, Plötz et al. 2020).

Analyses focused on PHEVs in the US by Isenstadt et al. (2022) and Hamza and Laberteaux (2024) suggest that their electric capabilities have been underutilized in real-world conditions also in North America, if compared with utility factors used in the EU before the revision of 2023. Gaps between rated and real-world all-electric driving shares were less pronounced than in the EU. This can be attributed to longer electric ranges of PHEV models (in particular EREVs) available in North America and possibly also to easier access to home charging. Utility factors used for window sticker ratings were revised in

[24] NEDC stands for New European Driving Cycle and is the cycle that was adapted by used in China through 2021, after which China developed its own test cycle (the China light-duty vehicle test cycle, or CLTC), and then in 2024 incorporated the WLTP into its vehicle emissions testing framework. As of 2024, all three test cycles are used in China.

2024 also in the US (US EPA, 2024), although recent analyses suggest the values before the revision were aligned with real-world usage (Hamza and Laberteaux, 2024).

Other considerations associated with PHEVs stem from the need for a dual powertrain architecture – with both an ICE and an electric motor – adding complexity, weight and space. This explains why PHEV and EREV powertrains are more common in large, heavy vehicle models, in premium market segments, and hardly ever used in small market segment (IEA, 2025b).[25] This highlights structural challenges for PHEVs as a low-impact mobility solution compared to well-utilized BEVs or smaller, fully electric models.

3.3 Specific advantages from smaller EVs

3.3.1 Better affordability

A focus on smaller EVs, with their lower unit costs as compared with larger EVs, can help counterbalance rising prices seen in the automotive sector with the decades-long shift towards SUVs.

While this effect is still mitigated by higher EV purchase costs vs. ICEVs due to the high cost of batteries (an aspect that requires policy attention), expectations for continuing reductions in battery costs have the capacity to narrow this gap. In China, BEVs are already there, especially in small market segments (IEA, 2024a).

3.3.2 Additional GHG emission savings

By lowering average vehicle prices, a reversal of the trend towards increasing vehicle size can also lead to a more dynamic market response, resulting – especially if paired with policies stimulating fleet renewal, such as restrictions of circulation of older, more polluting vehicles[26] – in the acceleration of vehicle scrappage, and hence also in lower lifetime GHG emissions (and potential for "locked-in" emissions) from legacy ICEVs.

Due to the outsized contribution of the use phase in the life-cycle GHG emissions of ICEVs, way larger than the emissions from battery manufacturing (Bieker, 2021), a scale up of small EVs (including through a faster fleet turnover) comes with additional savings with respect to those that would arise from lower contributions from manufacturing to GHG emissions/km for existing ICEVs.

[25] The case of small PHEV/EREV models by Leapmotors (marketed as BEVs in China), whose assembly in the EU was discontinued or scrapped by Stellantis (Reuters, 2025) provides an example of recent attempts to deploy the technology in smaller market segments, although with limited success, so far.

[26] These policies would also need complementary measures to bridge social challenges, as further discussed in the section on policy recommendations.

3.3.3 Better cost competitiveness from larger scale and contribution to increased industrial resilience

If smaller EVs effectively trigger faster fleet turnover, they can also help generate new opportunities for increased competitiveness (thanks to lower unit costs coming with larger volumes) in the automotive supply chain, including battery production, electricity supply and charging infrastructure.

If paired with policies and investments capable to secure greater resilience for industrial capacity, the increase in volume that accompanies the greater affordability of small EVs can help managing risks of job losses in the ICEV sector. Especially for economic clusters that are capable to seize the growth dynamics inherent in disruptive innovations like BEVs, increases in volumes of production can generate opportunities for new, diversified investments, with positive feedbacks on employment and value generation, (ILO, 2021, Tamba et al. 2022, OECD, 2024a).[27]

3.3.4 Support for the management of geopolitical risks

The faster adoption of small EVs (vs. a counterfactual with a lower amount of larger, more expensive ICEVs) can also help reduce risks of geopolitical instability, as it can enable market growth globally.

1. In developed economies, faster turnover resulting from smaller and more affordable EVs can mitigate the effects of the saturation of car ownership and the effects of policies aimed to reduce car dependency on the overall market size.
2. In emerging economies, the greater appeal of smaller, more affordable EVs can support a more dynamic new vehicle market development, as car ownership grows beyond early phases of motorisation.[28]

By creating a wider basis for growth opportunities, including for the battery value chain (and its diversification), a reorientation of the car market towards smaller and more affordable EVs can also help limit mitigate the pace of global shifts in geopolitical influence, helping to cool down international tensions. The large and more geographically diverse market availability of smaller, second-hand EVs can also contribute to this goal through a greater geographical diversification of second-hand electric car supplies.

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[27] While EVs have been estimated to require approximately 30 percent less labor to produce than ICEVs (OECD, 2024a), overall labour impacts from the EV transition can be net positive, given job opportunities in the battery value chain (including end-of-life and recycling), electricity supply, and charging infrastructure (ILO, 2021, Tamba et al. 2022, ILO, 2024). To ensure that this is the case in locations that host legacy automotive vehicle manufacturing and supply-chains, industrial capacity will need to adapt as the powertrain technology shifts towards EVs (Tamba et al. 2022).

[28] Early motorisation is less influenced by affordability constraints, as access to cars is limited to small shares of the population, i.e. the wealthiest. More dynamic market developments can also be triggered by affordable electric two-wheelers, beyond the car market, with trade-offs for car ownership developments.

Following the recent announcement of sweeping trade tariffs by the US, smaller and more affordable EVs are also better suited (especially in regulated markets) than large, more expensive vehicles to secure growth opportunities for the automotive sector. The reason lies in increasing risks of a slowdown in global economic growth, with impacts on the middle class that could dampen demand for more expensive goods (not just EVs), as well as delay purchase decisions or reorient it towards cheaper alternatives.

Chinese EV exports to the US have already been limited to very small volumes by earlier waves of tariffs, and Chinese EV exports to the US are currently minimal. Challenges emerge for carmakers to gain a foothold in new markets, especially in emerging and developing countries, given the recent growth in Chinese exports of small EVs and the exacerbation of the Chinese production overcapacity, as Chinese auto manufacturers continue to successfully seek new growth markets in nearly all global markets except for the US. While the new US tariffs will lead to products that would have otherwise been destined to the US to be reoriented to other markets, this is less of an issue for automotive.

To ensure an effective alignment with energy efficiency and to minimise environmental impacts, and as it could indeed expand the scope of adoption of EVs globally (including in emerging economies), a focus on small EVs also needs to be accompanied by the establishment of a global framework for improved economic circularity. This is still far from being in place, as most emerging economies do not yet have well-developed policy frameworks on end-of-life vehicles and batteries (FIA Foundation, 2023).

3.3.5 Enhanced energy and resource security benefits

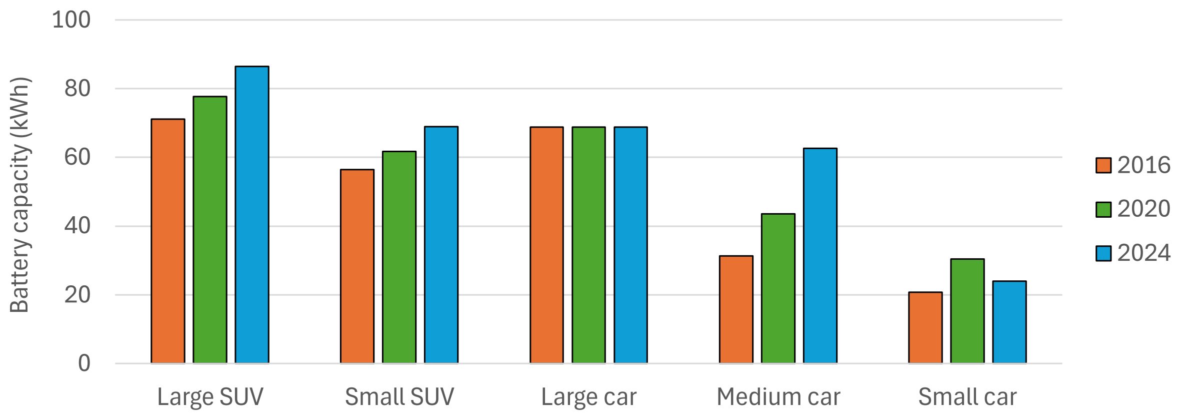
For countries that are major net importers of oil, both smaller vehicles and EVs offer reduced vulnerability to oil price shocks, and hence also far-reaching energy security benefits.

Key enablers of these benefits are the much greater energy efficiency and – especially for EVs – an energy mix that is far more diverse than the oil-centric paradigm inevitably paired with ICEVs.[29]

Resource security benefits accrue as smaller cars require smaller batteries (Figure 17). This has environmental advantages as it reduces the resource requirements, delivering more mobility with less battery resources. In doing so, it is similar to a focus of the early EV deployment on passenger vehicles with high load capacity and load factors, like urban buses.

[29] While some degree of energy diversification is possible with bio- and e-fuels, limitations in sustainable supplies suggest the need to prioritize the primary resources necessary to produce these fuels in sectors where electrification is less cost effective (ITF, 2024).

Figure 17. Average battery capacity across market segments



Source: 2023 battery ranges from IEA, 2025b and energy use per km for BEVs available in Cazzola et al., 2023.

Lower resource intensiveness is especially important in case of supply constraints and in the presence of supply chain bottlenecks. Material-related advantages, however, should be weighed with the risk to weaken the case for increased investments, as prospects for clear increases in material demand are more likely to stimulate the investments that are needed to support the technological transition that can support lower oil dependency, GHG and local pollutant emission reductions. This type of observation is not only relevant from an environmental standpoint, but also from a geopolitical one, especially in light of existing battery supply chain over-dependencies.

If considered from the perspective of securing a significant stock of EV batteries and related materials (rather than from the resource efficiency one), small EVs – like batteries used on buses – also need to be paired with higher overall EV market shares, vs. a counterfactual more focused on the electrification of large cars and SUVs.

Beyond energy and resource security, making sure that the transition towards EVs is an industrial development opportunity, not just for China, but also for other geographies, is crucial for social stability and also important for strategic reasons, due to the relevance of the automotive, battery and semiconductor industries for both civil and military applications (European Commission: DG for Research and Innovation, 2024).

3.3.6 Specific relevance for road safety

A wider adoption of smaller vehicles also comes with demonstrated opportunities to improve road safety, as the elevated mass and size of SUVs (irrespective of the engine type) tend to increase severity of accidents, disproportionately affecting vulnerable road users: pedestrians, cyclists, and occupants of smaller vehicles.

Avoiding continued increases in vehicle size and weight within and across global car markets is particularly important for BEVs, as their reduction in size comes with large reductions in vehicle mass (in absolute terms), in comparison with ICEVs, due to the significant contribution on the battery (as visible in Figure 13, which refers to the case of sedans and SUVs in the US).

4. Policy and industry actions that can support a shift away from large ICEVs, towards smaller EVs, while also addressing international challenges

4.1 Key policy features

Policy action will be important to respond to environmental, equity, affordability and industrial challenges (including those arising from geopolitical drivers) in a way that is positive for society. Policies need to combine the following features:

- A firm commitment to environmental protection.
- An equally firm commitment to better road safety (including for vulnerable users).
- The capacity to support social justice and cohesion, at the local and at the global scale, through positive contributions in terms of affordability and job creation.
- The ability to support economic resilience, not only in terms of productivity growth and enhanced competitiveness, but also through the diversification of industrial capacity.[30]
- The possibility to offer net improvements regarding security, including from the energy and resource diversification and access standpoint.

In the absence of demonstrable commitments to road safety and environmental protection, societal pressure to push for alternatives to car-centric mobility is likely to increase. Neglecting these important goals therefore puts the automotive industry at risk of social backlash, undermining their long-term growth prospects (particularly in emerging and developing economies) and endangering their capacity to transition to business and industrial models that are compatible with avoiding the impacts of climate change.

Similarly, vehicle sales strategy and design choices that result in reduced sales volumes risk negatively impacting the medium- to long-term competitiveness of automakers. Impacting jobs, these challenges to the automotive industry could then also risk bringing negative developments for social justice and cohesion.

This is especially relevant in replacement markets and developed economies, in particular Europe and the US, for different reasons:

[30] Industrial capacity has also relevant implications on security, given the role of the automotive industry in dual-use, civil and military applications.

- Developed markets are those that currently host a lot of the global car manufacturing capacity, and hence also are the most exposed to risk of that capacity being disrupted.
- Developed economies are those where the saturation in car ownership and increases in average age of vehicles will limit growth in terms of market volumes.
- Developed economies also are those where EV deployment has been more focused on premium segments, rather than on affordable EV models in small market segments (especially in comparison with China).
- China has been capable to better exploit the market scale advantage to acquire a competitive advantage in developing EV battery supply chains, in comparison with developed markets, including in particular Europe and the US.
- Developed markets are also those where there is a greater risk of a net erosion, with the loss of competitiveness and industrial capacity, of the social and wealth redistribution gains that occurred throughout the world over the past decades.

Other major car producing countries—including Brazil, India, Mexico and others in the ASEAN region—are also suffering from delays with respect to China in the deployment of domestically manufactured and affordable EVs. As EVs continue to gain market shares globally, these countries are also subject to competitiveness challenges, unless they manage to attract investments to diversify their production away from ICEVs. Contrary to the case of developed economies, they are less subject to market saturation risks. This is positive in terms of prospects for growth. Headwinds are more likely to come from the higher cost of capital than in developed economies and from lower capital availability overall, in these cases.

Improved affordability is instrumental to effectively stimulate a scale up for the technologies that are necessary to meet environmental goals without being detrimental for road safety, starting with small EVs (especially if they can gradually replace large ICEVs), thanks to clear price signals.

Policies stimulating cost-savings for more affordable EVs can trigger a virtuous circle, resulting in increased competitiveness (thanks to lower unit costs with a larger market size) and hence also a positive contribution to job creation, economic resilience, industrial capacity, energy and resource security. Increased market volumes induced by this virtuous circle can enable both greater profitability for investors and more equitable access to technology options that are clear enablers of better alignment with sustainability requirements.

4.2 Recommended policy instruments

The set of policy instruments that support e-mobility and a move away from SUVs, towards smaller vehicles, remains relevant. These policies are already detailed in earlier reports – and in the 2023 FIA Foundation assessment that highlighted and analysed the continued tendency towards vehicle size and weight increase (FIA Foundation, 2023). However, complementary policies are needed to also enable a greater diversification to address challenges arising from a disproportionate role currently played by China in the global battery and (although to a lower extent) EV value chain.

4.2.1 Policies that can stimulate a market shift from large and heavy ICEVs towards small EVs

Fiscal tools like differentiated taxation based on environmental performance of vehicles can strengthen an inclusive pathway to EV adoption. They are applicable to privately owned and company cars.[31] Programs like the French social leasing for electric cars (IDDRI and T&E, 2023), financed by carbon pricing or other forms of differentiated taxation, can improve access to EVs for lower-income groups and small businesses, adding an equity dimension to differentiated vehicle taxes based on environmental performance. Such programs can also incentivize manufacturers to offer affordable EV models, as they increase demand for high volume EV sales of smaller models.

Fiscal instruments, such as the use of footprint and/or weight as determinants of the way vehicles are taxed, can help effectively limit size and weight increase (FIA Foundation, 2023) and to support the promotion of both small EVs and multimodality (ITF, 2023). Differentiated taxation can also be extended to used vehicle imports, as in the case of Greece, New Zealand and other countries – for example in the Western Balkans and in Central Asia – that are heavily reliant on second-hand vehicle trade for their motorisation.

Fiscal policies such differentiated circulation taxes, growing with vehicle age, for ICEVs. can also strengthen the technology transition encouraging a faster fleet renewal than what would otherwise occur. Complementing them with redistributional measures would ensure access to clean vehicles for parts of society that cannot afford the change, that cannot access alternative mobility options, and that are therefore at risk to see their mobility disproportionately constrained.

Regulations requiring a progressive shift to EVs are most relevant in cases where the total cost of ownership is already favourable, i.e. for highly utilized vehicles, which can be the targets of specific, more ambitious, obligations. Company and public fleets are also amongst subsets of vehicles that can be subject to specific regulatory requirements.[32] One example in the case of France, where targeted requirements for public fleets have been foreseen as early as 2019 and where binding implementing obligation are currently being discussed (Feizt, 2025, Adam, 2024, Leseul and Fievet, 2025).

[31] For company cars, the recent reform developed in Belgium stands out as one of the best practices (ERM, 2024).

[32] A weaker version of these regulations is the case of commitments from private sector entities can complement and exceed policy requirements to facilitate increased EV adoption.

Measures reducing exposure to unexpected changes in the residual value of vehicles, such as guarantees of capital recovery (SIDBI, 2024), can complement differentiated taxation and regulatory obligations, helping hedge risks that may arise from rapid technology progress. Actors that can underwrite the risk reduction are not limited to public authorities but also include manufacturers (e.g. through leasing frameworks), insurance companies, commercial banks, corporate fleet buyers and subscription service providers.

Like taxation, regulatory requirements can also integrate specific features promoting the reversal of vehicle footprint and weight increases. These include caps, corporate-average reduction in footprint and/or weight and the use of footprint, rather than weight as a discriminant for the way CO_2 emission regulations apply across vehicles, to enable weight reduction as a compliance strategy (FIA Foundation, 2023). Policy makers can also reassess energy efficiency and emission requirements if they are less stringent for larger and heavier vehicles – as in the case of the United States (NHTSA, 2024) and the European Union (European Union, 2023). The fact that there are greater margins for energy savings from electrification in larger and heavier vehicles (as shown in Figure 12) provides a case for making regulations more stringent for larger/heavier vehicles. However, the regulatory stringency should also be set up in a way that requires investment in EVs across all market segments to preserve consumer choice and foster the supply of affordable EVs.

Regulations can also be applied to new and second-hand vehicles, for which cooperative efforts with developed economies can bring major improvements in terms of roadworthiness and better alignment with safety and environmental standards (FIA Foundation, 2023). Specific regulations on battery capacities can also complement those applied to vehicles to limit increases in battery size, and, with it, parallel growth in EV weight, size and upward pressure on costs (FIA Foundation, 2023).

These obligations can help making more affordable EVs available in the local second-hand vehicle market (Climate Group, n.d.). They can also have positive spillovers for local development of EV charging infrastructure (thanks to higher rates of use, with more EVs on the road).

Complementary regulations, such as restrictions of circulation of older, more polluting vehicles, are also important to steer away consumer preferences from large, aged, ICEVs, in favour of smaller, more affordable EVs.

Regulations, incentives and other policy instruments can enable both the mobilization of private **investments for EV charging** and the provision of universal access to charging. As these are in line with the need to ensure a “right to plug”, they are also well suited to support demand for more affordable and likely smaller EVs by lower income households and businesses.[33]

Key examples include measures facilitating the installation of charging points at a limited cost in buildings and parking facilities, programs to deploy on-demand charging points, incentives for the investment of private operators in charging hubs, the creation of a regulatory and support framework for highway-based fast charging stations (French Ministry of Ecological Transition, 2019) and the use of public service contracts (eventually including the bundling of different locations) for minimum deployment.[34]

Studies have shown that owning a smaller EV and charging it more frequently can be cheaper over the lifetime of the vehicle than owning a larger EV and charging less frequently (Poupinha & Dornoff, 2024).

Policies supporting cost-effective increases in low-carbon electricity generation and the cost-effective integration of EVs and the electricity grid can also support EV adoption by making EVs more cost-competitive on a total cost of ownership basis (Hildemeier et al. 2019, Muratori, 2024). In turn, increased electricity demand from EVs can provide an opportunity for structuring investments for the development of electricity grids and, in emerging economies, to enhance access to electricity.

Easing access to affordable capital, including with the support of multilateral development banks (MDBs) for infrastructure-related investments (e.g. EV chargers and grids) can also help level the playing field between developed and developing economies.

4.2.2 Complementary policies, addressing over-dependency challenges and other trade-related risks

Due to the structural disadvantage in terms of competitiveness for EV and battery manufacturing outside of China, complementary policies need to integrate **stronger support for research and innovation**. This should focus on the acceleration of the readiness of advanced and material-efficient battery technologies, as well as technologies and processes capable of delivering productivity increases in battery manufacturing and upstream steps of the battery value chain (European Commission: DG for Research and Innovation, 2024).

End-of-life vehicle, battery and material recycling is also a crucial area of technology development for EVs, as they are poised to provide a major alternative to continued reliance on primary critical minerals. Battery recycling is also set to gain increasing

[33] International technical standards related with EV charging can also accelerate the adoption of electric vehicles if aligned with an open approach, encouraging innovation and reducing costs.
[34] These contracts can require installation of charging points and grant licenses to operate them to mobility service providers through competitive tenders that – as in the case of other public services – may include partial cost coverage and/or risk management, while also setting affordability-related upper boundaries on electricity prices for customers.

relevance in decarbonising economies, due to the lower energy intensity of secondary material supplies, which, as explained previously, is particularly relevant in the case of aluminium. While this underscores the relevance of research and innovation support in battery second life, recycling and end-of-life management, it does not diminish the importance of a global approach to economic circularity. This global approach is necessary to enable access to cheaper second-hand EVs in markets currently heavily reliant on second hand vehicle imports, while also making sure that environmental and safety risks at end-of-life of EVs are minimized (Kendall et al., 2023).

Research and innovation support can also facilitate productivity gains in the way in which EVs and their batteries are designed, manufactured, operated and serviced (Draghi, 2024). Specific research projects focused on product innovation and diversification can also be especially relevant to scale up smaller EVs and help scale software-defined vehicles faster, and not only in premium segments. Deployment-oriented research is also needed to anticipate and govern the challenges for the stability of governmental revenues of the EV transition (European Commission: DG for Research and Innovation, 2024) – a challenge that cannot by any means be solved by transitioning from large ICEVs towards smaller EVs.

A common feature of policies that could support increased diversification in the battery supply chain, while making room for investments aimed to recover competitiveness, is the integration of a set of **specific conditionalities through non-discriminatory non-price criteria**. These may apply for the definition of regulatory requirements regarding batteries, raw material supplies and the processing of intermediate products in the battery supply chain and to economic instruments aiming to stimulate investment in more geographically diverse industrial capacity, such as fiscal incentives and grants.

To ensure alignment with free trade rules while also supporting greater supply chain diversification, these can leverage safety, quality, environmental, social and security-related aspects. Safety and quality requirements can incorporate durability requirements and other technical aspects, regarding interoperability of systems. Environment-related aspects can include consideration of carbon intensity of components, based on a life-cycle approach, as well as recyclability, traceability and minimum recycled content of materials, and, more broadly, supply-chain transparency-related requirements. Social considerations can include local recruitment and apprenticeship clauses. Cybersecurity is particularly relevant for security-related considerations, due to the integration of cameras and sensors in cars (Sebastian et al. 2023), the relevance of EV charging/discharging processes for advanced and smart electricity grids, their potential manipulation (Aljohani and Almutairi, 2024), and the strong impact that software-based tools have on the operation of industrial complexes, including via remote shutdowns (Baazil et al., 2024).

A concrete example of a policy factoring in these kinds of conditionalities exists in France. In this case, eligibility for demand-side purchase incentives for low-emissions vehicles is conditional on: (i) the vehicle meeting minimum carbon footprint requirements, as measured based on a life-cycle perspective), (ii) the use of recycled and bio-sourced materials, and (iii) battery repairability characteristics (ADEME, n.d., Légifrance, 2025). Other examples of legislation that incorporate the above-mentioned aspects are based on the use of interoperable software and hardware and regulatory requirements related with the traceability and transparency of mining and mineral processing activities.[35]

Non-price criteria based on environmental, local employment, and transparency requirements can also be used to define the conditions for access public funds (for research, innovation and public procurement). In the EU, these are already foreseen by the Net Zero Industry Act for renewable energy auctions (European Union, 2024). Their use could be extended to bankable, output-based funding and incentive programmes for increased diversification of battery supply chains, if these State aid instruments can be developed in a way that aligns with international trade rules.

Requirements on technology and intellectual property transfer and local content/labour or value-added requirements may also complement these tools, but they bear greater risks of a decoupling of trade policy from its governance by a clear set of principles. This is something that risks creating perverse and openly protectionist incentives, ultimately undermining the creation of a resilient and competitive industry (Draghi, 2024).

The use of these tools could help favour the relocation of productive capacities in a way that increases the diversification of the value chain (Hermine, 2024, Sebastian et al. 2023).

Choices to be developed in this context by industry and governments will also need to **leverage EV market growth** to foster a positive investment dynamic across the automotive ecosystem. This is key to enable increases in capacity utilisation and other positive impacts for increased competitiveness (Hermine, 2024). A focus on smaller, more affordable EV models can play a key role in unlocking this positive, growth-oriented market dynamic.

Securing a resilient and cost-effective market shift towards EVs may also benefit from the **development of joint ventures** with companies that have acquired a competitive advantage in specific countries (including China, Korea and Japan, in the case of EV batteries) **or the reliance on licensing agreements** for investments in other global regions (Lombardo et al., 2025). This could enable legacy automotive manufacturers to partner and learn from the most advanced battery makers while also stimulating an

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[35] The latter is an area that is subject to the continuous development of standards that define best practices, e.g. by the Initiative for Responsible Mining Assurance (IRMA, n.d.).

accelerated catch up in the industry, through competition dynamics (Autor and Hanson, 2025). Coordination regarding foreign direct investment decisions could strengthen opportunities to avoid unwelcome concessions in the context of potential security threats and where geopolitical rivals are involved (Draghi, 2024). It could also help retaining critical know-how (Draghi, 2024).

The development of joint ventures is an option already being pursued in a number of cases, are recently announced in the case of Stellantis and CATL (Stellantis, 2024), Ford is manufacturing batteries through licensing agreements with CATL in the United States, and GM also has similar plans (Zhang, 2024). Other cases supporting geographical diversification of battery manufacturing are based on the combination of direct investments by battery producers in different geographies and supply agreements with automotive manufacturers, as in the case of Mercedes and CATL in Europe (Mercedes-Benz, 2022).

Major Chinese battery manufacturers have leveraged their technological progress on EVs and battery supply chain by developing greenfield investments and deploying new productive capacity in other countries (Sebastian, 2023). While these have helped manage risks of industrial capacity losses for legacy technologies (subject to losses in market shares due to EVs) and have promoted the creation of new industrial capacity, better coordination in countries that attracted the investments could have offered better opportunities to ensure the transfer and further development of relevant know-how and leverage it for further innovation (Draghi, 2024). For example, placing a greater focus on new technologies, while also engaging with industrial partners in other countries, such as Korea and Japan, could have improved the current competitiveness of Western automotive and EV battery companies (Sebastian, 2023).

Despite some signals that licensing deals and joint ventures are also occurring at the level of cathode, anode, electrolyte and separator components, with examples in France (Reuters, 2024), battery cell and pack manufacturing capacity are currently diversifying faster than the upstream segments of the battery value chain (Moherenhout, 2024).

Progress on increased diversification of battery value chains will also need to overcome additional challenges emerging recently, due to the recent announcement by China on the restriction of efforts to transfer out of China key technologies for manufacturing EV batteries (Bradsher, 2025).

Governmental steering towards smaller vehicles may also be supported by **temporary trade tariffs** (which – to align with international trade rules, can leverage evidence of different forms of production incentives, in China) or by **negotiated price undertakings**, paired with industrial choices and policy decisions capable to improve productivity. This is likely more effective if developed without trade obstacles across economies that need to catch up (Autor and Hanson, 2025). It also requires coordination with close trading partners (to prevent indirect trade, while also ensuring access to affordable EVs, especially in low-income countries[36]) and calls for an acceleration of strategies enhancing product diversification and productivity improvements, especially but not only in premium market segments.[37]

A risk associated with trade tariffs and conditional access to policies supporting EV demand and supply lies in price increases for consumers. Addressing this challenge is possible by refocusing EV deployment toward smaller vehicles, seeking large volumes and more frequent replacement of vehicles in circulation as a profit maximisation strategy, rather than maintaining a focus on sales of larger, heavier and more expensive vehicles (which results in detrimental environmental, energy and mineral security implications).

Increasing the geographical diversity in the EV and battery supply chain also requires **other trade policy actions related mineral sourcing**, since some of the capital needed to mobilize investments will move across borders, as will raw and processed material/products (including semi-finished products), and supplies. Policies securing greater capital availability for investments in the different steps of a geographically diverse battery supply chains, and therefore also enabling better and more secure access to raw, processed materials and battery components, thanks to open trade, are particularly important in this context, also to counter the implications of the recent US trade tariffs.

Promoting responsible material sourcing practices could be instrumental to steer investments – including those made by major international extractive companies – towards greater diversification, as long as they also offer opportunities to generate value from product diversification. In the case of the European Union, for example, joint international supply auctions – such as those already foreseen in the EU Critical Raw Materials Act – can integrate minimum requirements in terms of transparency for sustainable sourcing, while also remaining open to competition (European Commission: DG for Research and Innovation, 2024).

[36] A key example is provided by the EU and the Balkans, in this respect.

[37] This is because premium market segments risk being more exposed to international competition, unless tariffs or price undertakings – which would anyway need to be temporary to ensure industrial resilience through competitiveness beyond the near term – can be differentiated across segments. A key reason for this greater exposure is the larger price of vehicles in premium segments, leaving greater room to lower-cost producers to overcome the impact of flat tariffs or price undertakings, in comparison with vehicles in cheaper market segments.

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