Global EV Outlook 2024

Moving towards increased affordability

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Abstract

The Global EV Outlook is an annual publication that identifies and assesses recent developments in electric mobility across the globe. It is developed with the support of members of the Electric Vehicles Initiative (EVI).

Combining analysis of historical data with projections – now extended to 2035 – the report examines key areas of interest such as the deployment of electric vehicles and charging infrastructure, battery demand, investment trends, and related policy developments in major and emerging markets. It also considers what wider EV adoption means for electricity and oil consumption and greenhouse gas emissions. The report includes analysis of lessons learned from leading markets, providing information for policy makers and stakeholders on policy frameworks and market systems that support electric vehicle uptake.

This edition also features analysis of electric vehicle affordability, second-hand markets, lifecycle emissions of electric cars and their batteries, and grid impacts from charging medium- and heavy-duty electric trucks. Two online tools are made available alongside the report: the Global EV Data Explorer and the Global EV Policy Explorer, which allow users to interactively explore EV statistics and projections, and policy measures worldwide.

Acknowledgements, contributors and credits

The *Global EV Outlook 2024* was prepared by the Energy Technology Policy (ETP) Division of the Directorate of Sustainability, Technology and Outlooks (STO) of the International Energy Agency (IEA). The project was designed and directed by Timur Gül, Chief Energy Technology Officer. Araceli Fernandez Pales, Head of the Technology Innovation Unit, provided strategic guidance throughout the development of the project. Elizabeth Connelly co-ordinated the analysis and production of the report.

The principal IEA authors were (in alphabetical order): Oskaras Alšauskas, Elizabeth Connelly, Mathilde Huismans, Ethan Jenness, Javier Jorquera Copier, Jean-Baptiste Le Marois, Teo Lombardo, Shane McDonagh, Vera O'Riordan, Apostolos Petropoulos and Jules Sery. Yoshihisa Tsukamoto and Biqing Yang contributed to the research on EV supportive policies and OEM electrification plans. Vedant Sinha contributed to analysis on EV price parity and data management. Anthony Vautrin contributed to the analysis on total and net load impacts of electric truck charging, Hikaru Ito and Hasti Wiandita contributed to research on Indonesia.

Valuable insights and feedback were provided by senior management and other colleagues from across IEA, including Laura Cozzi, Keisuke Sadamori, Brian Motherway, Alessandro Blasi, Toril Bosoni, Dennis Hesseling, Stéphanie Bouckaert, Alexander Bressers, Federico Callioni, Shobhan Dhir, Ciaran Healy, Thomas Spencer and Jacques Warichet. Per-Anders Widell provided essential support throughout the process. Lizzie Sayer edited the manuscript.

Special thanks go to Prof. Andreas Ulbig and his team at RWTH Aachen University (Andreas Bong and Chris Vertgewall) for their analytical input on electric heavy-duty vehicle integration in electricity grids.

Thanks go to the IEA's Communications and Digital Office, particularly to Jethro Mullen, Poeli Bojorquez, Curtis Brainard, Jon Custer, Hortense de Roffignac, Astrid Dumond, Merve Erdil, Grace Gordon, Julia Horowitz, Oliver Joy, Isabelle Nonain-Semelin, Clara Vallois, Lucile Wall and Wonjik Yang.

The work could not have been achieved without the financial support provided by the EVI member governments and the funds received through the Global E-Mobility Programme funded by the Global Environment Facility (GEF).

The report benefited from the high-calibre data and support provided by the following colleagues: Nissa Alexander (Department of Economic Development, Transport and Civil Aviation, Saint Lucia); Mozah Mohamed Alnuaimi (Ministry of Energy and Infrastructure, United Arab Emirates); Carlos Andrés Álvarez Álvarez (Ministry of Mines and Energy, Colombia); Soukaina Boudoudouh (IRESEN, Morocco); Klaas Burgdorf (Swedish Energy Agency); Bryan Cancán (MINAM, Peru); Pamela Castillo (Ministry of Energy, Chile); Adonay Urrutia Cortez (General Directorate for Energy, El Salvador); Laurent Demilie (Federal Public Service Mobility and Transport, Belgium); Albert Dessi (Department of Climate Change, Energy, the Environment and Water, Australia); Joanna Dobek (Ministry of Climate and Environment, Poland); Alexandra Doyle-Franklin (Energy Efficiency and Conservation Authority, New Zealand); Isabel Del Olmo Flórez (Institute for Diversification and Saving of Energy, Spain); Camille Gautier (Ministry of Ecological Transition, France); Fatima Habib (Office for Zero Emission Vehicles, United Kingdom); Jón Ásgeir Haukdal Þorvaldsson (National Energy Authority of Iceland); Tim Jonas (NREL, United States); Federico Karagulian (ENEA, Italy); Sky Liu (China Society of Automotive Engineers); Leticia Gonçalves Lorentz (EPE, Brazil); Toke Rueskov Madsen (Centre for Systems Analysis, Denmark); Gereon Meyer (VDI/VDE Innovation + Technik GmbH, Germany); Elvis Octave (Seychelles Public Transport Corporation); Hiten Parmar (The Electric Mission, South Africa); Xiaorong Qiao (Transport Canada); Daniel Schaller (Swiss Federal Office of Energy); Chizu Sekiguchi (METI, Japan); Daniel Thorsell (Norwegian Public Roads Administration); Sai Santhosh Tota (VTT, Finland); Katerina Tourtora (Ministry for Environment and Energy, Greece); Alexandre Videira (Mobi.E, Portugal); Sacha Scheffer (RVO, the Netherlands); and Nahum Yehoshua (Ministry of Energy, Israel).

The following peer reviewers provided essential feedback to improve the quality of the report: Nelson Humberto Acevedo Hurtado (Ministry of Environment and Sustainable Development, Colombia); Appurva Appan and Juan Camilo Ramirez Arjona (Ricardo AEA); Doris Agbevivi (Energy Commission, Ghana); Mozah Mohamed Alnuaim (Ministry of Energy and Infrastructure, United Arab Emirates); Dina Bacovski (AMF TCP); Edgar Barassa (Barassa & Cruz Consulting); Daniel Barber (Energy Efficiency and Conservation Authority, New Zealand); Harmeet Bawa (Hitachi Energy); Berkan Bayram (TEHAD, Türkyie); Thomas Becker (BMW); Filippo Berardi (GEF); Annika Berlin (UNEP); Ekta Meena Bibra (Clean Energy Canada); Georg Bieker (ICCT); Tomoko Blech (CHAdeMO); Giorgios Bonias (Shell); Victor Bonilla and Tali Trigg (EBRD); Angelique Brunon (TotalEnergies); Carol Burelle, Ocktaeck Lim and Xiao Lin (HEV TCP); Klaas Burgdorf (Swedish Energy Agency); Ryan Castilloux (Adams Intelligence); Pierpaolo Cazzola (UC Davis); Jianhua Chen (Energy Foundation China); Yong Chen and Nicholas Wagner (IRENA); Tom Courtright (Africa E-Mobility Alliance); Matteo Craglia (ITF); François Cuenot (UNECE); Ilka von Dalwigk (Innoenergy - European

Battery Alliance); Laurent Demilie (Federal Public Service Mobility and Transport, Belgium); Albert Dessi (Department of Climate Change, Energy, the Environment and Water, Australia); Michael Dwyer (EIA, United States); Heloísa Borges Bastos Esteves (EPE, Brazil); Hiroyuki Fukui (Toyota); Yariv Gabay (Ministry of Finance, Israel); Sebastian Galarza (Center for Sustainable Mobility); Camille Gautier (Ministry of Ecological Transition, France); Catherine Girard (Renault-Nissan-Mitsubishi Alliance); Fatima Habib (Office for Zero Emission Vehicles, United Kingdom); Stephan Healey, Joe Homsy, Xiaorong Qiao and Paula Vieira (Transport Canada); Anders Hove (Oxford Institute for Energy Studies); Antonio Iliceto (Terna); Viktor Irle and Neil King (EV Volumes); Daisy Jennings-Gray (Benchmark Mineral Intelligence); Tim Jonas (NREL, United States); Hiroyuki Kaneko (Nissan Motor); Tarek Keskes and Yanchao Li (World Bank); Stephanie Kodish and Joseph Teja (CALSTART - Drive to Zero); Francisco Laveron (Iberdrola); Toke Rueskov Madsen (Danish Energy Agency); Maurizio Maggiore (Independent); Urs Ruth (Bosch); Hans Eric Melin (Circular Energy Storage); Gian Paolo Montoya (EPM, Colombia); Samir Mulgaonkar (Department of Transport, California); Andi Novianto (Coordinating Ministry for Economic Affairs, Indonesia); Marcin Nowak (Polish Chamber of E-Mobility); Elvis Octave (Government of Seychelles) Mario Duran Ortiz (Independent); Jared Ottmann (Tesla); Sarbojit Pal (CEM Secretariat); Sara Pasquier (Fastned); Davide Puglielli and Emanuela Sartori (Enel); Aleksander Rajch (Polish Association of Alternative Fuels); Taylor Reich (ITDP); Huanhuan Ren (CATARC, Automotive Data of China); Sandra Roling (The Climate Group); Sacha Scheffer (Ministry of Infrastructure and Water Management, the Netherlands); Wulf-Peter Schmidt (Ford); Robert Spicer (BP); Jacopo Tattini (European Commission); Danilo Teobaldi (NIO); Jacob Teter (Independent); Lyle Trytten (Independent); Bianka Uhrinova (Equinor); Andreas Ulbig (RWTH Aachen); Ulderico Ulissi and Liu Ziyu (CATL); and Adonay Urrutia (General Directorate for Energy, El Salvador).

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Executive summary

Growth in electric car sales remains robust as major markets progress and emerging economies ramp up

Electric car sales keep rising and could reach around 17 million in 2024, accounting for more than one in five cars sold worldwide. Electric cars continue to make progress towards becoming a mass-market product in a larger number of countries. Tight margins, volatile battery metal prices, high inflation, and the phase-out of purchase incentives in some countries have sparked concerns about the industry's pace of growth, but global sales data remain strong. In the first quarter of 2024, electric car sales grew by around 25% compared with the first quarter of 2023, similar to the year-on-year growth seen in the same period in 2022. In 2024, the market share of electric cars could reach up to 45% in China, 25% in Europe and over 11% in the United States, underpinned by competition among manufacturers, falling battery and car prices, and ongoing policy support.

Growth expectations for 2024 build on a record year: in 2023, global sales of electric cars neared 14 million, reaching 18% of all cars sold. This is up from 14% in 2022. Electric car sales in 2023 were 3.5 million higher than in 2022, a 35% year-on-year increase. This indicates robust growth even as many major markets enter a new phase, with uptake shifting from early adopters to the mass market. Over 250 000 electric cars were sold every week last year, more than the number sold in a year just a decade ago. Chinese carmakers produced more than half of all electric cars sold worldwide in 2023, despite accounting for just 10% of global sales of cars with internal combustion engines.

The pace at which electric car sales pick up in emerging and developing economies outside China will determine their global success. The vast majority of electric car sales in 2023 were in China (60%), Europe (25%) and the United States (10%). By comparison, these regions accounted for around 65% of total car sales worldwide, showing that sales of electric models remain more geographically concentrated than those of conventional ones. While electric car sales in emerging economies have been lagging those in the three big markets, growth picked up in 2023 in countries such as Viet Nam (around 15% of all cars sold) and Thailand (10%). In emerging economies with large car markets, shares are still relatively low, but several factors point to further growth. Policy measures such as purchase subsidies and incentives for electric vehicle (EV) and battery manufacturing are playing a key role. In India (where electric cars have a 2% market share), the Production Linked Incentives (PLI) Scheme is supporting domestic manufacturing. In Brazil (3% share), Indonesia, Malaysia (2% share each), and Thailand, cheaper models, mainly from Chinese brands, are underpinning uptake. In Mexico, EV supply chains are rapidly developing, stimulated by access to subsidies from the US Inflation Reduction Act (IRA).

Policy support is boosting industry investment, building confidence that rapid electrification will continue

Every other car sold globally in 2035 is set to be electric based on today's energy, climate and industrial policy settings, as reflected in the IEA's Stated Policies Scenario. This has significant impacts on the car fleet. As soon as 2030, almost one in three cars on the roads in China is electric in this scenario, and almost one in five in both the United States and European Union. The rapid uptake of EVs of all types – cars, vans, trucks, buses and two/three-wheelers – avoids 6 million barrels per day (mb/d) of oil demand in the Stated Policies Scenario in 2030, and over 10 mb/d in 2035. This is equivalent to the amount of oil used for road transport in the United States today. Recent policy developments continue to reinforce expectations for swift electrification, such as new emissions standards adopted in Canada, the European Union and the United States over the past year. Industrial incentives – such as those in the US IRA, the EU Net Zero Industry Act, China's 14th Five-Year Plan, and India's PLI scheme – also encourage adding value and creating jobs across EV supply chains in those economies. If all the national energy and climate targets made by governments are met in full and on time, as in the Announced Pledges Scenario, two-thirds of all vehicles sold in 2035 could be electric, avoiding around 12 mb/d of oil.

Expectations of strong growth are bolstering investment in the EV supply chain. Recent reporting shows that from 2022 to 2023, investment announcements in EV and battery manufacturing totalled almost USD 500 billion, of which around 40% has been committed. Over 20 major car manufacturers, representing more than 90% of global car sales in 2023, have set electrification targets. Taking the targets of all the largest automakers together, more than 40 million electric cars could be sold in 2030, which would meet the level of deployment projected under today's policy settings.

Enough battery manufacturing capacity has reached a final investment decision to deliver on announced pledges from automakers and governments globally. Thanks to high levels of investment in the past 5 years, global EV battery manufacturing capacity far exceeded demand in 2023, at around 2.2 terawatt-hours and 750 gigawatt-hours, respectively. Demand is likely to grow quickly: up seven times by 2035 compared with 2023 in the Stated Policies Scenario, nine times in the Announced Pledges Scenario, and 12 times in the Net Zero Emissions by 2050 Scenario, which lays out a pathway to reach net zero energy sector emissions by mid-century. Manufacturing capacity appears capable of keeping pace with demand: committed and existing battery manufacturing capacity alone are practically aligned with the needs in a net zero pathway in 2030. Such prospects are opening significant opportunities across the supply chain for battery and mining companies, including in emerging markets outside China, although surplus capacity has been hurting margins and may lead to further market consolidation.

The pace of the transition to electric vehicles hinges on their affordability

Electric cars are getting cheaper as competition intensifies, particularly in China, but they remain more expensive than cars with internal combustion engines in other markets. A rapid transition to EVs will require bringing to market more affordable models. In China, we estimate that more than 60% of electric cars sold in 2023 were already cheaper than their average combustion engine equivalent. However, electric cars remain 10% to 50% more expensive than combustion engine equivalents in Europe and the United States, depending on the country and car segment. In 2023, two-thirds of available electric models globally were large cars, pick-up trucks or sports utility vehicles, pushing up average prices. When exactly price parity is reached is subject to a range of market variables, but current trends suggest that it could be reached by 2030 in major EV markets outside China for most models.

The pricing strategies of car manufacturers will be crucial for improving affordability, as will the pace of EV battery price decline. Turmoil in battery metal markets in 2022 led to the first price increase for lithium-ion packs, which became 7% more expensive than in 2021. In 2023, however, the prices of the key metals used to make batteries dropped, leading to a near-14% fall in pack prices year-on-year. China still supplies the cheapest batteries, but prices across regions are converging as batteries become a globalised commodity. Lithium-iron-phosphate batteries – which are significantly cheaper than those based on lithium, nickel, manganese and cobalt oxide – accounted for over 40% of global EV sales by capacity in 2023, more than double their share in 2020. Looking ahead, technological innovation will remain important for scaling up novel designs and chemistries such as sodium-ion batteries, which could cost as much as 20% less than lithium-based batteries without requiring any lithium.

In developing economies outside China, more affordable electric car models are arriving, and the future of electric two- and three-wheelers already looks bright. In 2023, 55% to 95% of the electric car sales across major emerging and developing economies were large models that are unaffordable for the average consumer, hindering mass-market uptake. However, smaller and much more affordable models launched in 2022 and 2023 have quickly become bestsellers, especially those by Chinese carmakers expanding overseas. Affordable electric two- and three-wheelers are also already available, helping deliver immediate benefits such as improved air quality and emissions reductions. Around 1.3 million electric two-wheelers were sold in India and Southeast Asia in 2023, accounting for 5% and 3% of total sales, respectively. One in five three-wheelers sold globally in 2023 was electric, and nearly 60% of those sold in India, boosted by the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) subsidy scheme.

As electric vehicle markets mature, second-hand electric cars will become more widely available. In 2023, the market size for used electric cars was around 800 000 in China, 400 000 in the United States, and over 450 000 across France, Germany, Italy, Spain, the Netherlands and the United Kingdom. The prices of used electric cars are falling quickly and becoming competitive with combustion engine equivalents. Looking ahead, international trade of used electric cars is also expected to increase, including to emerging and developing economies outside of China.

The battery recycling industry is getting ready for the 2030s. Recycling and reuse are needed for supply chain sustainability and security. Many technology developers are seeking to position themselves in EV end-of-life markets, but planned locations do not always align with where EV retirement may occur. Global battery recycling capacity reached 300 gigawatt-hours in 2023. If all announced projects materialise, it could exceed 1 500 gigawatt-hours in 2030, of which 70% would be in China. Globally, announced recycling capacity is more than three times the supply of batteries that could potentially be recycled in 2030, as EVs reach their end of life in the Announced Pledges Scenario. However, EV battery retirement is expected to grow rapidly from the second half of the 2030s.

The roll-out of public charging needs to keep pace with EV sales

The global number of installed public charging points was up 40% in 2023 relative to 2022, and growth for fast chargers outpaced that of slower ones. In major EV markets, the deployment of charging points is continuing apace thanks to targeted policies. Broad, affordable access to public charging infrastructure will be needed for a mass-market switch to electric transport and to enable longer journeys – even if most charging continues to take place privately in residential and workplace settings. To reach EV deployment levels in the Announced Policies Scenario, public charging needs to increase sixfold by 2035.

As more electric heavy-duty vehicles such as trucks and large buses hit the road, dedicated and flexible charging is needed. In 2023, electric buses accounted for 3% of total bus sales. Electric truck sales jumped 35% compared with 2022, accounting for about 3% of truck sales in China and 1.5% in Europe. Under today’s policy settings, the stock of electric buses increases sevenfold by 2035 and that of electric trucks around thirtyfold, supported by tougher emissions standards in the United States and European Union. This level of deployment could require a twentyfold jump in charging capacity by 2035 – not only in depots, but also along main transit routes to enable long-distance trucking. Increasing heavy-duty charging has important implications for expanding and operating electrical grids, with opportunities for greater flexibility and renewables integration. Policy support, careful planning and co-ordination will be essential to ensure a secure, affordable and low-emissions supply of electricity with limited strain on local grids.

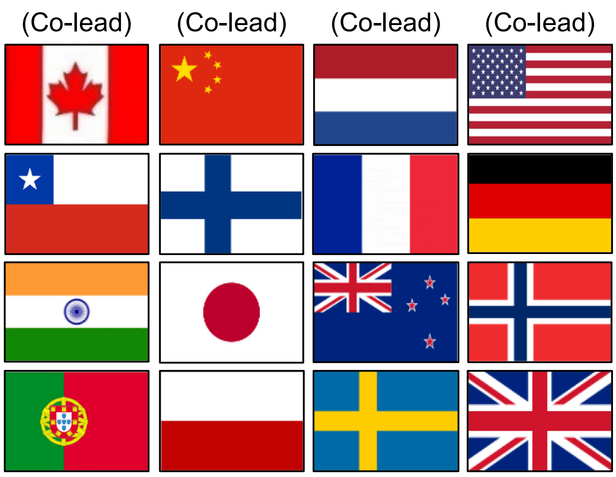
Electric Vehicles Initiative

The Electric Vehicles Initiative (EVI) is a multi-governmental policy forum established in 2010 under the Clean Energy Ministerial (CEM). Recognising the opportunities offered by EVs, the EVI is dedicated to accelerating the adoption of EVs worldwide. To do so, it strives to better understand the policy challenges related to electric mobility, to help governments address them and to serve as a platform for knowledge-sharing among government policy makers. The EVI also facilitates exchanges between government policy makers and a variety of other partners on topics important for the transition to electric mobility, such as charging infrastructure and grid integration as well as EV battery supply chains.

The International Energy Agency serves as the co-ordinator of the initiative. Governments that have been active in the EVI in the 2023-24 period include Canada, Chile, People's Republic of China (hereafter "China"), Finland, France, Germany, India, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden, United Kingdom and United States. Canada, China, the Netherlands and the United States are the co-leads of the initiative.

The Global EV Outlook annual series is the flagship publication of the EVI. It is dedicated to tracking and monitoring the progress of electric mobility worldwide and to informing policy makers on how to best accelerate electrification of the road transport sector.

ELECTRIC VEHICLES INITIATIVE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL



1. Trends in electric cars

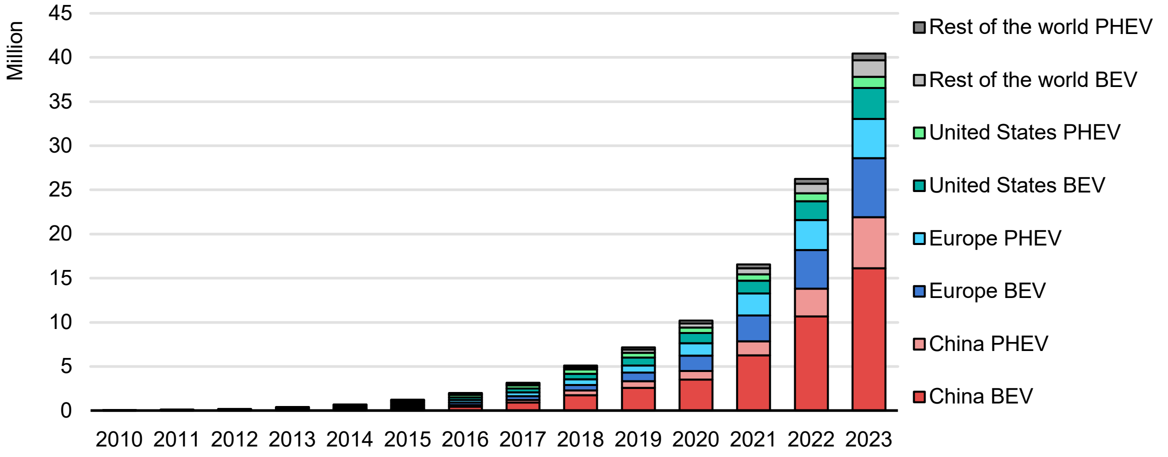
Electric car sales

Nearly one in five cars sold in 2023 was electric

Electric car sales neared 14 million in 2023, 95% of which were in China, Europe and the United States

Almost 14 million new electric cars[1] were registered globally in 2023, bringing their total number on the roads to 40 million, closely tracking the sales forecast from the 2023 edition of the Global EV Outlook (GEVO-2023). Electric car sales in 2023 were 3.5 million higher than in 2022, a 35% year-on-year increase. This is more than six times higher than in 2018, just 5 years earlier. In 2023, there were over 250 000 new registrations per week, which is more than the annual total in 2013, ten years earlier. Electric cars accounted for around 18% of all cars sold in 2023, up from 14% in 2022 and only 2% 5 years earlier, in 2018. These trends indicate that growth remains robust as electric car markets mature. Battery electric cars accounted for 70% of the electric car stock in 2023.

Global electric car stock trends, 2010-2023



Notes: BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle. Includes passenger cars only.
Sources: IEA analysis based on country submissions and data from ACEA, EAFO, EV Volumes and Marklines.

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

While sales of electric cars are increasing globally, they remain significantly concentrated in just a few major markets. In 2023, just under 60% of new electric car registrations were in the People's Republic of China (hereafter "China"), just under 25% in Europe,[2] and 10% in the United States – corresponding to nearly 95% of global electric car sales combined. In these countries, electric cars account for a large share of local car markets: more than one in three new car registrations in China was electric in 2023, over one in five in Europe, and one in ten in the United States. However, sales remain limited elsewhere, even in countries with developed car markets such as Japan and India. As a result of sales concentration, the global electric car stock is also increasingly concentrated. Nevertheless, China, Europe and the United States also represent around two-thirds of total car sales and stocks, meaning that the EV transition in these markets has major repercussions in terms of global trends.

In China, the number of new electric car registrations reached 8.1 million in 2023, increasing by 35% relative to 2022. Increasing electric car sales were the main reason for growth in the overall car market, which contracted by 8% for conventional (internal combustion engine) cars but grew by 5% in total, indicating that electric car sales are continuing to perform as the market matures. The year 2023 was the first in which China's New Energy Vehicle (NEV)[3] industry ran without support from national subsidies for EV purchases, which have facilitated expansion of the market for more than a decade. Tax exemption for EV purchases and non-financial support remain in place, after an extension, as the automotive industry is seen as one of the key drivers of economic growth. Some province-led support and investment also remains in place and plays an important role in China's EV landscape. As the market matures, the industry is entering a phase marked by increased price competition and consolidation. In addition, China exported over 4 million cars in 2023, making it the largest auto exporter in the world, among which 1.2 million were EVs. This is markedly more than the previous year – car exports were almost 65% higher than in 2022, and electric car exports were 80% higher. The main export markets for these vehicles were Europe and countries in the Asia Pacific region, such as Thailand and Australia.

In the United States, new electric car registrations totalled 1.4 million in 2023, increasing by more than 40% compared to 2022. While relative annual growth in 2023 was slower than in the preceding two years, demand for electric cars and absolute growth remained strong. The revised qualifications for the Clean Vehicle Tax Credit, alongside electric car price cuts, meant that some popular EV models became eligible for credit in 2023. Sales of the Tesla Model Y, for example, increased 50% compared to 2022 after it became eligible for the full USD 7 500 tax credit. Overall, the new criteria established by the Inflation Reduction Act (IRA)

[2] Throughout this report, unless otherwise specified, regional groupings refer to those described in the Annex.
[3] In the Chinese context, the term New Energy Vehicles (NEVs) includes BEVs, PHEVs and FCEVs.

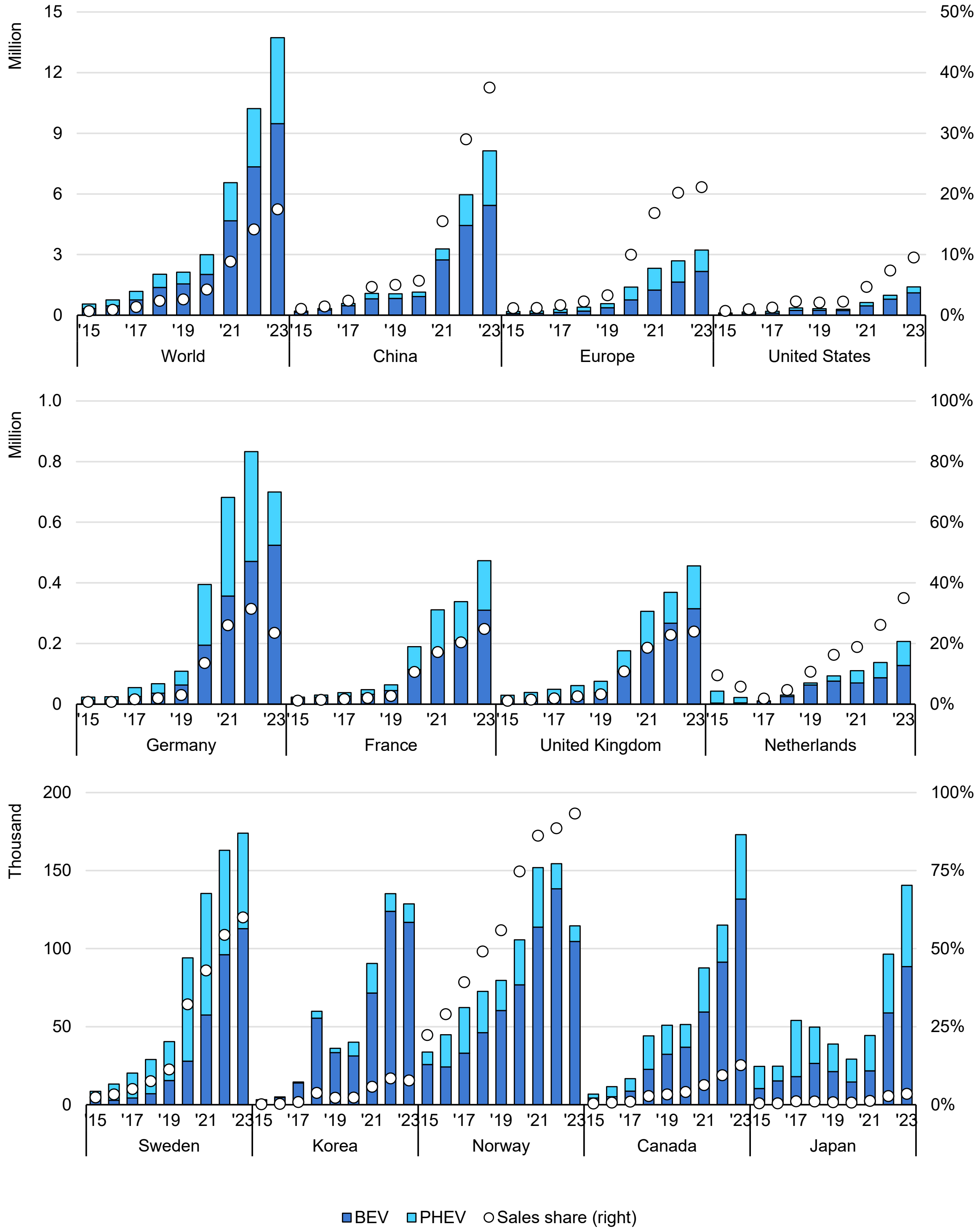
appear to have supported sales in 2023, despite earlier concerns that tighter domestic content requirements for EV and battery manufacturing could create immediate bottlenecks or delays, such as for the Ford F-150 Lightning. As of 2024, new guidance for the tax credits means the number of eligible models has fallen to less than 30 from about 45,[4] including several trim levels of the Tesla Model 3 becoming ineligible. However, in 2023 and 2024, leasing business models enable electric cars to qualify for the tax credits even if they do not fully meet the requirements, as leased cars can qualify for a less strict commercial vehicle tax credit and these tax credit savings can be passed to lease-holders. Such strategies have also contributed to sustained electric car roll-out.

In Europe, new electric car registrations reached nearly 3.2 million in 2023, increasing by almost 20% relative to 2022. In the European Union, sales amounted to 2.4 million, with similar growth rates. As in China, the high rates of electric car sales seen in Europe suggest that growth remains robust as markets mature, and several European countries reached important milestones in 2023. Germany, for example, became the third country after China and the United States to record half a million new battery electric car registrations in a single year, with 18% of car sales being battery electric (and another 6% plug-in hybrid).

However, the phase-out of several purchase subsidies in Germany slowed overall EV sales growth. At the start of 2023, PHEV subsidies were phased out, resulting in lower PHEV sales compared to 2022, and in December 2023, all EV subsidies ended after a ruling on the Climate and Transformation Fund. In Germany, the sales share for electric cars fell from 30% in 2022 to 25% in 2023. This had an impact on the overall electric car sales share in the region. In the rest of Europe, however, electric car sales and their sales share increased. Around 25% of all cars sold in France and the United Kingdom were electric, 30% in the Netherlands, and 60% in Sweden. In Norway, sales shares increased slightly despite the overall market contracting, and its sales share remains the highest in Europe, at almost 95%.

[4] Based on model trim eligibility from the US government website as of 31 March 2024.

Electric car registrations and sales share in selected countries and regions, 2015-2023



Notes: BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle.
Sources: IEA analysis based on country submissions and data from ACEA, EAFO, EV Volumes and Marklines.

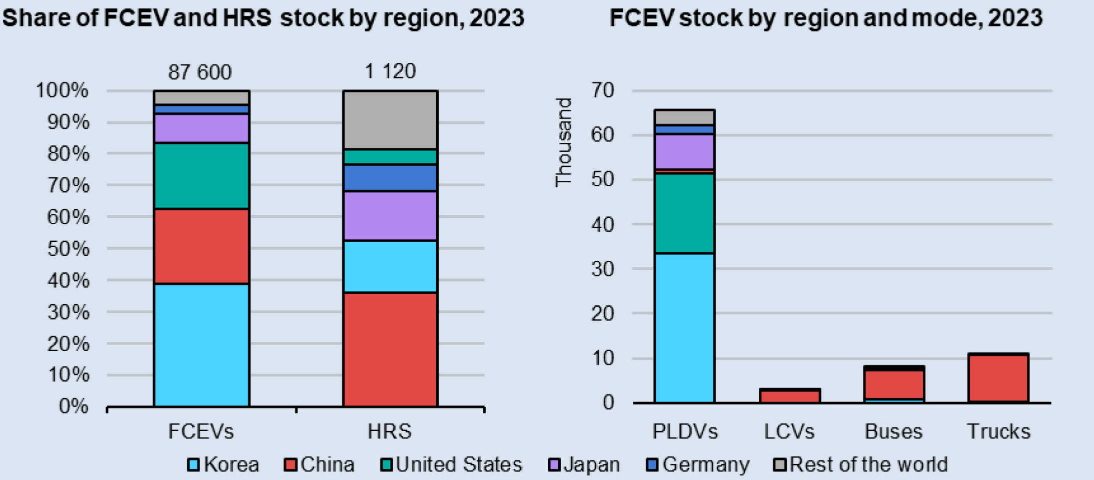
For the first time, China was the front-runner in fuel cell electric vehicle deployment in 2023

In 2023, the global stock of fuel cell electric vehicles (FCEVs) increased by around 20% compared to 2022, reaching 87 600 by the end of the year. Of the 15 400 new FCEVs hitting the roads in 2023, about half were cars, around one-quarter were medium- and heavy-duty trucks, and almost 10% were buses. The fastest-growing segment was light commercial vehicles, for which the stock approximately tripled in 2023, mainly thanks to sales in China. The stock of heavy-duty fuel cell trucks doubled.

At the end of 2023, Asia accounted for over 70% of FCEVs worldwide, followed by North America with 20% and Europe with less than 10%. Korea is the leading country in terms of FCEV stock, accounting for almost 40% of all FCEVs, mainly due to its large passenger car fleet (exceeding 33 000). The United States is home to 18 200 FCEVs, almost all of which are fuel cell cars. The United States has the second-largest fuel cell car stock worldwide, with around 30% of the global stock.

However, in 2023, China became home to the second-largest FCEV fleet, overtaking the United States, and constituting over 20% of the total FCEV stock. Despite having fewer than 800 fuel cell cars, China has the largest fleet across all other segments. It accounts for around 95% of medium- and heavy-duty fuel cell trucks, 90% of fuel cell LCVs, and just over 80% of fuel cell buses. However, China is still some distance – less than halfway – from meeting the government's aim of reaching 50 000 FCEVs by 2025.

Fuel cell electric vehicle and hydrogen refuelling station stock by region, 2023



Notes: FCEVs = fuel cell electric vehicles; HRS = hydrogen refuelling stations; PLDVs = passenger light-duty vehicles; LCVs = light commercial vehicles.
Source: IEA analysis based on data from the Advanced Fuel Cells Technology Collaboration Programme.

For further information on the deployment status of FCEVs and other hydrogen-based technologies, see the IEA Global Hydrogen Review report series.

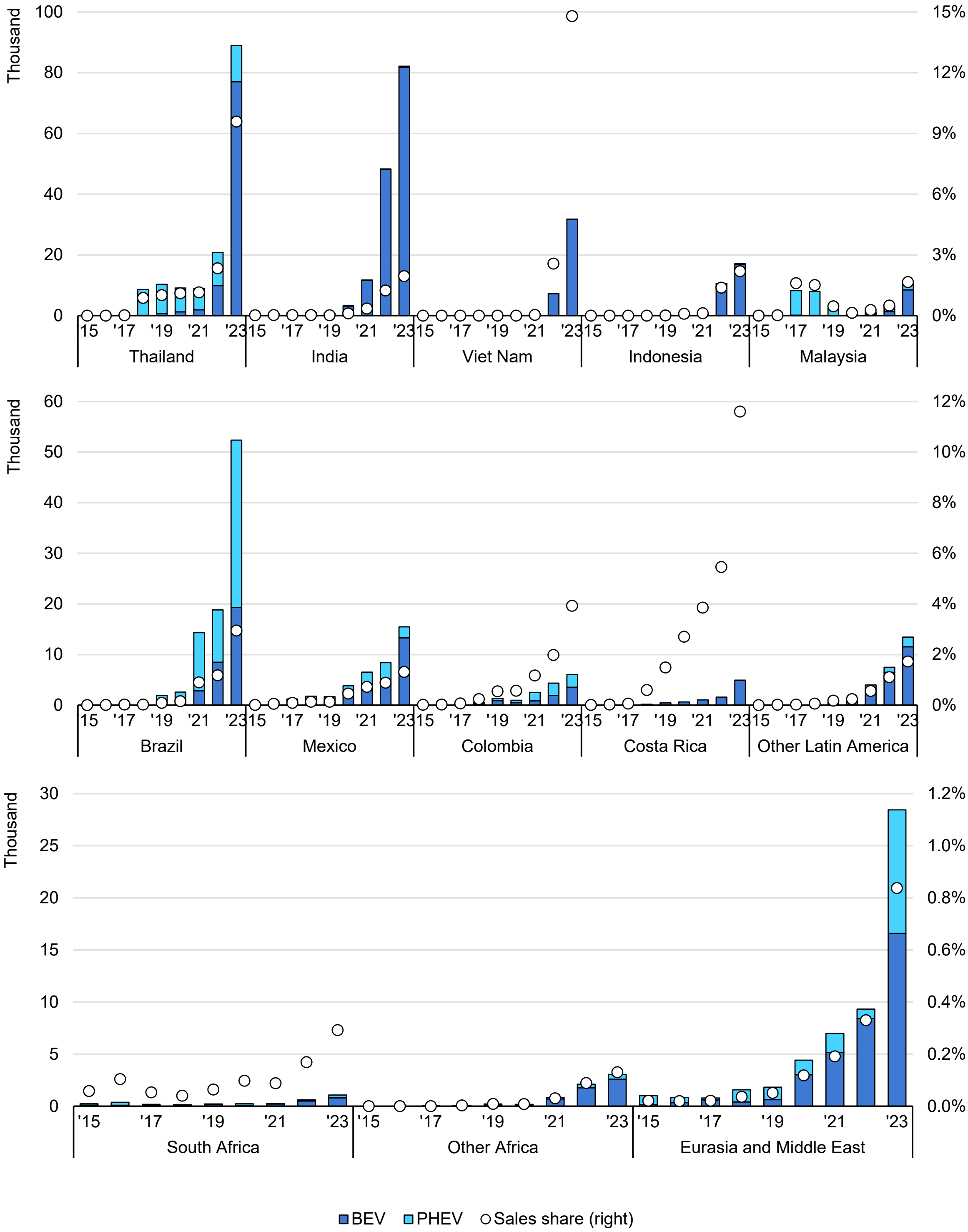
Sales in emerging markets are increasing, albeit from a low base, led by Southeast Asia and Brazil

Electric car sales continued to increase in emerging market and developing economies (EMDEs) outside China in 2023, but they remained low overall. In many cases, personal cars are not the most common means of passenger transport, especially compared with shared vans and minibuses, or two- and three-wheelers (2/3Ws), which are more prevalent and more often electrified, given their relative accessibility and affordability. The electrification of 2/3Ws and public or shared mobility will be key to achieve emissions reductions in such cases (see later sections in this report). While switching from internal combustion engine (ICE) to electric cars is important, the effect on overall emissions differs depending on the mode of transport that is displaced. Replacing 2/3Ws, public and shared mobility or more active forms of transport with personal cars may not be desirable in all cases.

In India, electric car registrations were up 70% year-on-year to 80 000, compared to a growth rate of under 10% for total car sales. Around 2% of all cars sold were electric. Purchase incentives under the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme, supply-side incentives under the Production Linked Incentive (PLI) scheme, tax benefits and the Go Electric campaign have all contributed to fostering demand in recent years. A number of new models also became popular in 2023, such as Mahindra's XUV400, MG's Comet, Citroën's e-C3, BYD's Yuan Plus, and Hyundai's Ioniq 5, driving up growth compared to 2022. However, if the forthcoming FAME III scheme includes a subsidy reduction, as has been speculated in line with lower subsidy levels in the 2024 budget, future growth could be affected. Local carmakers have thus far maintained a strong foothold in the market, supported by advantageous import tariffs, and account for 80% of electric car sales in cumulative terms since 2010, led by Tata (70%) and Mahindra (10%).

In Thailand, electric car registrations more than quadrupled year-on-year to nearly 90 000, reaching a notable 10% sales share – comparable to the share in the United States. This is all the more impressive given that overall car sales in the country decreased from 2022 to 2023. New subsidies, including for domestic battery manufacturing, and lower import and excise taxes, combined with the growing presence of Chinese carmakers, have contributed to rapidly increasing sales. Chinese companies account for over half the sales to date, and they could become even more prominent given that BYD plans to start operating EV production facilities in Thailand in 2024, with an annual production capacity of 150 000 vehicles for an investment of just under USD 500 million. Thailand aims to become a major EV manufacturing hub for domestic and export markets, and is aiming to attract USD 28 billion in foreign investment within 4 years, backed by specific incentives to foster investment.

Electric car sales in selected countries and regions, 2015-2023



Notes: BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle. For regional groupings, see Annex C.
Sources: IEA analysis based on country submissions and data from ACEA, EAFO, EV Volumes, Marklines, Asomove, MDAE, and Andemos.

In Viet Nam, after an exceptional 2022 for the overall car market, car sales contracted by 25% in 2023, but electric car sales still recorded unprecedented growth: from under 100 in 2021, to 7 000 in 2022, and over 30 000 in 2023, reaching a 15% sales share. Domestic front-runner VinFast, established in 2017, accounted for nearly all domestic sales. VinFast also started selling electric sports utility vehicles (SUVs) in North America in 2023, as well as developing manufacturing facilities in order to unlock domestic content-linked subsidies under the US IRA. VinFast is investing around USD 2 billion and targets an annual production of 150 000 vehicles in the United States by 2025. The company went public in 2023, far exceeding expectations with a debut market valuation of around USD 85 billion, well beyond General Motors (GM) (USD 46 billion), Ford (USD 48 billion) or BMW (USD 68 billion), before it settled back down around USD 20 billion by the end of the year. VinFast also looks to enter regional markets, such as India and the Philippines.

In Malaysia, electric car registrations more than tripled to 10 000, supported by tax breaks and import duty exemptions, as well as an acceleration in charging infrastructure roll-out. In 2023, Mercedes-Benz marketed the first domestically assembled EV, and both BYD and Tesla also entered the market.

In Latin America, electric car sales reached almost 90 000 in 2023, with markets in Brazil, Colombia, Costa Rica and Mexico leading the region. In Brazil, electric car registrations nearly tripled year-on-year to more than 50 000, a market share of 3%. Growth in Brazil was underpinned by the entry of Chinese carmakers, such as BYD with its Song and Dolphin models, Great Wall with its H6, and Chery with its Tiggo 8, which immediately ranked among the best-selling models in 2023. Road transport electrification in Brazil could bring significant climate benefits given the largely low-emissions power mix, as well as reducing local air pollution. However, EV adoption has been slow thus far, given the national prioritisation of ethanol-based fuels since the late 1970s as a strategy to maintain energy security in the face of oil shocks. Today, biofuels are important alternative fuels available at competitive cost and aligned with the existing refuelling infrastructure. Brazil remains the world's largest producer of sugar cane, and its agribusiness represents about one-fourth of GDP. At the end of 2023, Brazil launched the Green Mobility and Innovation Programme, which provides tax incentives for companies to develop and manufacture low-emissions road transport technology, aggregating to more than BRA 19 billion (Brazilian reals) (USD 3.8 billion) over the 2024-2028 period. Several major carmakers already in Brazil are developing hybrid ethanol-electric models as a result. China's BYD and Great Wall are also planning to start domestic manufacturing, counting on local battery metal deposits, and plan to sell both fully electric and hybrid ethanol-electric models. BYD is investing over USD 600 million in its electric car plant in Brazil – its first outside Asia – for an annual capacity of 150 000 vehicles. BYD also partnered with Raízen to develop charging infrastructure in eight Brazilian cities starting in 2024. GM, on the other hand, plans to stop producing ICE (including ethanol) models and go fully electric, notably to produce for export markets. In 2024, Hyundai announced investments of USD 1.1 billion to 2032 to start local manufacturing of electric, hybrid and hydrogen cars.

In Mexico, electric car registrations were up 80% year-on-year to 15 000, a market share just above 1%. Given its proximity to the United States, Mexico's automotive market is already well integrated with North American partners, and benefits from advantageous trade agreements, large existing manufacturing capacity, and eligibility for subsidies under the IRA. As a result, local EV supply chains are developing quickly, with expectations that this will spill over into domestic markets. Tesla, Ford, Stellantis, BMW, GM, Volkswagen (VW) and Audi have all either started manufacturing or announced plans to manufacture EVs in Mexico. Chinese carmakers such as BYD, Chery and SAIC are also considering expanding to Mexico. Elsewhere in the region, Colombia and Costa Rica are seeing increasing electric car sales, with around 6 000 and 5 000 in 2023, respectively, but sales remain limited in other Central and South American countries.

Throughout Africa, Eurasia and the Middle East, electric cars are still rare, accounting for less than 1% of total car sales. However, as Chinese carmakers look for opportunities abroad, new models – including those produced domestically – could boost EV sales. For example, in Uzbekistan, BYD set up a joint venture with UzAuto Motors in 2023 to produce 50 000 electric cars annually, and Chery International established a partnership with ADM Jizzakh. This partnership has already led to a steep increase in electric car sales in Uzbekistan, reaching around 10 000 in 2023. In the Middle East, Jordan boasts the highest electric car sales share, at more than 45%, supported by much lower import duties relative to ICE cars, followed by the United Arab Emirates, with 13%.

Policy support in Indonesia is attracting international majors and boosting electric car sales

Until 2019, annual electric car sales in Indonesia were below 100, increasing tenfold to under 1 000 in 2020-2021. In 2022, annual sales jumped to over 10 000, and in 2023 they reached 17 000, supported by purchase incentives. Electric cars benefit from a reduced Value-Added Tax of 1% (compared to 11% for conventional cars), are exempt from the luxury tax that applies to many vehicles, and from import tax, and are eligible for regional tax reductions.

Increasing model availability is also helping boost sales. As in many other countries in the region, foreign carmakers – especially Chinese – are increasingly entering the market. Chinese companies accounted for 75% of electric car sales in 2022, and 45% in 2023. For example, Wuling's Air EV, which is competitively priced relative to conventional cars, at around IDR 220 million (Indonesian rupiah) (USD 14 000), has become a best-seller. Other best-selling models, such as Toyota's Kijang at IDR 420 million (USD 25 000) or Hyundai's Ioniq at IDR 670 million (USD 42 000), remain more expensive than conventional equivalents, appealing to a pool of wealthier early adopters.

In 2023, in order to promote domestic manufacturing, the government of Indonesia limited purchase incentives to models meeting local content requirements of 40%. As of 2023, only two models (Hyundai's Ioniq and Wuling's Air) met this criteria, which, alongside rising interest rates for credit-backed car purchases, may have hampered growth. In 2023, sales fell short of the government's target of subsidising 36 000 electric cars, and at the end of the year, local content requirements were relaxed until 2026. As a result, international companies are now setting up manufacturing facilities in the country, such as BYD and VinFast, both expected in 2024. Available BYD models will be priced at IDR 400 million (USD 25 000), and VinFast at IDR 250 million (USD 16 000). BYD plans to invest USD 1.3 billion in manufacturing facilities with an annual capacity of 150 000 cars, and VinFast to assemble 50 000 cars a year.

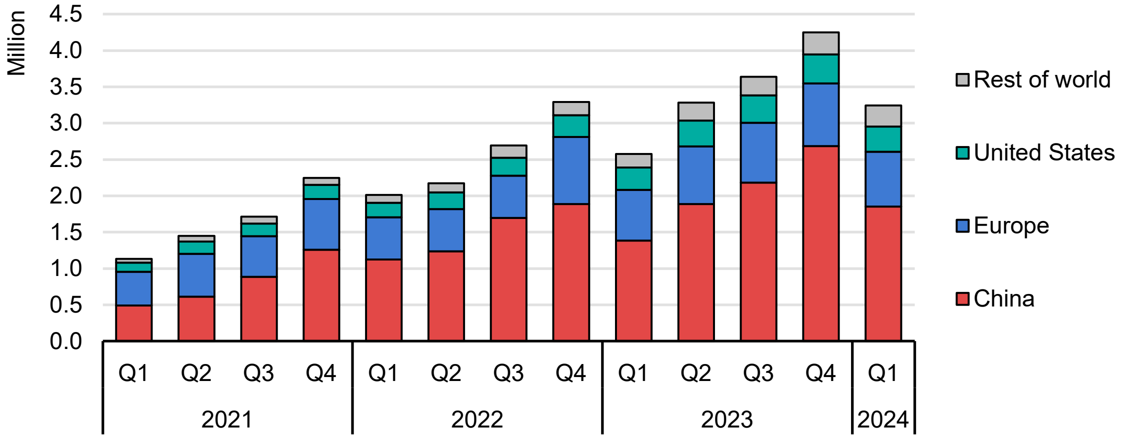
Electric buses and 2/3Ws have not yet experienced the same success. In 2023, Indonesia's 100 electric buses were primarily concentrated in Jakarta, and imported from China; the provincial government aims to add another 200 in 2024. Electric 2/3W sales reached about 11 500 in 2023, well below the government target to subsidise 200 000. Factors limiting 2/3W uptake include low ranges and lack of charging points to enable interurban journeys.

Looking forward, Indonesia aims to have 2 million electric cars and 13 million electric 2/3Ws on the road by 2030. The new capital city will mandate EVs as the main means of transportation. Battery manufacturing capacity is also ramping up, capitalising on rich nickel reserves. In 2024, Indonesia announced a joint venture between Hyundai, LG Energy Solution, and Indonesia Battery Corporation, as part of a IDR 140 trillion (USD 9.8 billion) public support package.

Strong electric car sales in the first quarter of 2024 surpass the annual total from just four years ago

Electric car sales remained strong in the first quarter of 2024, surpassing those of the same period in 2023 by around 25% to reach more than 3 million. This growth rate was similar to the increase observed for the same period in 2023 compared to 2022. The majority of the additional sales came from China, which sold about half a million more electric cars than over the same period in 2023. In relative terms, the most substantial growth was observed outside of the major EV markets, where sales increased by over 50%, suggesting that the transition to electromobility is picking up in an increasing number of countries worldwide.

Quarterly electric car sales, 2021-2024



Source: IEA analysis based on data from on EV Volumes, China Passenger Car Association and the European Automobile Manufacturers' Association.

From January to March of this year, nearly 1.9 million electric cars were sold in China, marking an almost 35% increase compared to sales in the first quarter of 2023. In March, NEV sales in China surpassed a share of 40% in overall car sales for the first time, according to retail sales reported by the China Passenger Car Association. As witnessed in 2023, sales of plug-in hybrid electric cars are growing faster than sales of pure battery electric cars. Plug-in hybrid electric car sales in the first quarter increased by around 75% year-on-year in China, compared to just 15% for battery electric car sales, though the former started from a lower base.

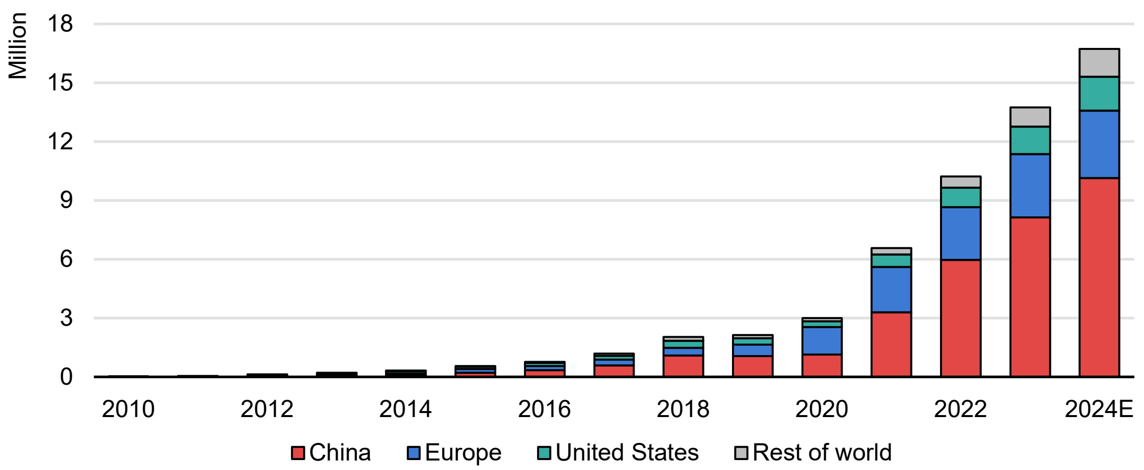
In Europe, the first quarter of 2024 saw year-on-year growth of over 5%, slightly above the growth in overall car sales and thereby stabilising the EV sales share at a similar level as last year. Electric car sales growth was particularly high in Belgium, where around 60 000 electric cars were sold, almost 35% more than the year before. However, Belgium represents less than 5% of total European car sales. In the major European markets – France, Germany, Italy and the United Kingdom (together representing about 60% of European car sales) – growth in electric car sales was lower. In France, overall EV sales in the first quarter grew by about 15%, with BEV sales growth being higher than for PHEVs. While this is less than half the rate as over the same period last year, total sales were nonetheless higher and led to a slight increase in the share of EVs in total car sales. The United Kingdom saw similar year-on-year growth (over 15%) in EV sales as France, about the same rate as over the same period last year. In Germany, where battery electric car subsidies ended in 2023, sales of electric cars fell by almost 5% in the first quarter of 2024, mainly as a result of a 20% year-on-year decrease in March. The share of EVs in total car sales was therefore slightly lower than last year. As in China, PHEV sales in both Germany and the United Kingdom were stronger than BEV sales. In Italy, sales of electric cars in the first three months of 2024 were more than 20% lower than over the same period in 2023, with the majority of the decrease taking place in the PHEV segment. However, this trend could be reversed based on the introduction of a new incentive scheme, and if Chinese automaker Chery succeeds in appealing to Italian consumers when it enters the market later this year.

In the United States, first-quarter sales reached around 350 000, almost 15% higher than over the same period the year before. As in other major markets, the sales growth of PHEVs was even higher, at 50%. While the BEV sales share in the United States appears to have fallen somewhat over the past few months, the sales share of PHEVs has grown.

In smaller EV markets, sales growth in the first months of 2024 was much higher, albeit from a low base. In January and February, electric car sales almost quadrupled in Brazil and increased more than sevenfold in Viet Nam. In India, sales increased more than 50% in the first quarter of 2024. These figures suggest that EVs are gaining momentum across diverse markets worldwide.

Since 2021, first-quarter electric car sales have typically accounted for 15-20% of the total global annual sales. Based on this observed trend, coupled with policy momentum and the seasonality that EV sales typically experience, we estimate that electric car sales could reach around 17 million in 2024. This indicates robust growth for a maturing market, with 2024 sales to surpass those of 2023 by more than 20% and EVs to reach a share in total car sales of more than one-fifth.

Electric car sales, 2010-2024



Note: 2024 sales ("2024E") are estimated based on market trends through the first quarter of 2024.
Source: IEA analysis based on data from EV Volumes (2024) and the China Passenger Car Association (2024).

The majority of the additional 3 million electric car sales projected for 2024 relative to 2023 are from China. Despite the phase-out of NEV purchase subsidies last year, sales in China have remained robust, indicating that the market is maturing. With strong competition and relatively low-cost electric cars, sales are to grow by almost 25% in 2024 compared to last year, reaching around 10 million. If confirmed, this figure will come close to the total global electric car sales in 2022. As a result, electric car sales could represent around 45% of total car sales in China over 2024.

In 2024, electric car sales in the United States are projected to rise by 20% compared to the previous year, translating to almost half a million more sales, relative to 2023. Despite reporting of a rocky end to 2023 for electric cars in the United States, sales shares are projected to remain robust in 2024. Over the entire year, around one in nine cars sold are expected to be electric.

Based on recent trends, and considering that tightening CO_2 targets are due to come in only in 2025, the growth in electric car sales in Europe is expected to be the lowest of the three largest markets. Sales are projected to reach around 3.5 million units in 2024, reflecting modest growth of less than 10% compared to the previous year. In the context of a generally weak outlook for passenger car sales, electric cars would still represent about one in four cars sold in Europe.

Outside of the major EV markets, electric car sales are anticipated to reach the milestone of over 1 million units in 2024, marking a significant increase of over 40% compared to 2023. Recent trends showing the success of both homegrown and Chinese electric carmakers in Southeast Asia underscore that the region is set to make a strong contribution to the sales of emerging EV markets (see the section on Trends in the electric vehicle industry). Despite some uncertainty surrounding whether India's forthcoming FAME III scheme will include subsidies for electric cars, we expect sales in India to remain robust, and to experience around 50% growth compared to 2023. Across all regions outside the three major EV markets, electric car sales are expected to represent around 5% of total car sales in 2024, which – considering the high growth rates seen in recent years – could indicate that a tipping point towards global mass adoption is getting closer.

There are of course downside risks to the 2024 outlook for electric car sales. Factors such as high interest rates and economic uncertainty could potentially reduce the growth of global electric car sales in 2024. Other challenges may come from the IRA restrictions on US electric car tax incentives, and the tightening of technical requirements for EVs to qualify for the purchase tax exemption in China. However, there are also upside potentials to consider. New markets may open up more rapidly than anticipated, as automakers expand their EV operations and new entrants compete for market share. This could lead to accelerated growth in electric car sales globally, surpassing the initial estimations.

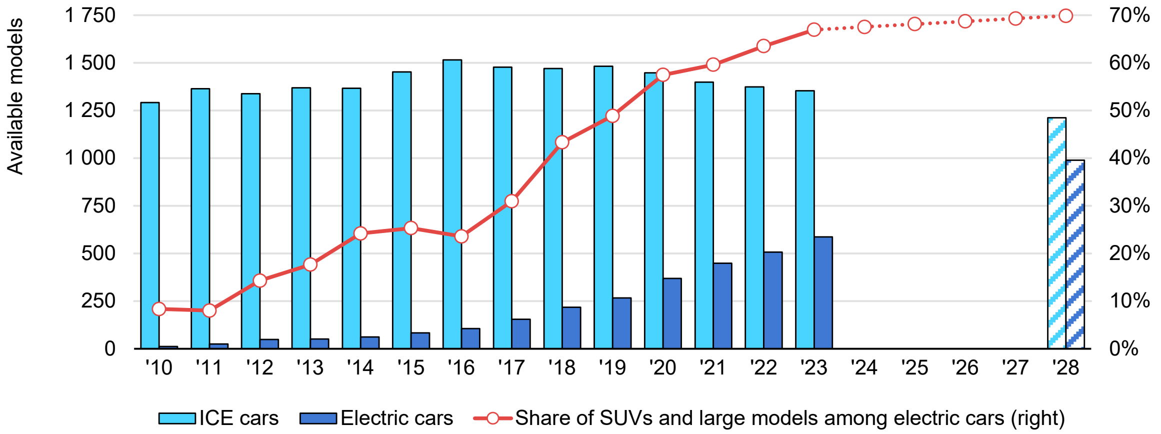
Electric car availability and affordability

More electric models are becoming available, but the trend is towards larger ones

The number of available electric car models nears 600, two-thirds of which are large vehicles and SUVs

In 2023, the number of available models for electric cars increased 15% year-on-year to nearly 590, as carmakers scaled up electrification plans, seeking to appeal to a growing consumer base. Meanwhile, the number of fully ICE models (i.e. excluding hybrids) declined for the fourth consecutive year, at an average of 2%. Based on recent original equipment manufacturer (OEM) announcements, the number of new electric car models could reach 1 000 by 2028. If all announced new electric models actually reach the market, and if the number of available ICE car models continues to decline by 2% annually, there could be as many electric as ICE car models before 2030.

Car model availability by powertrain over 2010-2023 and in 2028 based on announced launches, and share of SUVs and large models among electric cars



Notes: ICE = internal combustion engine. SUVs = sports utility vehicle. ICE does not include hybrids. Electric cars include BEV and PHEV cars. Analysis based on models for which there was at least one new registration in a given year; a model on sale but never sold is not counted, and as such actual model availability may be underestimated. Large cars include E and F segments, multi-purpose vehicles and B segments with SUV body type. The SUV category encompasses segments C to F with SUV body type. The two columns for 2028 are based on electric model announcements, which are available only until 2028, and on a sustained decrease in the number of ICE models based on the trend over 2020-2023.

Source: IEA analysis based on data from EV Volumes and Marklines.

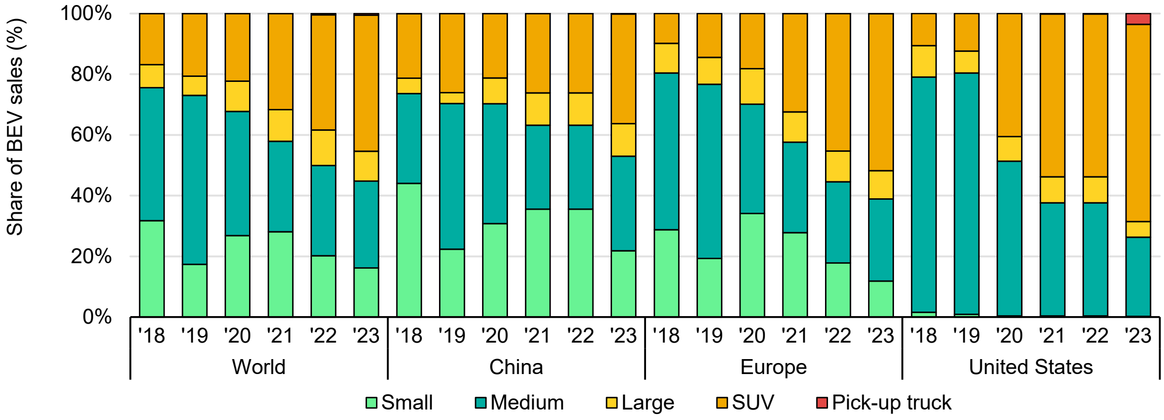
As reported in GEVO-2023, the share of small and medium electric car models is decreasing among available electric models: in 2023, two-thirds of the battery-electric models on the market were SUVs,[5] pick-up trucks or large cars. Just 25% of battery electric car sales in the United States were for small and medium models, compared to 40% in Europe and 50% in China. Electric cars are following the same trend as conventional cars, and getting bigger on average. In 2023, SUVs, pick-up trucks and large models accounted for 65% of total ICE car sales worldwide, and more than 80% in the United States, 60% in China and 50% in Europe.

Several factors underpin the increase in the share of large models. Since the 2010s, conventional SUVs in the United States have benefited from less stringent tailpipe emissions rules than smaller models, creating an incentive for carmakers to market more vehicles in that segment. Similarly, in the European Union, CO_2 targets for passenger cars have included a compromise on weight, allowing CO_2 leeway for heavier vehicles in some cases. Larger vehicles also mean larger margins for carmakers. Given that incumbent carmakers are not yet making a profit on their EV offer in many cases, focusing on larger models enables them to increase their margins. Under the US IRA, electric SUVs can qualify for tax credits as long as they are priced under USD 80 000, whereas the limit stands at USD 55 000 for a sedan, creating an incentive to market SUVs if a greater margin can be gathered. On the demand side, there is now strong willingness to pay for SUVs or large models. Consumers are typically interested in longer-range and larger cars for their primary vehicles, even though small models are more suited to urban use. Higher marketing spend on SUVs compared to smaller models can also have an impact on consumer choices.

The progressive shift towards ICE SUVs has been dramatically limiting fuel savings. Over the 2010-2022 period, without the shift to SUVs, energy use per kilometre could have fallen at an average annual rate 30% higher than the actual rate. Switching to electric in the SUV and larger car segments can therefore achieve immediate and significant CO_2 emissions reductions, and electrification also brings considerable benefits in terms of reducing air pollution and non-tailpipe emissions, especially in urban settings. In 2023, if all ICE and HEV sales of SUVs had instead been BEV, around 770 Mt CO_2 could have been avoided globally over the cars' lifetimes (see section 10 on lifecycle analysis). This is equivalent to the total road emissions of China in 2023.

[5] SUVs may be defined differently across regions, but broadly refer to vehicles that incorporate features commonly found in off-road vehicles (e.g. four-wheel drive, higher ground clearance, larger cargo area). In this report, small and large SUVs both count as SUVs. Crossovers are counted as SUVs if they feature an SUV body type; otherwise they are categorised as medium-sized vehicles.

Breakdown of battery electric car sales in selected countries and regions by car size, 2018-2023



Notes: BEV = battery electric vehicle; SUV = sports utility vehicle. Analysis based on sales-weighted registrations. Small cars include A and B segments. Medium cars include C and D segments and A segments with SUV body type. Large cars include E and F segments, multi-purpose vehicles and B segments with SUV body type. SUV category in figure encompasses segments C to F with SUV body type.
Source: IEA analysis based on data from EV Volumes.

Nevertheless, from a policy perspective, it is critical to mitigate the negative spillovers associated with an increase in larger electric cars in the fleet.

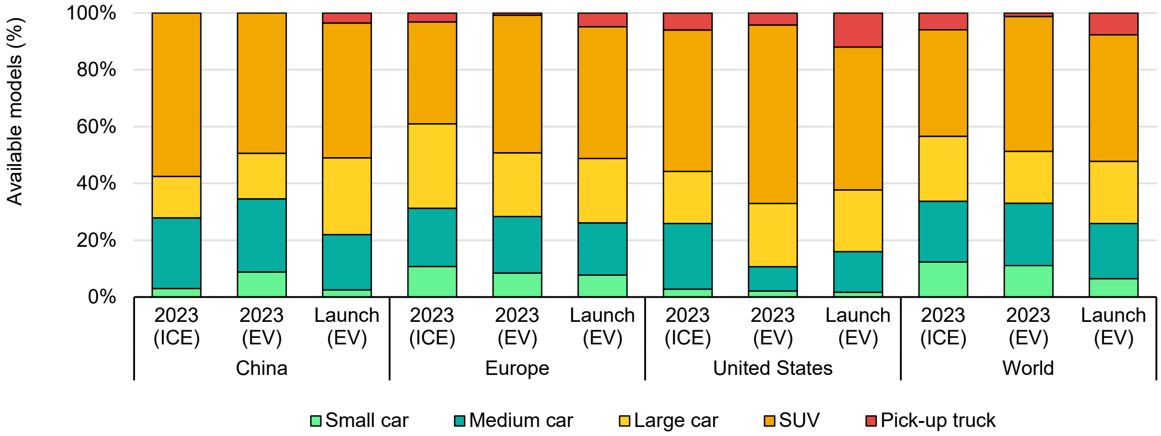
Larger electric car models have a significant impact on battery supply chains and critical mineral demand. In 2023, the sales-weighted average battery electric SUV in Europe had a battery almost twice as large as the one in the average small electric car, with a proportionate impact on critical mineral needs. Of course, the range of small cars is typically shorter than SUVs and large cars (see later section on ranges). However, when comparing electric SUVs and medium-sized electric cars, which in 2023 offered a similar range, the SUV battery was still 25% larger. This means that if all electric SUVs sold in 2023 had instead been medium-sized cars, around 60 GWh of battery equivalent could have been avoided globally, with limited impact on range. Accounting for the different chemistries used in China, Europe, and the United States, this would be equivalent to almost 6 000 tonnes of lithium, 30 000 tonnes of nickel, almost 7 000 tonnes of cobalt, and over 8 000 tonnes of manganese.

Larger manganese also require more power, or longer charging times. This can put pressure on electricity grids and charging infrastructure by increasing occupancy, which could create issues during peak utilisation, such as at highway charging points at high traffic times.

In addition, larger vehicles also require greater quantities of materials such as iron and steel, aluminium and plastics, with a higher environmental and carbon footprint for materials production, processing and assembly. Because they are heavier, larger models also have higher electricity consumption. The additional energy consumption resulting from the increased mass is mitigated by regenerative braking to some extent, but in 2022, the sales-weighted average electricity consumption of electric SUVs was 20% higher than that of other electric cars.[6]

Major carmakers have announced launches of smaller and more affordable electric car models over the past few years. However, when all launch announcements are considered, far fewer smaller models are expected than SUVs, large models and pick-up trucks. Only 25% of the 400+ launches expected over the 2024-2028 period are small and medium models, which represents a smaller share of available models than in 2023. Even in China, where small and medium models have been popular, new launches are typically for larger cars.

Breakdown of available car models and expected new launches by powertrain and segment in selected countries and regions, 2023-2028



Notes: ICE = Internal combustion engine; EV = electric vehicle. EV includes both battery electric cars and plug-in hybrids. Data based on company announcements for new electric car model launches. “Launch” only refers to the expected models over the 2024-2028 period and is not cumulative with models available in 2023.
Sources: IEA analysis based on data from EV Volumes and Marklines.

Several governments have responded by introducing policies to create incentives for smaller and lighter passenger cars. In Norway, for example, all cars are subject to a purchase tax based on weight, CO_2 and nitrogen oxides (NO_x) emissions, though electric cars were exempt from the weight-based tax prior to 2023. Any imported cars weighing more than 500 kg must also pay an entry fee for each additional kg. In France, a progressive weight-based tax applies to ICE and PHEV cars weighing above 1 600 kg, with a significant impact on price: weight tax for a Land Rover Defender 130 (2 550 kg) adds up to more than EUR 21 500, versus zero for a Renault Clio (1 100 kg). Battery electric cars have been exempted to

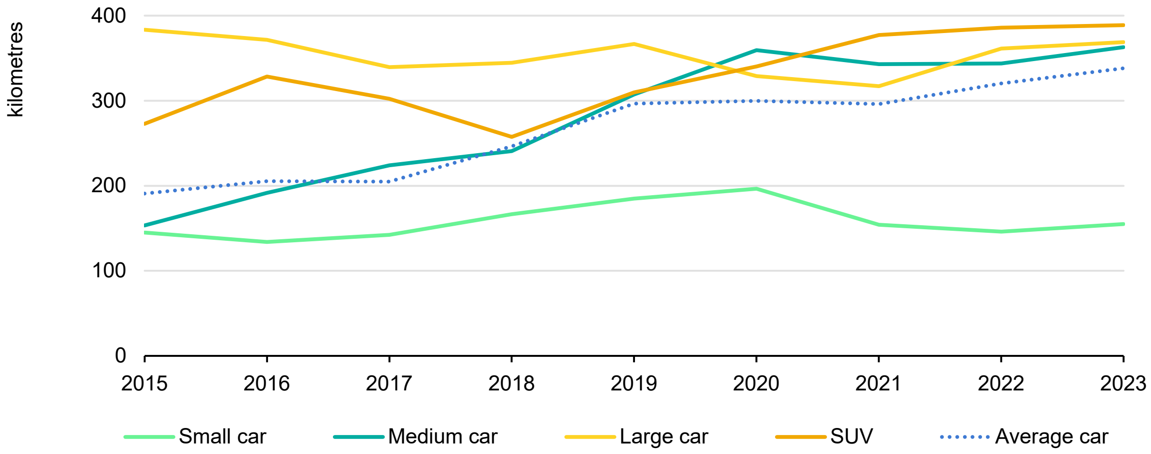
[6] Measured under the Worldwide Harmonised Light Vehicles Test Procedure using vehicle model sales data from IHS Markit.

date. In February 2024, a referendum held in Paris resulted in a tripling of city parking fees for visiting SUVs, applicable to ICE, hybrid and plug-in hybrid cars above 1 600 kg and battery electric ones above 2 000 kg, in an effort to limit the use of large and/or polluting vehicles. Other examples exist in Estonia, Finland, Switzerland and the Netherlands. A number of policy options may be used, such as caps and fleet averages for vehicle footprint, weight, and/or battery size; access to finance for smaller vehicles; and sustained support for public charging, enabling wider use of shorter-range cars.

Average range is increasing, but only moderately

Concerns about range compared to ICE vehicles, and about the availability of charging infrastructure for long-distance journeys, also contribute to increasing appetite for larger models with longer range.

Sales-weighted average range of battery electric cars by segment, 2015-2023



Notes: SUV = sports utility vehicle. Range in kilometres calculated using global weighted average fuel economy (Worldwide Harmonised Light Vehicle Test Procedure [WLTP]) and battery capacity by size segment. Fuel economy reflects on-road conditions by applying a factor of 1.1. Small cars include A and B segments. Medium cars include C and D segments and A segments with SUV body type. Large cars include E and F segments, multi-purpose vehicles and B segments with SUV body type. SUV category in figure encompasses segments C to F with SUV body type.
Source: IEA analysis based on data from EV Volumes.

With increasing battery size and improvements in battery technology and vehicle design, the sales-weighted average range of battery electric cars grew by nearly 75% between 2015 and 2023, although trends vary by segment. The average range of small cars in 2023 – around 150 km – is not much higher than it was in 2015, indicating that this range is already well suited for urban use (with the exception of taxis, which have much higher daily usage). Large, higher-end models already offered higher ranges than average in 2015, and their range has stagnated through 2023, averaging around 360-380 km. Meanwhile, significant improvements have been made for medium-sized cars and SUVs, the range of which now stands around 380 km, whereas it averaged around 150 km for medium cars and 270 km for SUVs in 2015. This is encouraging for consumers looking to purchase an electric car for longer journeys rather than urban use.

Since 2020, growth in the average range of vehicles has been slower than over the 2015-2020 period. This could result from a number of factors, including fluctuating battery prices, carmakers' attempts to limit additional costs as competition intensifies, and technical constraints (e.g. energy density, battery size). It could also reflect that beyond a certain range at which most driving needs are met, consumers' willingness to pay for a marginal increase in battery size and range is limited. Looking forward, however, the average range could start increasing again as novel battery technologies mature and prices fall.

More affordable electric cars are needed to reach a mass-market tipping point

An equitable and inclusive transition to electric mobility, both within countries and at the global level, hinges on the successful launch of affordable EVs (including but not limited to electric cars). In this section, we use historic sales and price data for electric and ICE models around the world to examine the total cost of owning an electric car, price trends over time, and the remaining electric premium, by country and vehicle size.[7] Specific models are used for illustration.

Total cost of ownership

Car purchase decisions typically involve consideration of retail price and available subsidies as well as lifetime operating costs, such as fuel costs, insurance, maintenance and depreciation, which together make up the total cost of ownership (TCO). Reaching TCO parity between electric and ICE cars creates important financial incentives to make the switch. This section examines the different components of the TCO, by region and car size.

In 2023, upfront retail prices for electric cars were generally higher than for their ICE equivalents, which increased their TCO in relative terms. On the upside, higher fuel efficiency and lower maintenance costs enable fuel cost savings for electric cars, lowering their TCO. This is especially true in periods when fuel prices are high, in places where electricity prices are not too closely correlated to fossil

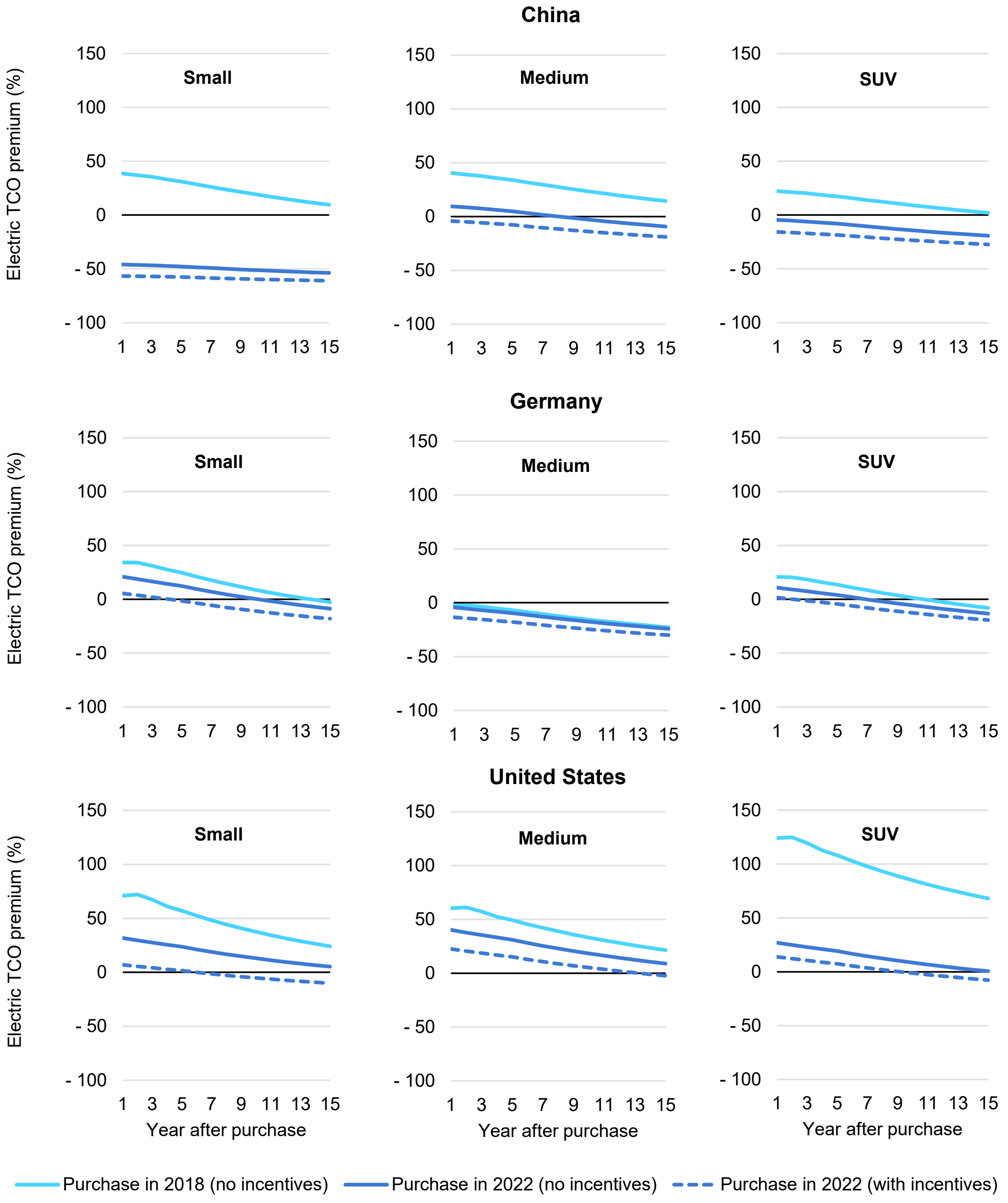
[7] Price data points collected from various data providers and ad-hoc sources cover 65-95% of both electric and ICE car sales globally. By "price", we refer to the advertised price that the customer pays for the acquisition of the vehicle only, including legally required acquisition taxes (e.g. including Value-Added Tax and registration taxes but excluding consumer tax credits). Prices reflect not only the materials, components and manufacturing costs, but also the costs related to sales and marketing, administration, R&D and the profit margin. In the case of a small electric car in Europe, for example, these mark-up costs can account for around 40% of the final pre-tax price. They account for an even greater share of the final pre-tax price when consumers purchase additional options, or opt for larger models, for which margins can be higher. The price for the same model may differ across countries or regions (e.g. in 2023, a VW ID.3 could be purchased in China at half its price in Europe). Throughout the whole section, prices are adjusted for inflation and expressed in constant 2022 USD.

fuel prices. Depreciation is also a major factor in determining TCO: As a car ages, it loses value, and depreciation for electric cars tends to be faster than for ICE equivalents, further increasing their TCO. Accelerated depreciation could, however, prove beneficial for the development of second-hand markets.

However, the trend towards faster depreciation for electric vehicles might be reversed for multiple reasons. Firstly, consumers are gaining more confidence in electric battery lifetimes, thereby increasing the resale value of EVs. Secondly, strong demand and the positive brand image of some BEV models can mean they hold their value longer, as shown by Tesla models depreciating more slowly than the average petrol car in the United States. Finally, increasing fuel prices in some regions, the roll-out of low-emissions zones that restrict access for the most polluting vehicles, and taxes and parking fees specifically targeted at ICE vehicles could mean they experience faster depreciation rates than EVs in the future. In light of these two possible opposing depreciation trends, the same fixed annual depreciation rate for both BEVs and ICE vehicles has been applied in the following cost of ownership analysis.

Subsidies help lower the TCO of electric cars relative to ICE equivalents in multiple ways. A purchase subsidy lowers the original retail price, thereby lowering capital depreciation over time, and a lower retail price implies lower financing costs through cumulative interest. Subsidies can significantly reduce the number of years required to reach TCO parity between electric and ICE equivalents. As of 2022, we estimate that TCO parity could be reached in most cases in under 7 years in the three major EV markets, with significant variations across different car sizes. In comparison, for models purchased at 2018 prices, TCO parity was much harder to achieve.

Difference in total cost of ownership for a battery electric vehicle and a conventional car purchased in 2018 and 2022, by country and segment, over time after purchase



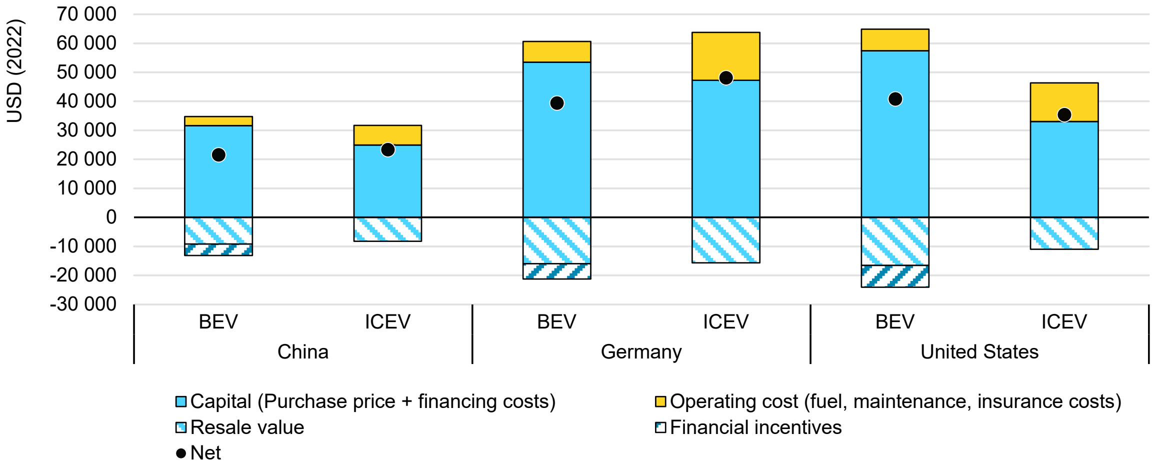
Notes: TCO = total cost of ownership; SUV = sports utility vehicle. First owner cumulative cost of ownership with depreciation considered. Incentives include subsidies, vehicle purchase tax exemptions and tax credits. All calculation assumptions are listed in Table 1 located in the general annex of this document.

Sources: IEA analysis based on IHS Markit data for sales-weighted average upfront purchase prices.

In Germany, for example, we estimate that the sales-weighted average price of a medium-sized battery electric car in 2022 was 10-20% more expensive than its ICE equivalent, but 10-20% cheaper in cumulative costs of ownership after 5 years, thanks to fuel and maintenance costs savings. In the case of an electric SUV, we estimate that the average annual operating cost savings would amount to USD 1 800 when compared to the equivalent conventional SUV over a period of 10 years. In the United States, despite lower fuel prices with respect to electricity, the higher average annual mileage results in savings that are close to Germany at USD 1 600 per year. In China, lower annual distance driven reduces fuel cost savings potential, but the very low price of electricity enables savings of about USD 1 000 per year. These figures provide an indication of how long it would take to recoup the initial purchase price gap between a BEV and its equivalent ICEV through operating cost savings.

In EMDEs, some electric cars can also be cheaper than ICE equivalents over their lifetime. This is true in India, for example, although it depends on the financing instrument. Access to finance is typically much more challenging in EMDEs due to higher interest rates and the more limited availability of cheap capital. Passenger cars have also a significantly lower market penetration in the first place, and many car purchases are made in second-hand markets. Later sections of this report look at markets for used electric cars, as well as the TCO for electric and conventional 2/3Ws in EMDEs, where they are far more widespread than cars as a means of road transport.

Breakdown of the cost of ownership for a sales-weighted average medium-sized battery electric and conventional car purchased in 2022, 5 years after purchase, by country



Notes: "BEV" = battery electric vehicle; "ICEV" = internal combustion engine vehicle. First owner cumulative cost of ownership 5 years after purchase. Financial incentives include subsidies, vehicle purchase tax exemptions and tax credits. All calculation assumptions are listed in Table 1 located in the general annex of this document.

Sources: IEA analysis based on IHS Markit data for sales-weighted average upfront purchase prices.

Upfront retail price parity

Achieving price parity between electric and ICE cars will be an important tipping point. Even when the TCO for electric cars is advantageous, the upfront retail price plays a decisive role, and mass-market consumers are typically more sensitive to price premiums than wealthier buyers. This holds true not only in emerging and developing economies, which have comparatively high costs of capital and comparatively low household and business incomes, but also in advanced economies. In the United States, for example, surveys suggest affordability was the top concern for consumers considering EV adoption in 2023. Other estimates show that even among SUV and pick-up truck consumers, only 50% would be willing to purchase one above USD 50 000.

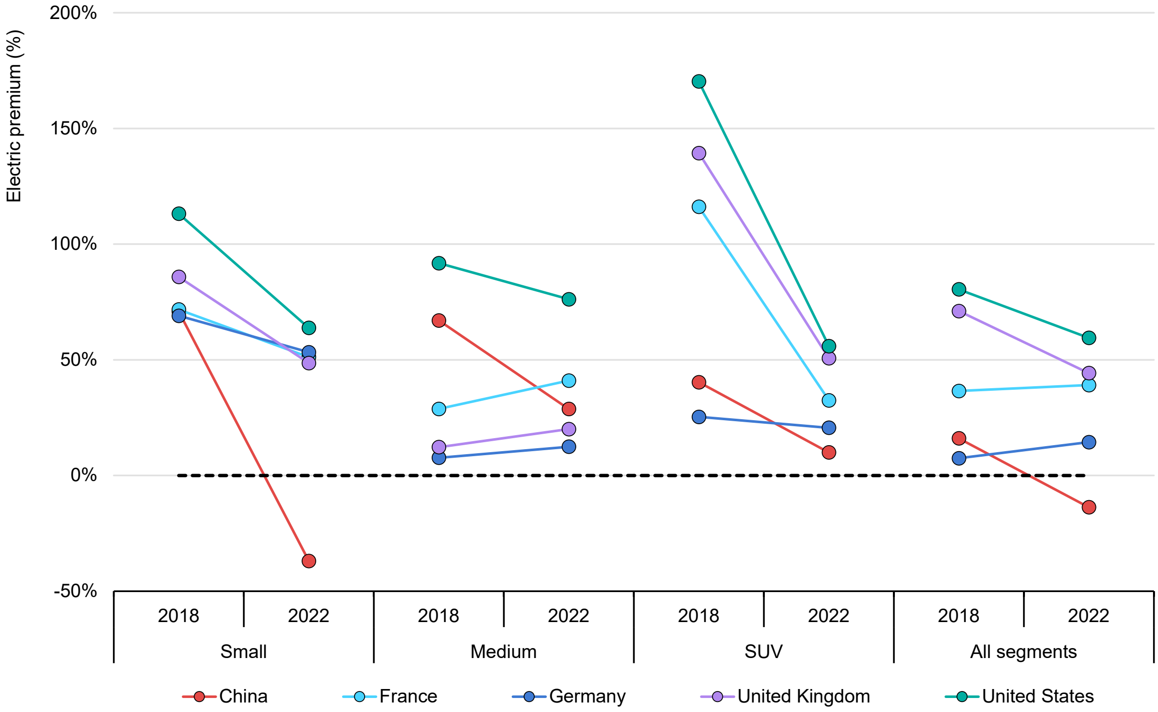
In this section, we examine historic price trends for electric and ICE cars over the 2018-2022 period, by country and car size, and for best-selling models in 2023.

Electric cars are generally getting cheaper as battery prices drop, competition intensifies, and carmakers achieve economies of scale. In most cases, however, they remain on average more expensive than ICE equivalents. In some cases, after adjusting for inflation, their price stagnated or even moderately increased between 2018 and 2022.

Larger batteries for longer ranges increase car prices, and so too do the additional options, equipment, digital technology and luxury features that are often marketed on top of the base model. A disproportionate focus on larger, premium models is pushing up the average price, which – added to the lack of available models in second-hand markets (see below) – limits potential to reach mass-market consumers. Importantly, geopolitical tension, trade and supply chain disruptions, increasing battery prices in 2022 relative to 2021, and rising inflation, have also significantly affected the potential for further cost declines.

Competition can also play an important role in bringing down electric car prices. Intensifying competition leads carmakers to cut prices to the minimum profit margin they can sustain, and – if needed – to do so more quickly than battery and production costs decline. For example, between mid-2022 and early-2024, Tesla cut the price of its Model Y from between USD 65 000 and USD 70 000 to between USD 45 000 and USD 55 000 in the United States. Battery prices for such a model dropped by only USD 3 000 over the same period in the United States, suggesting that a profit margin may still be made at a lower price. Similarly, in China, the price of the Base Model Y dropped from CNY 320 000 (Yuan renminbi) (USD 47 000) to CNY 250 000 (USD 38 000), while the corresponding battery price fell by only USD 1 000. Conversely, in cases where electric models remain niche or aimed at wealthier, less price-sensitive early adopters, their price may not fall as quickly as battery prices, if carmakers can sustain greater margins.

Price gap between the sales-weighted average price of conventional and electric cars in selected countries, before subsidy, by size, 2018 and 2022



Notes: SUV = Sports utility vehicle. “All” includes all car sizes (small, medium, SUV, large and pick-up trucks). A positive value means that the sales-weighted average battery electric car is more expensive than its internal combustion engine equivalent.
Sources: IEA analysis based on data from IHS Markit, EV Volumes, Marklines and various sources for retail prices.

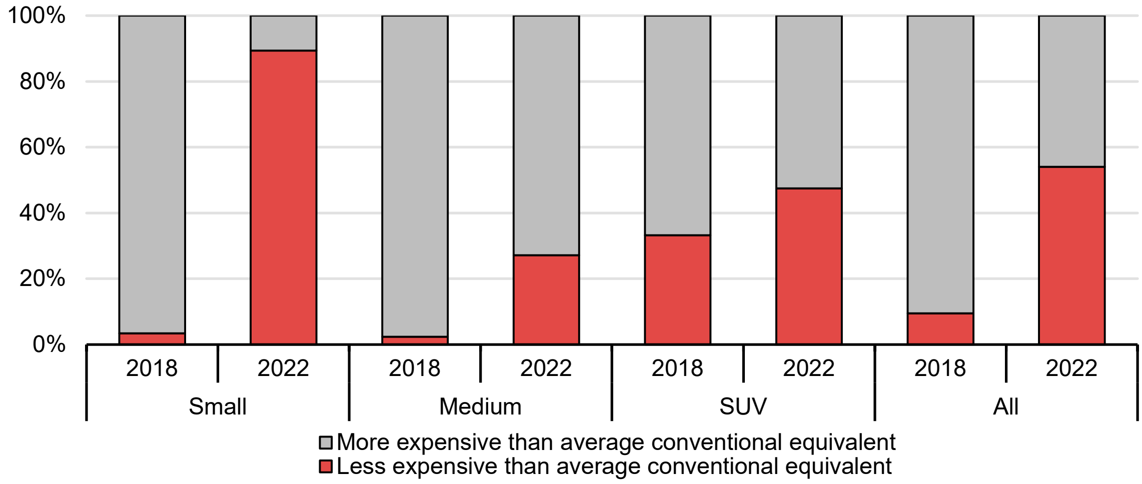
China

In China, where the sales share of electric cars has been high for several years, the sales-weighted average price of electric cars (before purchase subsidy) is already lower than that of ICE cars. This is true not only when looking at total sales, but also at the small cars segment, and is close for SUVs. After accounting for the EV exemption from the 10% vehicle purchase tax, electric SUVs were already on par with conventional ones in 2022, on average.

Electric car prices have dropped significantly since 2018. We estimate that around 55% of the electric cars sold in China in 2022 were cheaper than their average ICE equivalent, up from under 10% in 2018. Given the further price declines between 2022 and 2023, we estimate that this share increased to around 65% in 2023. These encouraging trends suggest that price parity between electric and ICE cars could also be reached in other countries in certain segments by 2030, if the sales share of electric cars continues to grow, and if supporting infrastructure – such as for charging – is sustained.

As reported in detail in GEVO-2023, China remains a global exception in terms of available inexpensive electric models. Local carmakers already market nearly 50 small, affordable electric car models, many of which are priced under CNY 100 000 (USD 15 000). This is in the same range as best-selling small ICE cars in 2023, which cost from CNY 70 000 to CNY 100 000. In 2022, the best-selling electric car was SAIC's small Wuling Hongguang Mini EV, which accounted for 10% of all BEV sales. It was priced around CNY 40 000, weighing under 700 kg for a 170-km range. In 2023, however, it was overtaken by Tesla models, among other larger models, as new consumers seek longer ranges and higher-end options and digital equipment.

Share of battery electric car sales in China that are more or less expensive than conventional equivalents, by car size, 2018-2022



Notes: SUV = sports utility vehicle. The price of each battery electric vehicle sale is compared to the sales-weighted average price of all internal combustion engine (conventional) vehicles within the same segment. Price data excludes any vehicle purchase tax exemption or vehicle purchase subsidy.
Sources: IEA analysis based on data from IHS Markit.

United States

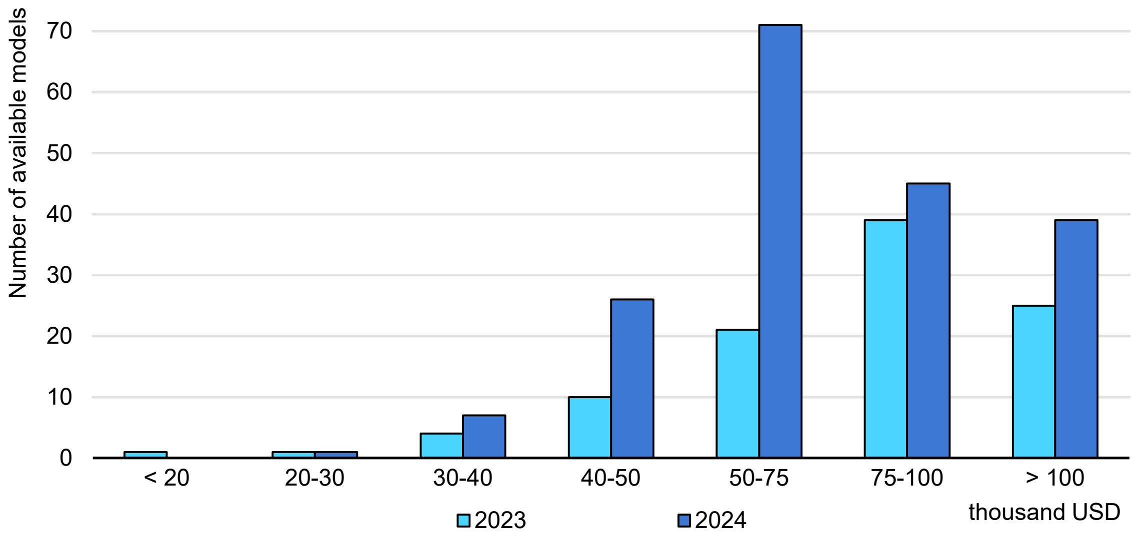
In the United States, the sales-weighted average price of electric cars decreased over the 2018-2022 period, primarily driven by a considerable drop in the price of Tesla cars, which account for a significant share of sales. The sales-weighted average retail price of electric SUVs fell slightly more quickly than the average SUV battery costs over the same period. The average price of small and medium models also decreased, albeit to a smaller extent.

Across all segments, electric models remained more expensive than conventional equivalents in 2022. However, the gap has since begun to close, as market size increases and competition leads carmakers to cut prices. For example, in 2023-2024, Tesla's Model 3 could be found in the USD 39 000 to USD 42 000 range, which is comparable to the average price for new ICE cars, and a new Model Y priced under USD 50 000 was launched. Rivian is expecting to launch its R2 SUV in 2026 at USD 45 000, which is much less than previous vehicles. Average price parity between electric and conventional SUVs could be reached by 2030, but it may only be reached later for small and medium cars, given their lower availability and popularity.

Smaller, cheaper electric models have further to go to reach price parity in the United States. We estimate that in 2022, only about 5% of the electric cars sold in the United States were cheaper than their average ICE equivalent. In 2023, the cheapest electric cars were priced around USD 30 000 (e.g. Chevrolet Bolt, Nissan Leaf, Mini Cooper SE). To compare, best-selling small ICE options cost under USD 20 000 (e.g. Kia Rio, Mitsubishi Mirage), and many best-selling medium ICE options between USD 20 000 and USD 25 000 (e.g. Honda Civic, Toyota Corolla, Kia Forte, Hyundai Avante, Nissan Sentra).

Around 25 new all-electric car models are expected in 2024, but only 5 of them are expected below USD 50 000, and none under the USD 30 000 mark. Considering all the electric models expected to be available in 2024, about 75% are priced above USD 50 000, and fewer than 10 under USD 40 000, even after taking into account the USD 7 500 tax credit under the IRA for eligible cars as of February 2024. This means that despite the tax credit, few electric car models directly compete with small mass-market ICE models.

Number of available battery electric car models in the United States, by retail price after tax credit when eligible, 2023 and 2024



Notes: Data as of February 2024. Clean Vehicle Tax Credit applied where applicable.
Sources: IEA analysis based on data from InsideEVs.

In December 2023, GM stopped production of its best-selling electric car, the Bolt, announcing it would introduce a new version in 2025. The Nissan Leaf (40 kWh) therefore remains the cheapest available electric car in 2024, at just under USD 30 000, but is not yet eligible for IRA tax credits. Ford announced in 2024 that it would move away from large and expensive electric cars as a way to convince more consumers to switch to electric, at the same time as increasing output of ICE models to help finance a transition to electric mobility. In 2024, Tesla announced it would start producing a next-generation, compact and affordable electric car in June 2025, but the company had already announced in 2020 that it would deliver a USD 25 000 model within 3 years. Some micro urban electric cars are already available between USD 5 000 and USD 20 000 (e.g. Arcimoto FUV, Nimbus One), but they are rare. In theory, such models could cover many use cases, since 80% of car journeys in the United States are under 10 miles.

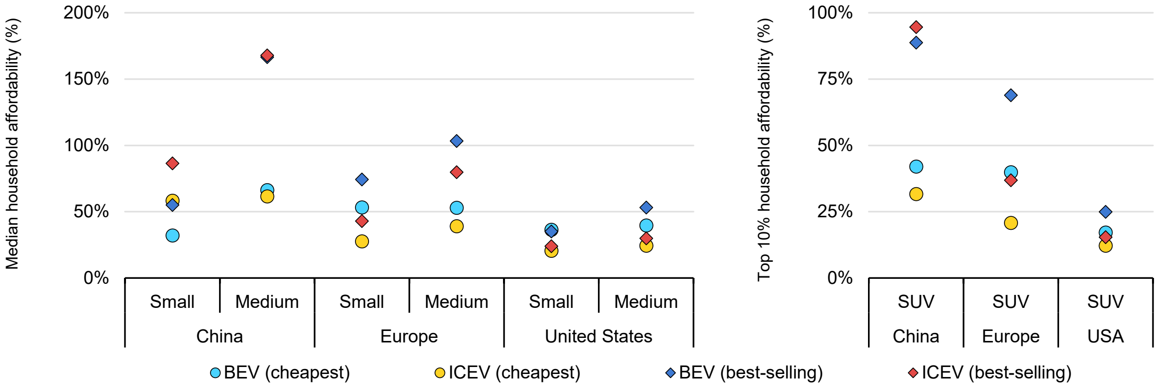
Europe

Pricing trends differ across European countries, and typically vary by segment.

In Norway, after taking into account the EV sales tax exemption, electric cars are already cheaper than ICE equivalents across all segments. In 2022, we estimate that the electric premium stood around -15%, and even -30% for medium-sized cars. Five years earlier, in 2018, the overall electric premium was less advantageous, at around -5%. The progressive reintroduction of sales taxes on electric cars may change these estimates for 2023 onwards.

Germany's electric premium ranks among the lowest in the European Union. Although the sales-weighted average electric premium increased slightly between 2018 and 2022, it stood at 15% in 2022. It is particularly low for medium-sized cars (10-15%) and SUVs (20%), but remains higher than 50% for small models. In the case of medium cars, the sales-weighted average electric premium was as low as EUR 5 000 in 2022. We estimate that in 2022, over 40% of the medium electric cars sold in Germany were cheaper than their average ICE equivalent. Looking at total sales, over 25% of the electric cars sold in 2022 were cheaper than their average ICE equivalent. In 2023, the cheapest models among the best-selling medium electric cars were priced between EUR 22 000 and EUR 35 000 (e.g. MG MG4, Dacia Spring, Renault Megane), far cheaper than the three front-runners priced above EUR 45 000 (VW ID.3, Cupra Born, and Tesla Model 3). To compare, best-selling ICE cars in the medium segment were also priced between EUR 30 000 and EUR 45 000 (e.g. VW Golf, VW Passat Santana, Skoda Octavia Laura, Audi A3, Audi A4). At the end of 2023, Germany phased out its subsidy for electric car purchases, but competition and falling model prices could compensate for this.

Retail price of cheapest electric and conventional cars as a share of median annual household income (left) and top 10% annual household income (right), by country and car size, 2023



Notes: "BEV" = battery electric vehicle; "ICEV" = internal combustion engine vehicle; "USA" = United States; SUV = sports utility vehicle. Car prices are for base models with no additional options or equipment. For BEV sales, the sample covers price data for 60-90% in China, 75-100% in the United States, and 85-95% in Europe, depending on the segment. For ICEV sales, the sample covers price data for the top 40-55% of total sales. Annual income values are used. Median household income values are around USD 14 000 in China, USD 43 000 in Europe (data for Germany), and USD 80 000 in the United States. Top 10% income values are around USD 32 000 in China, USD 84 000 in Europe (data for Germany) and USD 200 000 in the United States.

Sources: IEA analysis based on data from EV Volumes, Marklines and various sources for retail prices, and from the World Bank for income.

In France, the sales-weighted average electric premium stagnated between 2018 and 2022. The average price of ICE cars also increased over the same period, though more moderately than that of electric models. Despite a drop in the price of electric SUVs, which stood at a 30% premium over ICE equivalents in 2022, the former do not account for a high enough share of total electric car sales to drive down the overall average. The electric premium for small and medium cars remains around 40-50%.

These trends mirror those of some of the best-selling models. For example, when adjusting prices for inflation, the small Renault Zoe was sold at the same price on average in 2022-2023 as in 2018-2019, or EUR 30 000 (USD 32 000). It could be found for sale at as low as EUR 25 000 in 2015-2016. The earlier models, in 2015, had a battery size of around 20 kWh, which increased to around 40 kWh in 2018-2019 and 50 kWh in newer models in 2022-2023. Yet European battery prices fell more quickly than the battery size increased over the same period, indicating that battery size alone does not explain car price dynamics.

In 2023, the cheapest electric cars in France were priced between EUR 22 000 and EUR 30 000 (e.g. Dacia Spring, Renault Twingo E-Tech, Smart EQ Fortwo), while best-selling small ICE models were available between EUR 10 000 and EUR 20 000 (e.g. Renault Clio, Peugeot 208, Citroën C3, Dacia Sandero, Opel

Corsa, Skoda Fabia). Since mid-2024, subsidies of up to EUR 4 000 can be granted for electric cars priced under EUR 47 000, with an additional subsidy of up to EUR 3 000 for lower-income households.

In the United Kingdom, the sales-weighted average electric premium shrank between 2018 and 2022, thanks to a drop in prices for electric SUVs, as in the United States. Nonetheless, electric SUVs still stood at a 45% premium over ICE equivalents in 2022, which is similar to the premium for small models but far higher than for medium cars (20%).

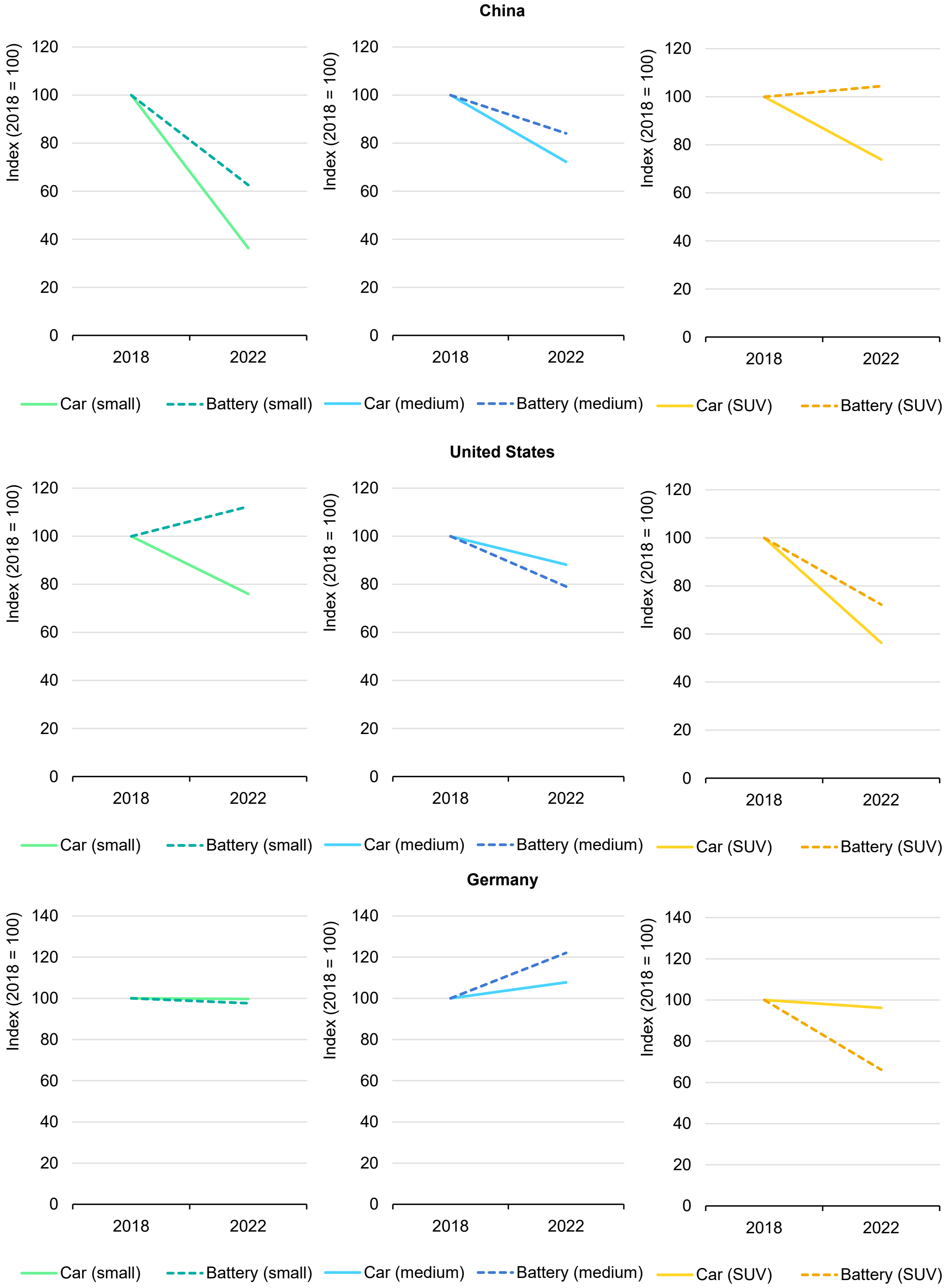
In 2023, the cheapest electric cars in the United Kingdom were priced from GBP 27 000 to GBP 30 000 (USD 33 000 to 37 000) (e.g. MG MG4, Fiat 500, Nissan Leaf, Renault Zoe), with the exception of the Smart EQ Fortwo, priced at GBP 21 000. To compare, best-selling small ICE options could be found from GBP 10 000 to 17 000 (e.g. Peugeot 208, Fiat 500, Dacia Sandero) and medium options below GBP 25 000 (e.g. Ford Puma). Since July 2022, there has been no subsidy for the purchase of electric passenger cars.

Elsewhere in Europe, electric cars remain typically much more expensive than ICE equivalents. In Poland, for example, just a few electric car models could be found at prices competitive with ICE cars in 2023, under the PLN 150 000 (Polish zloty) (EUR 35 000) mark. Over 70% of electric car sales in 2023 were for SUVs, or large or more luxurious models, compared to less than 60% for ICE cars.

In 2023, there were several announcements by European OEMs for smaller models priced under EUR 25 000 in the near-term (e.g. Renault R5, Citroën e-C3, Fiat e-Panda, VW ID.2all). There is also some appetite for urban microcars (i.e. L6-L7 category), learning from the success of China's Wuling. Miniature models bring important benefits if they displace conventional models, helping reduce battery and critical mineral demand. Their prices are often below USD 5 000 (e.g. Microlino, Fiat Topolino, Citroën Ami, Silence S04, Birò B2211).

In Europe and the United States, electric car prices are expected to come down as a result of falling battery prices, more efficient manufacturing, and competition. Independent analyses suggest that price parity between some electric and ICE car models in certain segments could be reached over the 2025-2028 period, for example for small electric cars in Europe in 2025 or soon after. However, many market variables could delay price parity, such as volatile commodity prices, supply chain bottlenecks, and the ability of carmakers to yield sufficient margins from cheaper electric models. The typical rule in which economies of scale bring down costs is being complicated by numerous other market forces. These include a dynamic regulatory context, geopolitical competition, domestic content incentives, and a continually evolving technology landscape, with competing battery chemistries that each have their own economies of scale and regional specificities.

Sales-weighted average price of battery electric cars, and average battery price, by country and car size, 2018-2022



Notes: SUV = sports utility vehicle. Prices adjusted for inflation before index. The battery price is calculated based on the average battery size in a given country, segment and year, multiplied by the corresponding regional pack price.
Sources: IEA analysis based on data from IHS Markit, EV Volumes, BNEF and other sources.

Japan

Japan is a rare example of an advanced economy where small models – both for electric and ICE vehicles – appeal to a large consumer base, motivated by densely populated cities with limited parking space, and policy support. In 2023, about 60% of total ICE sales were for small models, and over half of total electric sales. Two electric cars from the smallest “Kei” category, the Nissan Sakura and Mitsubishi eK-X, accounted for nearly 50% of national electric car sales alone, and both are priced between JPY 2.3 million (Japanese yen) and JPY 3 million (USD 18 000 to USD 23 000). However, this is still more expensive than best-selling small ICE cars (e.g. Honda N Box, Daihatsu Hijet, Daihatsu Tanto, Suzuki Spacia, Daihatsu Move), priced between USD 13 000 and USD 18 000. In 2024, Nissan announced that it would aim to reach cost parity (of production, not retail price) between electric and ICE cars by 2030.

Emerging market and developing economies

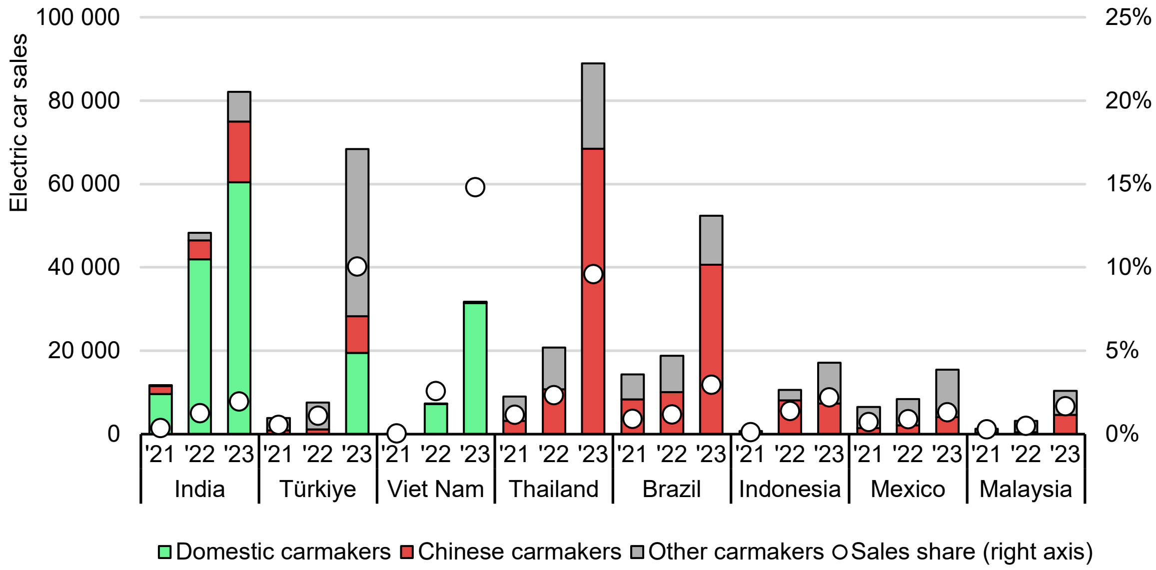
In EMDEs, the absence of small and cheaper electric car models is a significant hindrance to wider market uptake. Many of the available car models are SUVs or large models, targeting consumers of high-end goods, and far too expensive for mass-market consumers, who often do not own a personal car in the first place (see later sections on second-hand car markets and 2/3Ws).

In India, while Tata’s small Tiago/Tigor models, which are priced between USD 10 000 and USD 15 000, accounted for about 20% of total electric car sales in 2023, the average best-selling small ICE car is priced around USD 7 000. Large models and SUVs accounted for over 65% of total electric car sales. While BYD announced in 2023 the goal of accounting for 40% of India’s EV market by 2030, all of its models available in India cost more than INR 3 million (Indian rupees) (USD 37 000), including the Seal, launched in 2024 for INR 4.1 million (USD 50 000).

Similarly, SUVs and large models accounted for the majority share of electric car sales in Thailand (60%), Indonesia (55%), Malaysia (over 85%) and Viet Nam (over 95%). In Indonesia, for example, Hyundai’s Ionic 5 was the most popular electric car in 2023, priced at around USD 50 000. Looking at launch announcements, most new models expected over the 2024-2028 period in EMDEs are SUVs or large models. However, more than 50 small and medium models could also be introduced, and the recent or forthcoming entry of Chinese carmakers suggests that cheaper models could hit the market in the coming years.

In 2022-2023, Chinese carmakers accounted for 40-75% of the electric car sales in Indonesia, Thailand and Brazil, with sales jumping as cheaper Chinese models were introduced. In Thailand, for example, Hozon launched its Neta V model in 2022 priced at THB 550 000 (Thai baht) (USD 15 600), which became a best-seller in 2023 given its relative affordability compared with the cheapest ICE equivalents at around USD 9 000. Similarly, in Indonesia, the market entry of Wuling's Air EV in 2022-2023 was met with great success. In Colombia, the best-selling electric car in 2023 was the Chinese mini-car, Zhidou 2DS, which could be found at around USD 15 000, a competitive option relative to the country's cheapest ICE car, the Kia Picanto, at USD 13 000.

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



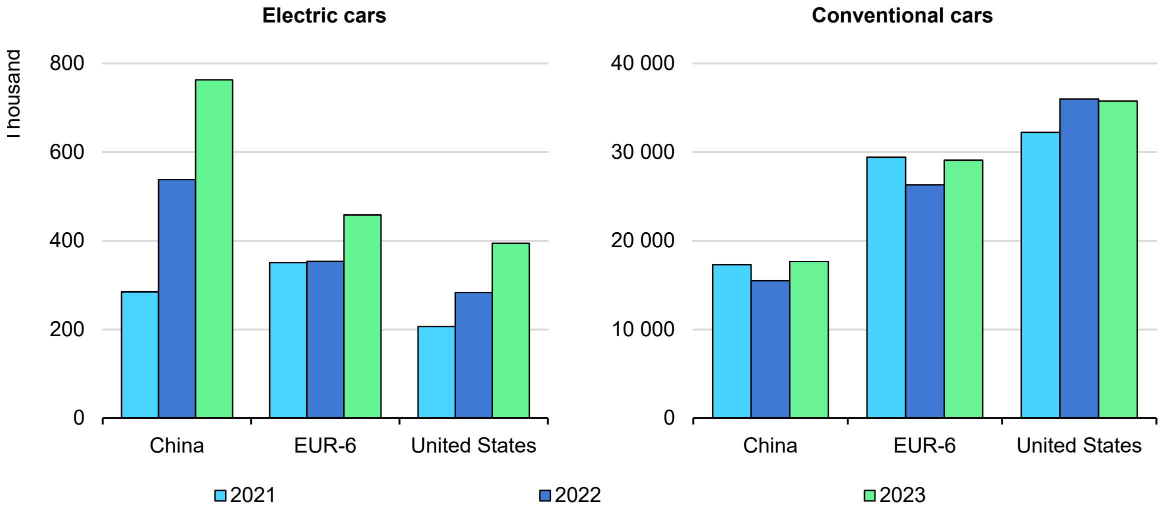
Notes: In the case of joint ventures between international incumbent carmakers and Chinese companies, sales are distributed among countries when model-level data are available (e.g. in the case of the GM-SAIC-Wuling joint venture, Wuling models are counted as headquartered in China, not the United States).
Source: IEA analysis based on data from EV Volumes.

Second-hand markets for electric cars are on the rise

As electric vehicle markets mature, the second-hand market will become more important

In the same way as for other technology products, second-hand markets for used electric cars are now emerging as newer generations of vehicles progressively become available and earlier adopters switch or upgrade. Second-hand markets are critical to foster mass-market adoption, especially if new electric cars remain expensive, and used ones become cheaper. Just as for ICE vehicles – for which buying second-hand is often the primary method of acquiring a car in both emerging and advanced economies – a similar pattern will emerge with electric vehicles. It is estimated that eight out of ten EU citizens buy their car second-hand, and this share is even higher – around 90% – among low- and middle-income groups. Similarly, in the United States, about seven out of ten vehicles sold are second-hand, and only 17% of lower-income households buy a new car.

Second-hand market size for electric and conventional cars by region, 2021-2023



Notes: In this figure, EUR-6 refers to France, Germany, Italy, Spain, the Netherlands and the United Kingdom.
Sources: IEA analysis based on data from Recurrent on US electric cars, Cox Automotive on the US total car market, Autovista on the total car market in France, Germany, Italy, Spain and the United Kingdom, BOVAG for the total and electric cars in the Netherlands, SMMT on electric cars in the United Kingdom, CADA on the total and electric car markets in China, and using the assumption that 1% of the used car market is electric for France, Germany, Italy and Spain following findings of the ICCT.

As major electric car markets reach maturity, more and more used electric cars are becoming available for resale. Our estimates suggest that in 2023, the market size for used electric cars amounted to nearly 800 000 in China, 400 000 in the United States and more than 450 000 for France, Germany, Italy, Spain, the Netherlands and the United Kingdom combined. Second-hand sales have not been included in the numbers presented in the previous section of this report, which focused on sales of new electric cars, but they are already significant. On aggregate, global second-hand electric car sales were roughly equal to new electric car sales in the United States in 2023. In the United States, used electric car sales are set to increase by 40% in 2024 relative to 2023. Of course, these volumes are dwarfed by second-hand ICE markets: 30 million in the European countries listed above combined, nearly 20 million in China, and 36 million in the United States. However, these markets have had decades to mature, indicating greater longer-term potential for used electric car markets.

Used car markets already provide more affordable electric options in China, Europe and the United States

Second-hand car markets are increasingly becoming a source of more affordable electric cars that can compete with used ICE equivalents. In the United States, for example, more than half of second-hand electric cars are already priced below

USD 30 000. Moreover, the average price is expected to quickly fall towards USD 25 000, the price at which used electric cars become eligible for the federal used car rebate of USD 4 000, making them directly competitive with best-selling new and used ICE options. The price of a second-hand Tesla in the United States dropped from over USD 50 000 in early 2023 to just above USD 33 000 in early 2024, making it competitive with a second-hand SUV and many new models as well (either electric or conventional). In Europe, second-hand battery electric cars can be found between EUR 15 000 and EUR 25 000 (USD 16 000-27 000), and second-hand plug-in hybrids around EUR 30 000 (USD 32 000). Some European countries also offer subsidies for second-hand electric cars, such as the Netherlands (EUR 2 000), where the subsidy for new cars has been steadily declining since 2020, while that for used cars remains constant, and France (EUR 1 000). In China, used electric cars were priced around CNY 75 000 on average in 2023 (USD 11 000).

In recent years, the resale value[8] of electric cars has been increasing. In Europe, the resale value of battery electric cars sold after 12 months has steadily increased over the 2017-2022 period, surpassing that of all other powertrains and standing at more than 70% in mid-2022. The resale value of battery electric cars sold after 36 months stood below 40% in 2017, but has since been closing the gap with other powertrains, reaching around 55% in mid-2022. This is the result of many factors, including higher prices of new electric cars, improving technology allowing vehicles and batteries to retain greater value over time, and increasing demand for second-hand electric cars. Similar trends have been observed in China.

High or low resale values have important implications for the development of second-hand electric car markets and their contributions to the transition to road transport electrification. High resale values primarily benefit consumers of new cars (who retain more of the value of their initial purchase), and carmakers, because many consumers are attracted by the possibility of reselling their car after a few years, thereby fostering demand for newer models. High resale values also benefit leasing companies, which seek to minimise depreciation and resell after a few years.

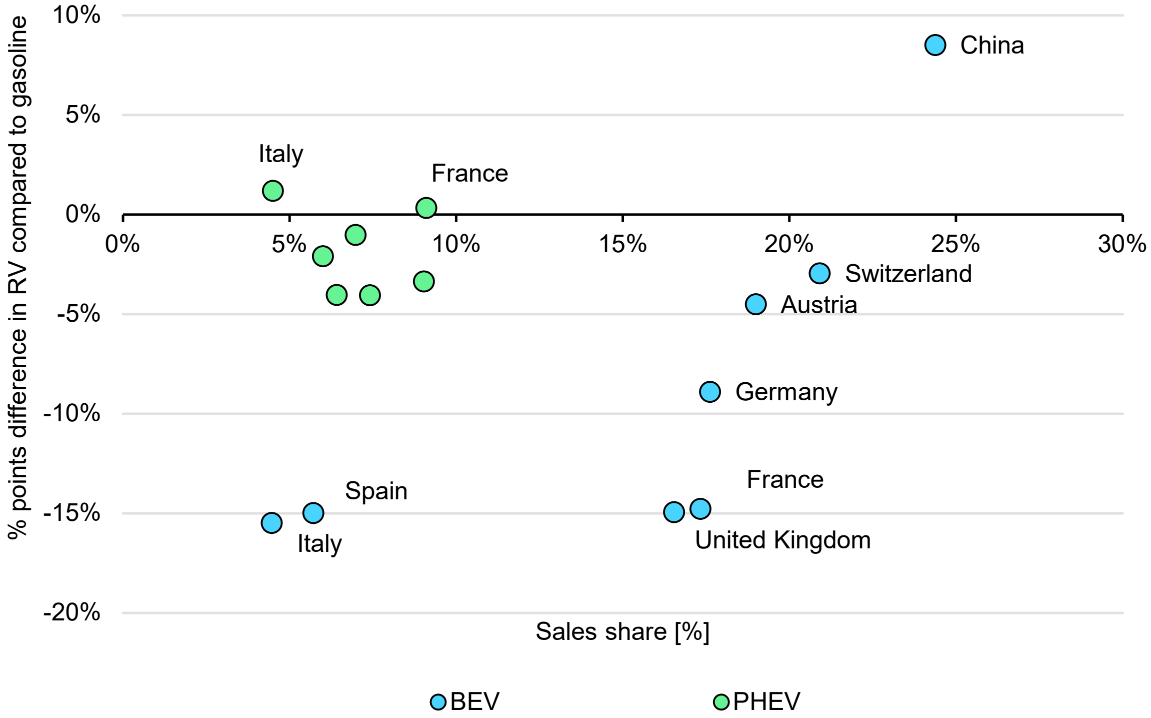
Leasing companies have a significant impact on second-hand markets because they own large volumes of vehicles for a shorter period (under three years, compared to 3 to 5 years for a private household). Their impact on markets for new cars can also be considerable: leasing companies accounted for over 20% of new cars sold in Europe in 2022.

Overall, a resale value for electric cars on par with or higher than that of ICE equivalents contributes to supporting demand for new electric cars. In the near term, however, a combination of high prices for new electric cars and high resale

[8] This metric of depreciation used in second-hand technology markets represents the value of the vehicle when being resold in relation to the value when originally purchased. A resale value of 70% means that a product purchased new will lose 30% of its original value, on average, and sell at such a discount relative to the original price.

values could hinder widespread adoption of used EVs among mass-market consumers seeking affordable cars. In such cases, policy support can help bridge the gap with second-hand ICE prices.

Difference between the relative resale value of battery electric and plug-in hybrid vehicles compared to gasoline conventional cars, 2023



Notes: RV = resale value; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle. The y-axis shows the difference between the resale value of gasoline internal combustion engine (ICE) cars and battery electric and plug-in hybrid electric cars: a positive value means that EVs will lose less value than ICEs, while a negative value indicates a loss in value. Data is not available for PHEVs in China. This data shows the average across all segments in the second-hand market and does not correct for the difference in age between the powertrains.

Sources: IEA analysis based on data from Autovista for resale values in European countries and from CADA for China.

International trade for used electric cars to emerging markets is expected to increase

As the EV stock ages in advanced markets, it is likely that more and more used EVs will be traded internationally, assuming that global standards enable technology compatibility (e.g. for charging infrastructure). Imported used vehicles present an opportunity for consumers in EMDEs, who may not have access to new models because they are either too expensive or not marketed in their countries.

Data on used car trade flows are scattered and often contradictory, but the history of ICE cars can be a useful guide to what may happen for electric cars. Many EMDEs have been importing used ICE vehicles for decades. UNEP estimates that Africa imports 40% of all used vehicles exported worldwide, with African countries typically becoming the ultimate destination for used imports. Typical trade flows include Western European Union member states to Eastern European Union member states and to African countries that drive on the right-hand side; Japan to Asia and to African countries that drive on the left-hand side; and the United States to the Middle East and Central America.

Used electric car exports from large EV markets have been growing in recent years. For China, this can be explained by the recent roll-back of a policy forbidding exports of used vehicles of any kind. Since 2019, as part of a pilot project, the government has granted 27 cities and provinces the right to export second-hand cars. In 2022, China exported almost 70 000 used vehicles, a significant increase on 2021, when fewer than 20 000 vehicles were exported. About 70% of these were NEVs, of which over 45% were exported to the Middle East. In 2023, the Ministry of Commerce released a draft policy on second-hand vehicle export that, once approved, will allow the export of second-hand vehicles from all regions of China. Used car exports from China are expected to increase significantly as a result.

In the European Union, the number of used electric cars traded internationally is also increasing. In both 2021 and 2022, the market size grew by 70% year-on-year, reaching almost 120 000 electric cars in 2022. More than half of all trade takes place between EU member states, followed by trade with neighbouring countries such as Norway, the United Kingdom and Türkiye (accounting for 20% combined). The remainder of used EVs are exported to countries such as Mexico, Tunisia and the United States. As of 2023, the largest exporters are Belgium, Germany, the Netherlands, and Spain.

Last year, just over 1% of all used cars leaving Japan were electric. However these exports are growing and increased by 30% in 2023 relative to 2022, reaching 20 000 cars. The major second-hand electric car markets for Japanese vehicles are traditionally Russia and New Zealand (over 60% combined). After Russia's invasion of Ukraine in 2022, second-hand trade of conventional cars from Japan to Russia jumped sharply following a halt in operations of local OEMs in Russia, but this trade was quickly restricted by the Japanese government, thereby bringing down the price of second-hand cars in Japan. New Zealand has very few local vehicle assembly or manufacturing facilities, and for this reason many cars entering New Zealand are used imports. In 2023, nearly 20% of all electric cars that entered New Zealand were used imports, compared to 50% for the overall car market.

In emerging economies, local policies play an important role in promoting or limiting trade flows for used cars. In the case of ICE vehicles, for example, some countries (e.g. Bolivia, Côte d'Ivoire, Peru) limit the maximum age of used car imports to prevent the dumping of highly polluting cars. Other countries (e.g. Brazil, Colombia, Egypt, India, South Africa) have banned used car imports entirely to protect their domestic manufacturing industries.

Just as for ICE vehicles, policy measures can either help or hinder the import of used electric cars, such as by setting emission standards for imported used cars. Importing countries will also need to simultaneously support roll-out of charging infrastructure to avoid problems with access like those reported in Sri Lanka after an incentive scheme significantly increased imports of used EVs in 2018.

The median age of vehicle imports tends to increase as the GDP per capita of a country decreases. In some African countries, the median age of imports is over 15 years. Beyond this timeframe, electric cars may require specific servicing to extend their lifetime. To support the availability of second-hand markets for electric cars, it will be important to develop strategies, technical capacity, and business models to swap very old batteries from used vehicles. Today, many countries that import ICE vehicles, including EMDEs, already have servicing capacity in place to extend the lifetimes of used ICE vehicles, but not used EVs. On the other hand, there are typically fewer parts in electric powertrains than in ICE ones, and these parts can even be more durable. Battery recycling capacity will also be needed, given that the importing country is likely to be where the imported EV eventually reaches end-of-life. Including end-of-life considerations in policy-making today can help mitigate the risk of longer-term environmental harm that could result from the accumulation of obsolete EVs and associated waste in EMDEs.

Policy choices in more mature markets also have an impact on possible trade flows. For example, the current policy framework in the European Union for the circularity of EV batteries may prevent EVs and EV batteries from leaving the European Union, which brings energy security advantages but might limit reuse. In this regard, advanced economies and EMDEs should strengthen co-operation to facilitate second-hand trade while ensuring adequate end-of-life strategies. For example, there could be incentives or allowances associated with extended vehicle lifetimes via use in second-hand markets internationally before recycling, as long as recycling in the destination market is guaranteed, or the EV battery is returned at end of life.

2. Trends in other light-duty electric vehicles

Electric two- and three-wheelers

India, China and Association of Southeast Asian Nations (ASEAN) countries are the biggest two- and three-wheeler (2/3W)[9] markets worldwide. In 2023, sales of 2/3Ws in these markets, including both electric and ICE powertrains, reached 19 million, 17 million and 14 million units, respectively. Indonesia, Viet Nam, the Philippines and Thailand are the biggest markets among ASEAN countries, with sales of 2/3Ws far outnumbering sales of LDVs, highlighting their importance in the region. Likewise, the number of 2/3Ws in India is 157 per 1 000 people, compared with only 35 passenger cars.

Despite having smaller 2/3W markets overall, 2/3Ws also play a critical role in Latin America and Africa for daily passenger and commercial transportation. Electrifying 2/3Ws is therefore a promising lever for decarbonising mobility and improving urban air quality in these regions.

In 2023, the sales share of electric 2/3Ws was just 13% globally, while in terms of stock shares, 2/3Ws represent the most electrified road transport segment, with about 8% of 2/3Ws being electric. China sold the most electric 2/3Ws in 2023, with over 30% of the 2/3W sales being electric (decreasing from about 50% in 2022), followed by India (8%) and ASEAN countries (3%).

Global sales of electric two-wheelers continue to decline due to falling sales in China, though growth in the rest of Asia is steady

The global market for electric two-wheelers (2Ws) shrank 18% in 2023, continuing the downward trend of 2022, which was almost entirely due to supply chain challenges stemming from China's pandemic-related restrictions. The decline at the global level was largely driven by a 25% drop in China, which continues to command the vast majority of global electric 2W sales. The Chinese electric 2W market downturn could be explained by the continuing supply chain disruptions related to 2022 zero-Covid policies.

[9] In this report, two-wheelers refer to vehicles with a top speed of at least 25 km/hr and which fit the L1 and L3 classes definition of UNECE. This excludes micromobility options such as electric-assisted bicycles and low-speed electric scooters. The definition of a three-wheeler is aligned with UNECE L2, L4 or L5 classes.

The fall in global electric 2W sales masks steady growth in the expanding Indian market and in some ASEAN countries. However, they are still dwarfed by China, which accounted for 78% of global sales, with nearly 6 million electric 2Ws sold in 2023, compared to 880 000 in India and 380 000 in ASEAN countries.

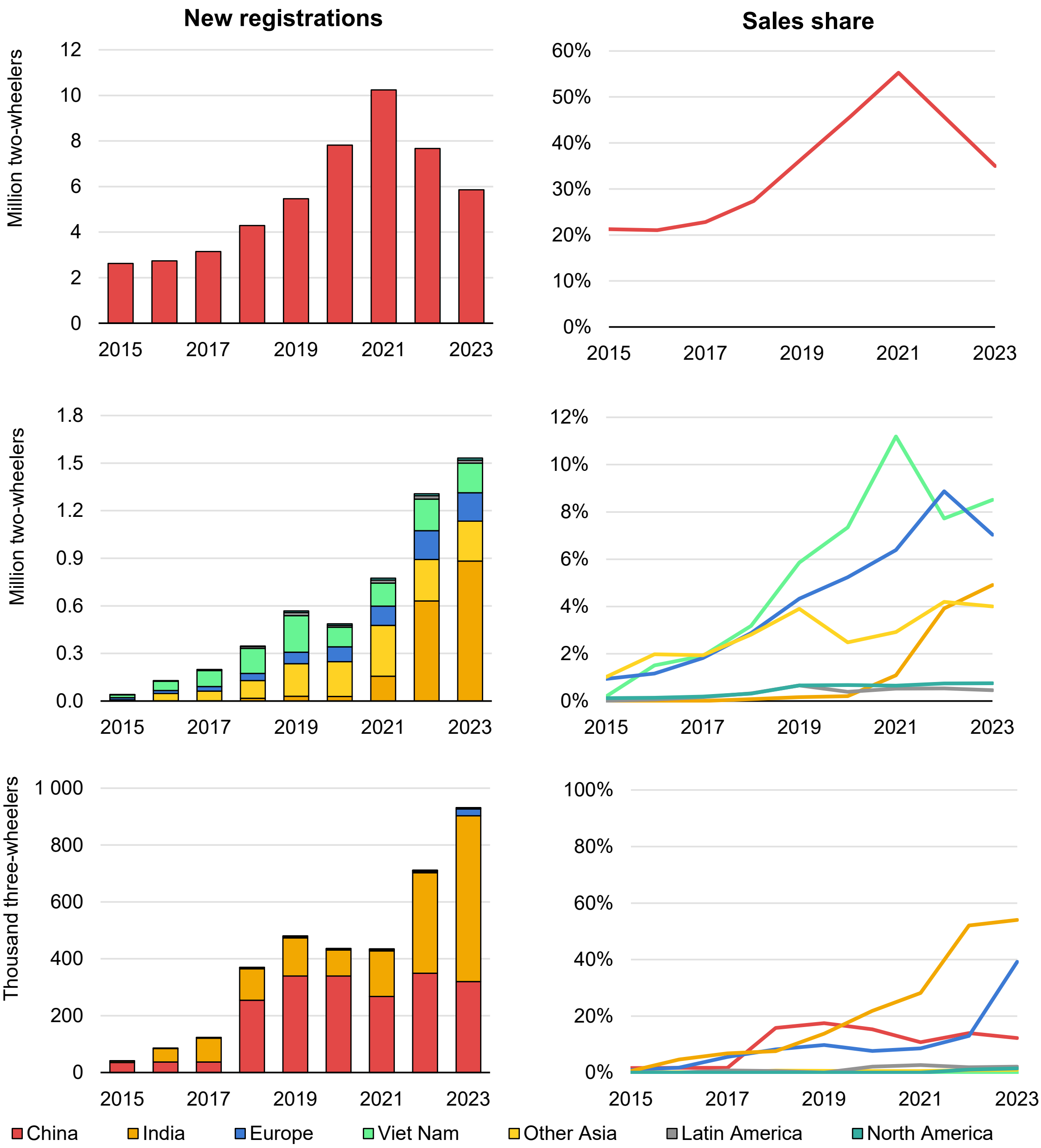
In India – the second-largest electric 2W market globally – 2023 sales grew by 40% compared to 2022. The Indian electric 2W market is dominated by the five largest domestic manufacturers (Ola Electric, TVS Motor, Ather, Bajaj and Ampere), which accounted for more than 75% of sales. The rapid growth seen in India is the result of strong policy support for EV deployment, such as the FAME II measure, which was first introduced in 2019 as a three-year purchase incentive policy. FAME II came to an end on 31 March 2024, and will initially be replaced by a new four-month subsidy extension scheme called the Electric Mobility Promotion Scheme (EMPS), announced in March 2024, which outlays over INR 4.9 billion (Indian rupees) (almost USD 60 million) to subsidise electric 2/3W purchases. The EMPS aims to support the roll-out of 372 000 additional electric 2/3Ws equipped with Li-ion batteries, bridging the gap between the FAME II scheme and potential future EV subsidies.

Other policies such as the supply-side incentives under the PLI scheme, Goods and Service Tax (GST) and Regional Transport Office (RTO) tax rebates, along with India’s Go Electric campaign, have all helped bolster electric 2W uptake. As an illustration of the effect of the latest subsidy schemes, in 2023, the sales-weighted average price of an electric 2W – after subsidies and tax rebates – was over 15% lower than its ICE equivalent, despite the upfront purchase price remaining around 30% higher on average. The savings potential of an electric 2W proves even more compelling from a TCO perspective. An electric 2W purchased in 2024 (assuming sales-weighted average prices from 2023) after 5 years of ownership would be more than 40% cheaper than its ICE equivalent over the same period (see figure below), despite the EMPS scheme offering reduced subsidies compared to FAME II.

Although sales decreased to 250 000 units in 2023, Viet Nam remains the most dynamic electric 2W market amongst ASEAN countries, with a 9% share of 2W sales. ASEAN countries have the specificity of having higher share of scooters relative to other types of 2W, along with a high share of models equipped with lead-acid batteries, which accounted for 68% of electric 2W sales in 2020. The Vietnamese electric 2W market is dominated by a handful of home-grown manufacturers (such as VinFast, Pega and Dibao), whose overall manufacturing production capacity exceeds the local domestic sales, thus giving them the capacity to export to other ASEAN country markets. Elsewhere, Indonesia is aiming to increase its domestic electric motorbike manufacturing, allocating USD 455 million in subsidies to reach 800 000 new electric motorcycle sales, along with the conversion of 200 000 conventional motorcycles.

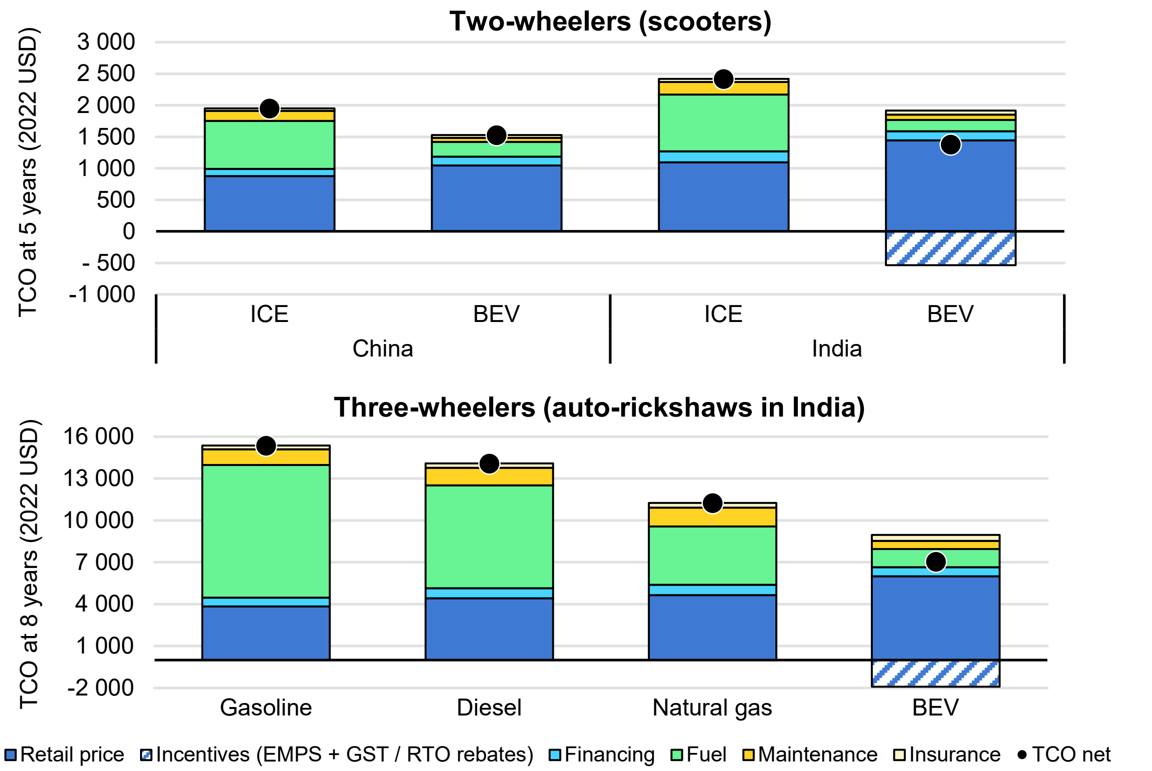
China, India, and all ASEAN countries remain far ahead of all other regions in terms of electric 2/3W sales, where other regions combined account for less than 5% of global sales. Türkiye ranks as the first market outside of Asia, followed by France, the Netherlands, Italy and Spain.

Electric two- and three-wheeler sales and sales share by region, 2015-2023



Notes: Other Asia includes Afghanistan, Bangladesh, Brunei, Cambodia, Lao People's Democratic Republic, Myanmar, Mongolia, Nepal, Pakistan, Singapore, Sri Lanka and Chinese Taipei.
Sources: IEA analysis based on country submissions and data from MotorcyclesData.com and AutocarPro.in.

Breakdown of total cost of ownership of two- and three-wheelers in China and India, 2023



Notes: TCO = total cost of ownership; ICE = internal combustion engine; BEV = battery electric vehicle; EMPS = Electric Mobility Promotion Scheme; GST = Goods and Service Tax; RTO = Regional Transport Office. In the upper part of the figure the sales-weighted average electric 2W purchased in 2023 is compared to its ICE equivalent in both China and India. We show the TCO after 5 years of service for 2Ws versus a TCO after 8 years of service for 3Ws bought in India in 2023. All TCO calculation assumptions are listed in Table 1 located in the general annex of this report.

Sources: IEA analysis based on retail price data from MotorcyclesData.com and BNEF, and fuel consumption data from BNEF in the case of auto-rickshaws.

India overtakes China as the largest market for electric three-wheelers as global sales continue to grow

Globally, the three-wheeler (3W) market grew 13% in 2023, to reach 4.5 million sales, 21% of which were electric, compared to 18% in 2022. Almost 1 million electric 3Ws were sold in 2023, reflecting 30% growth compared to 2022. The market is highly concentrated, with China and India together accounting for more than 95% of all electric and 80% of conventional 3W sales. India overtook China in 2023 to become the biggest market for electric 3Ws, with over 580 000 sales. India saw its sales increase by 65% with respect to 2022, thanks to government financial incentives and resulting reductions in the cost of ownership of electric 3Ws. Sales in China declined 8% in 2023, to 320 000, making the country the second-largest electric 3W market.

The Chinese market continues to have a high share of lead-acid batteries in sales, despite government efforts to ban this technology in low-speed EVs and encourage a transition towards Li-ion technology, motivated by environmental concerns associated with the afterlife of lead-acid batteries when not recycled properly. Due to their low upfront purchase price, lead-acid battery powered electric 3Ws remain a widespread transport technology across India and rural China. In India, estimates of their market share range from 55% to 98%. However, Li-ion batteries are expected to continue gaining ground in the Indian 3W market following the introduction of the 2024 EMPS subsidy scheme, which specifically aims to reduce the purchase price of models equipped with advanced battery chemistries.

In 2023 in India, despite the upfront price being 55% higher than for its gasoline equivalent, the average electric 3W model (auto-rickshaw) is more than 50% cheaper to own after 8 years of service, and even without subsidies is over 40% cheaper (see figure above). Even when considering the most cost-effective ICE 3W running on natural gas, the electric model achieves TCO parity as soon as 2 years after purchase, and works out about 40% cheaper over an 8-year lifetime. However, subsidies still play an important role, as without them, the TCO breakeven point is only reached after 4 years.

Electric light commercial vehicles

One in twenty-five light commercial vehicles sold in 2023 was electric, following the path set by passenger cars

The market for electric light commercial vehicles (LCVs) continued to increase in 2023. Global electric LCV sales grew by more than 50%, and the sales share grew to just under 5%.

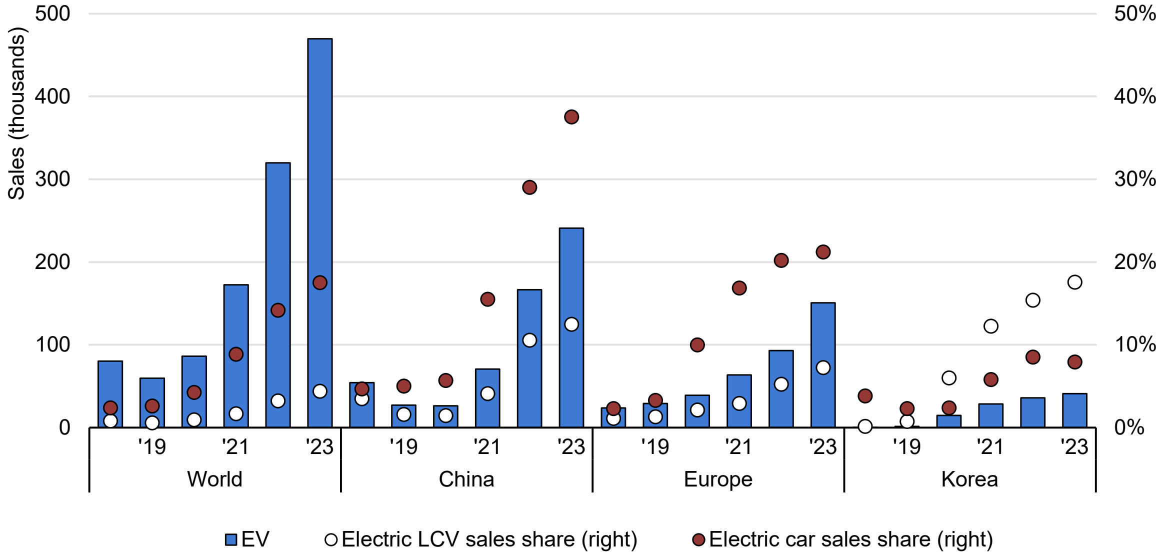
Two of the biggest electric LCV markets, China and Europe, saw a large increase in sales in 2023, as part of a broader trend of increasing LCV sales – both electric and ICE. In China, electric LCV sales exceeded 240 000, and in Europe, the electric LCV market leapt by 60% to reach almost 150 000.

As the electric LCV market matures, several OEMs have announced new electric models and new partnerships. Some of these new models are designed specifically for niche commercial activities, such as the B-ON Pelkan electric delivery van. In a partnership with Uber, Kia announced a modular van design with a body that can be swapped from shuttling to last-mile delivery depending on activity.

The average range of new LCVs increased by 55% between 2015 and 2023. For example, the two most popular electric LCV models in 2015 (Nissan e-NV200 and the Renault Kangoo BEV) had a range of around 170 km. This compares to a much longer range – between 210 and 260 km – demonstrated by two very popular models (Hyundai Porter and Ford E-Transit) in 2023. Despite this increase, companies expanding their electric fleets have called for improvements in the accuracy of range labelling.

Korea is the only country in which the penetration of electric LCVs is moving faster than electric passenger cars. In Korea, the Hyundai Porter and the Kia Bongo are the only electric LCV models sold. Both are produced by local manufacturers, and seem particularly suited for the Korean light freight market, which is characterised by shorter distances. These models are also favourably priced compared to ICE equivalents: The Kia Bongo 3 EV, for example, sells for around USD 25 000, including a subsidy of USD 7 700.

Electric light commercial vehicle sales and sales shares, 2018-2023



Notes: EV = electric vehicle; LCV = light commercial vehicle where weight is less than 3.5 tonnes. In China, LCVs include small-sized buses, some light-duty trucks and mini trucks. To better align with IEA classifications, a share of the light-duty trucks are considered as medium-duty trucks (defined here as having a gross vehicle weight greater than 3.5 tonnes and less than 15 tonnes).
Sources: IEA analysis based on country submissions data from EV Volumes, and Interact Analysis.

3. Trends in heavy electric vehicles

Electric truck and bus sales

The multiple benefits of city bus electrification boost adoption in advanced and emerging economies

Sales of electric buses, comprising all medium- and large-sized buses, are far ahead of those of other heavy-duty vehicle (HDV) segments (including medium- and heavy-duty trucks[10]). Several European countries (such as Belgium, Norway and Switzerland) and China achieved sales shares above 50% in 2023, and more than one-fifth of bus sales were electric in Canada, Chile, Finland, the Netherlands, Poland, Portugal and Sweden. Globally, almost 50 000 electric buses were sold in 2023, equating to 3% of total bus sales and bringing the global stock to approximately 635 000 in total. This relatively low share is primarily due to the limited sales shares in most EMDEs, as well as the low market penetration of electric buses in some larger markets such as the United States and Korea.

Early policy support for electrifying public transport, and the availability of domestically produced electric buses, coupled with incentives, meant that China took an early and significant lead in electric bus sales. In 2020, China was responsible for about 90% of electric bus sales worldwide. In 2023, this fell to around 60%, largely due to a decrease in domestic demand for both electric and ICE buses and, to a lesser extent, increasing sales in other regions. The fall in Chinese demand could be a consequence of the early success seen for electric buses – around 65% of China's electric bus stock was deployed before 2019. It may also be linked to the ending of purchase subsidies for BEV and PHEV buses at the end of 2022. Despite China's lead in global sales having shrunk, Chinese manufacturers continue to export large volumes of electric buses, accounting for over 85% of electric city bus deployments in Latin America. They have also increased their market share in the European Union from 10% of bus sales in 2017 to 30% in 2023, driven by companies such as Yutong and BYD.

City buses, in particular, have strong potential for electrification thanks to their relatively fixed driving patterns and lower daily travel distances, and have spearheaded growth in electric bus sales. In the European Union, BEVs reached a 43% sales share among city buses in 2023, demonstrating clear progress towards the proposed target of 100% of city bus sales being zero emission

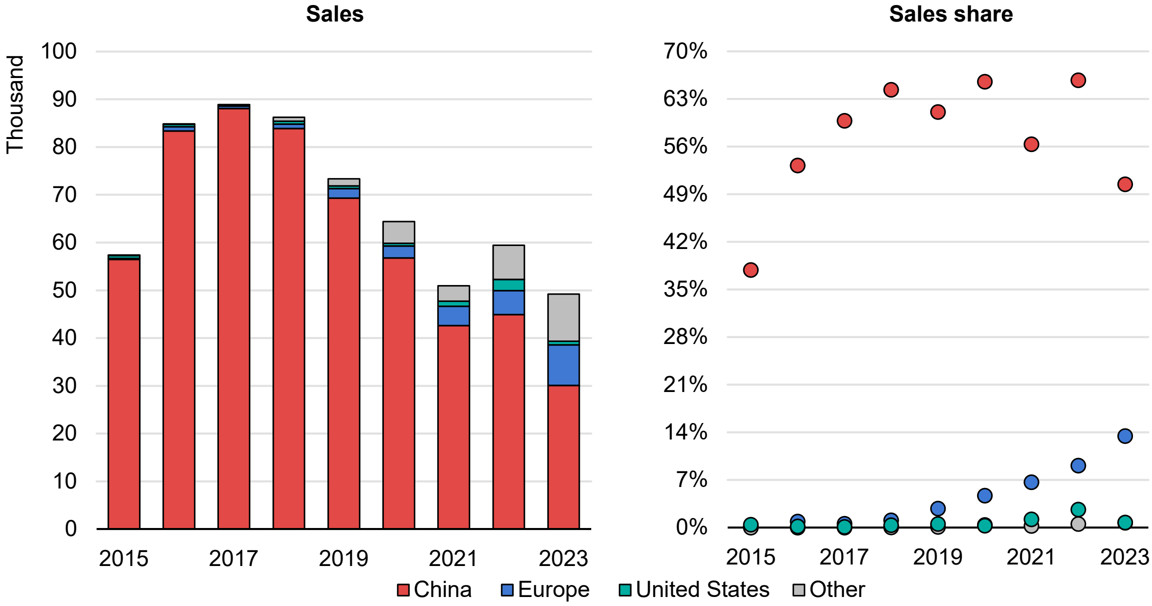
[10] "Trucks" refers to both medium (3.5-15 tonnes Gross Vehicle Weight [GVW]) and heavy (15 tonnes GVW and above) trucks.

vehicles (ZEVs) by 2035. Over the same period, just 1% of European Union coach sales were battery electric, though uptake is increasing there and around the world.

There has also been encouraging progress in EMDEs, where a focus on the co-benefits of electric buses – such as reduced air pollution and greater access to public transport – has boosted take-up. This has been further supported by the wide availability of electric buses in already competitive markets. Cities across Latin America, such as Bogota and Santiago, have deployed nearly 6 500 electric buses to date. BasiGo, Africa's largest electric bus company, has an order book of 350 buses, which represents almost 2% of electric bus sales outside of China in 2023, and aims to sell a further 1 000 electric buses in Kenya and 200 in Rwanda in the coming years.

Along with high potential for electrification of city buses, infrastructure developments can also support the transition. The bus rapid transit (BRT) system, which is based on the use of dedicated bus lanes with priority access at intersections and off-board fare collection, can support the establishment of high-capacity, efficient services for cities. The new all-electric BRT system in Dakar – the first on the African continent – is a strong example. This network, announced at the end of 2023, will serve 320 000 passengers per day. Elsewhere, the European bus rapid transit of 2030 (eBRT2030) scheme aims to improve the urban transport environment by developing innovative solutions for electric BRTs, with demonstrations in Amsterdam, Athens, Barcelona and Prague, among other cities.

Electric bus sales and sales share by region, 2015-2023



Notes: Only medium- and large-sized electric buses are included; minibuses and passenger vans are treated as light commercial vehicles.

Sources: IEA analysis based on country submissions and data from EV Volumes, as well as China EV100, CADA, CCVDA and Interact Analysis for sales data for China.

Electric truck sales are gaining momentum

Sales of electric trucks increased 35% in 2023 compared to 2022, meaning that total sales of electric trucks surpassed electric buses for the first time, at around 54 000. China is the leading market for electric trucks, accounting for 70% of global sales in 2023, down from 85% in 2022. In Europe, electric truck sales increased almost threefold in 2023 to reach more than 10 000 (>1.5% sales share). The United States also saw a threefold increase, though electric truck sales reached just 1 200, less than 0.1% of total truck sales.

We expect electric truck sales to continue to increase thanks to strong and ambitious policies, such as the European Union's CO_2 standards for HDVs, which target a 90% CO_2 emissions reduction by 2040. In the United States, the newly adopted heavy-duty emissions regulation is expected to result in ZEV sales shares of up to 60% by 2032 in different segments.

At the city level, zero emissions (or "green") zones for freight, are being implemented in 15 different cities as diverse as London, Los Angeles, Madrid, Quito, Shenzhen, Seoul and Taoyuan City. Together, these cities have a total population of over 52 million. In addition, initiatives such as EV100+, the Global Memorandum of Understanding on Zero-Emission Medium and Heavy Duty Vehicles co-led by Drive to Zero, the European Clean Trucking Alliance, the eTransport coalition, the First Movers Coalition–Trucking, and the Fleet Electrification Coalition have increased their membership. They continue to advocate for more ambitious policies, such as accelerated sales targets and zero emission government fleets.

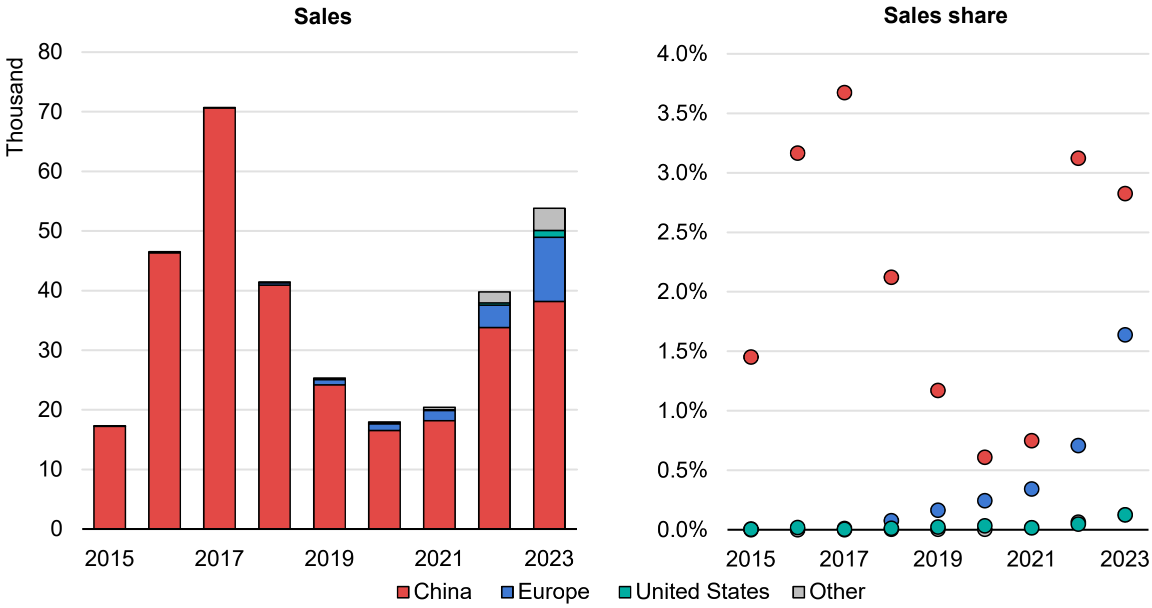
In the United States, there have been efforts to use demonstration projects to identify truck segments ripe for electrification. In June 2023, the North American Council for Freight Efficiency, together with the Rocky Mountain Institute, launched Run on Less – Electric DEPOT. Through this initiative, depots deployed almost 300 electric trucks of various sizes to gather telemetry data with the aim of identifying use cases where electric trucks are already a viable solution, as well as where challenges remain.

Similarly, the UK Government is investing USD 250 million under the Zero Emission HGV and Infrastructure Programme to run real-world trials of zero-emission trucks. The programme will deploy 370 trucks and almost 60 refuelling and electric charging sites.

Electric truck adoption is also gaining momentum in EMDEs outside of China. In India, NITI Aayog launched the Electric Freight Accelerator for Sustainable Transport, a platform to pioneer collaboration between the government and private sector partners for large-scale freight electrification. This initiative has spurred 16 major manufacturing and logistics companies to collectively signal demand for

7 750 electric freight vehicles by 2030. To meet this demand, focused efforts will be needed on policy regulation, establishing market certainty, scalable pilot support, infrastructure development, and creating blended financing platforms to attract private investments.

Electric truck sales and sales share by region, 2015-2023



Note: Trucks refers to medium- and heavy-duty freight trucks.
Sources: IEA analysis based on country submissions and data from EV Volumes, as well as China EV100, CADA, CCVDA and Interact Analysis for sales data for China .

Electric heavy-duty vehicle model availability

China produces the largest selection of battery electric heavy-duty vehicles

Chinese OEMs currently produce by far the largest number of models of battery electric HDVs – 430 in total – with a particular focus on buses suitable for urban public transport, which make up almost 40% of all models.[11] In 2021 alone, Chinese OEMs released almost 150 bus models, providing more choice and covering more applications in what was already the world's largest electric bus market. Since 2021, the number of additional new models has continued to grow, but with a more even distribution across different segments – over 65 new models

[11] Excludes minibuses, i.e. buses with 25 seats or fewer. Where the number of seats changes by 5 or less, variations of the same model are counted as one throughout this analysis. For the purposes of this calculation, buses suitable for urban public transport are defined as having a seating capacity of between 30 and 70.

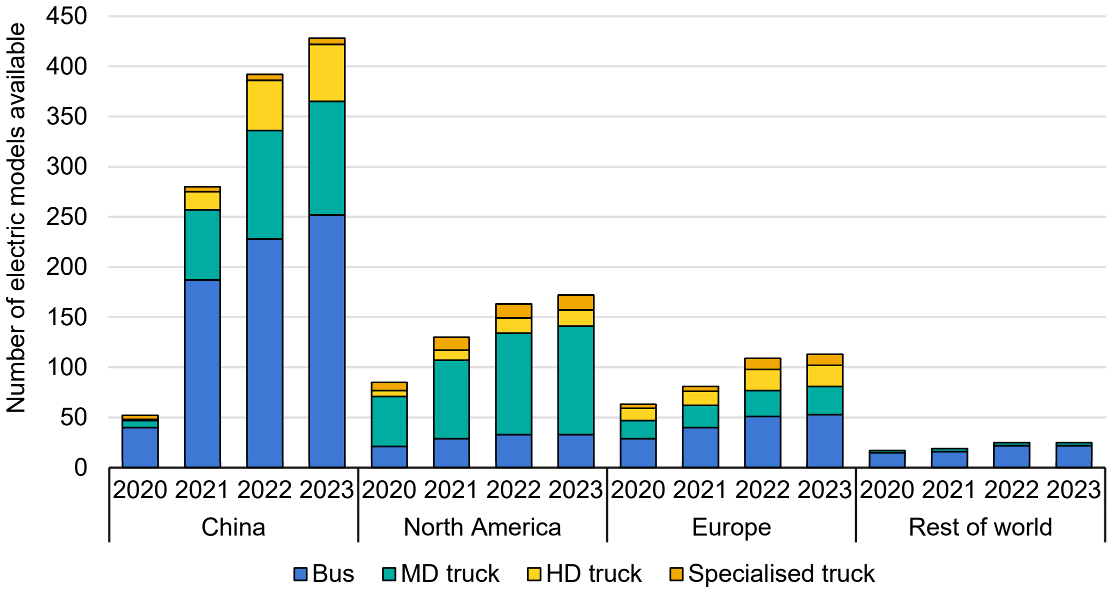
for buses, and around 40 each for medium-duty and heavy-duty trucks – thereby enabling wider electrification. A significant number of models is now available in each segment in China.

North American OEMs produce a far smaller number of battery electric models – over 170 – with a greater emphasis on the medium-duty truck market, which accounts for more than 60% of all models. New brands such as Rizon are targeting the electric medium-duty segment in North America, where despite their higher upfront costs, electric trucks are already competitive with diesel trucks in terms of total cost of ownership, especially when charged at depot as opposed to higher-cost public charging. Costs are even more competitive when factoring in incentives available in the United States and Canada. Though both the United States and Canada also have policy incentives specifically targeting buses, they have relatively small public transport markets and, as a consequence, buses suitable for urban public transport make up just over 10% of all models. Instead, OEMs have targeted the school bus niche, producing nine different models excluding minibuses.

Despite producing a lower number of battery electric models overall, at around 120, European OEMs offer the most even distribution of models across segments. They also have the highest share of heavy-duty trucks, with more than 20% of all models. This has allowed European OEMs, in particular the Volvo group (which includes the Mack, Renault, and Dongfeng (joint venture) truck brands), to gain a large share of not only the European, but also the North American heavy-duty electric truck market. European OEMs also produce a significant number of niche vehicles such as refuse trucks (around 10% of all models), which – like medium-duty trucks – are already cost-competitive with their ICE counterparts.

On average, individual Chinese OEMs produce more models across segments, which differentiates Chinese OEMs from those in other regions. Only about half of Chinese OEMs produce models for a single segment, compared to around 70% in North America and Europe.

Available battery electric heavy-duty vehicle models by original equipment manufacturer headquarters, type of vehicle and release date, 2020-2023



Notes: MD = medium-duty; HD = heavy-duty. This figure is based on a continuously updated inventory but may not be fully comprehensive due to new model announcements and small manufacturers not yet captured in the database. Values for 2020 include models released between 2016 and 2020 inclusive. The database contains coaches, school buses, shuttle buses, and transit buses, categorised here as "Bus", which refers to those with more than 25 seats. "MD truck" includes medium-duty (MD) trucks, MD step vans, and cargo vans with a gross vehicle weight (GVW) of greater than 3.5 t but less than 15 t. "HD truck" includes all freight trucks with a GVW of greater than 15 t. "Specialised truck" includes garbage/refuse trucks, concrete mixers, and other specialised mobile commercial trucks. Buses with 25 seats or fewer and light commercial vehicles, which have a GVW of less than 3.5 t, are excluded from this analysis. Vehicles of the same model that appear more than once in the database, but with small variations in specifications, such as battery capacity, payload or seating, are counted as one model.

Sources: IEA analysis based on the Global Drive to Zero ZETI tool database.

Model availability is a key indicator of the growing maturity of the battery electric HDV market, but the number of OEMs is also important for assessing competition and ability to meet future demand.

The number of OEMs producing electric HDVs in China trebled between 2020 and 2023, from 12 to 36, in response to increasing sales of electric trucks domestically, as well as increasing electric bus sales abroad. In addition to growth in the number of Chinese OEMs, companies such as BYD, Skywell, Dongfeng and Foton have also expanded their offerings, with models in the bus, MD truck, and HD truck segments, offering potential advantages in terms of economies of scale and supply chains. The strength of the domestic market may also have allowed Chinese firms to build more robust supply chains.

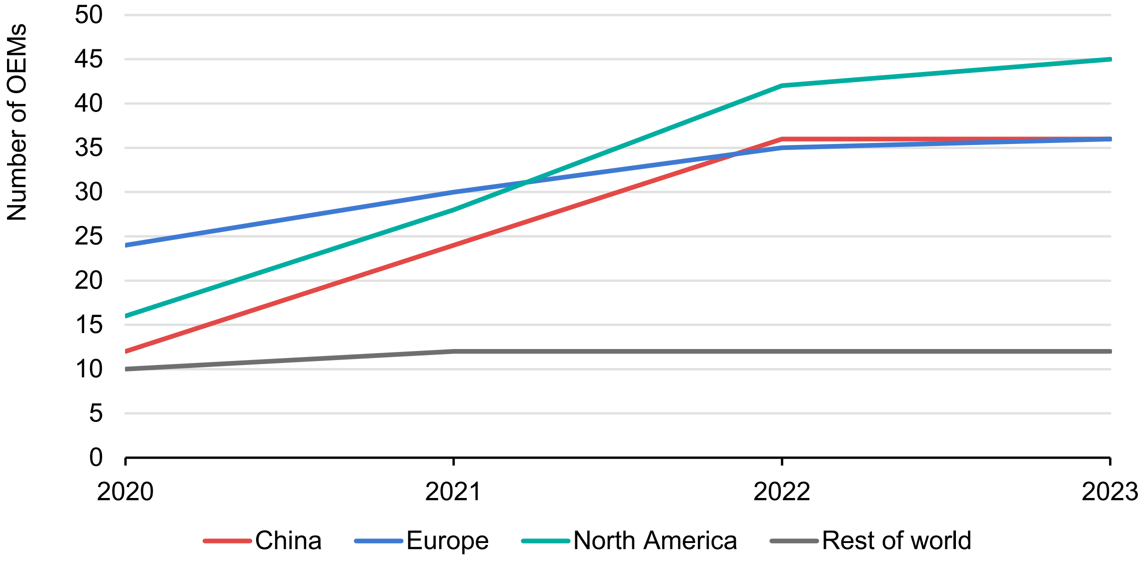
North America also experienced an almost threefold increase in the number of HDV OEMs between 2020 and 2023, from 16 to 45. Early support in states such as California and anticipation of national policies supported investment in HDV manufacturing, which was later boosted by demand incentives and regulations.

United States-based OEMs typically specialise in models for a smaller number of segments than Chinese OEMs. Only Lion offers vehicles in the bus, MD truck, and HD truck categories, along with Exro's recently acquired SEA Electric, which builds vehicles for different applications by adapting its powertrain to glider chassis platforms from other OEMs.

Europe had the highest number of HDV OEMs in 2020, but still saw a 50% increase between 2020 and 2023 to reach 36, the same number as China but less than the United States. Established OEMs such as Volvo Trucks, MAN, Mercedes, and Quantron offer vehicles in three or more segments. This wide range of offerings, coupled with an already strong position in the global market, and relatively low sales shares in Europe prior to 2023, meant there was less space for new entrants to compete.

Manufacturers in the rest of the world have not responded to the electric HDV opportunity in the same way, mirroring the slower uptake of electric HDVs to date and fewer supportive policies than in leading electric HDV markets. Of the OEMs outside of China, North America and Europe, nine produce models in the bus segment alone, with India's Tata Motors producing both buses and MD trucks. Korean OEM Hyundai produces only FCEV HDVs, while only three Japanese OEMs feature in the database.

Cumulative number of original equipment manufacturers that have released battery electric medium- and heavy-duty commercial vehicles by location of headquarters, 2020-2023



Notes: All original equipment manufacturers with at least one battery electric heavy-duty vehicle model in the database are included. Buses with 25 seats or fewer and light commercial vehicles, which have a gross vehicle weight of less than 3.5 t, are excluded from this analysis.

Sources: IEA analysis based on the Global Drive to Zero ZETI tool database.

4. Trends in electric vehicle charging

Charging for electric light-duty vehicles

There are almost ten times as many private chargers as public ones, with most owners charging at home

Home charging is currently the most common means of charging electric cars. EV owners with access to a private parking space that can be equipped for charging can charge overnight, which is not only convenient but also typically takes advantage of lower electricity prices while demand is relatively low.

The availability of home charging varies substantially between regions and is linked to differences in urban, suburban and rural populations, as well as income bracket. In dense cities, where most people live in multi-unit dwellings, access to home charging is more limited and EV owners rely more heavily on public charging. This is most apparent in Korea, which is one of the world's most densely populated countries and has the highest ratio of public charging capacity to EVs.

Though access to charging is different to actual use, it is a useful proxy for the levels of home charging among EV owners across countries. The share of EVs in new car sales is over 90% in Norway, whereas it stands at under 2% in Mexico, yet the shares of EV owners reportedly charging at home are similar, at 82% and 71%, respectively. The United Kingdom has one of the highest reported shares of access to home charging, at 93%, more than half of which are smart chargers.[12] This is partly due to the United Kingdom being the first country to release smart charge point regulations, but, importantly, it could also be attributed to the high share of early EV adopters that also own a home in which a charger can be installed. In India, 55% of consumers state that they have access to home charging today. Changes to building regulations in order to mandate chargers, as have been proposed by the European Union, are an effective way of increasing access over time, especially for people who live in rented accommodation.

In regions where the voltage of the power grid is 220V or above, EV owners can charge their vehicle from a regular domestic socket overnight. This is the most

[12] Smart chargers are defined in the study concerned as being chargers connected to the internet such that they can be operated remotely to optimise energy consumption.

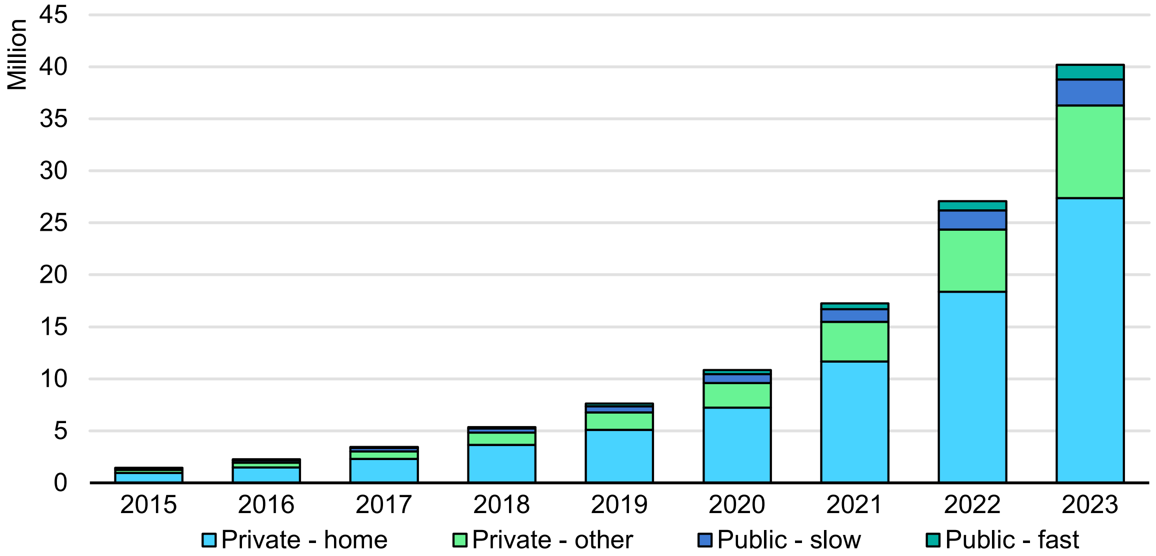
common case and holds true in Europe, Australia, large parts of Latin America, and most of Asia. In regions where the voltage is lower, typically 100-120V, recharging speeds from regular domestic sockets are much slower,[13] and can present a safety risk. As such, in countries with a 100-120V power grid, the ability to recharge in under ten hours requires installation of a dedicated charger.[14] This is the case in some countries where the share of EV charging at home is high, such as the United States (83%) and Canada (80%). However, it also includes developing countries with ambitious electrification targets, such as Indonesia, Costa Rica and Colombia, where both the cost (in the region of several hundred US dollars) and lower availability of private parking spaces may present significant hurdles to private charger installation. Reliance on more expensive public charging may therefore be higher. Beyond home charging, private charging also includes other non-publicly accessible chargers, such as chargers reserved for the employees, fleets or customers of certain establishments. There are, for example, 15 900 such private non-home chargers in the United States. In the European Union, over 250 000 chargers are described as having restricted access.

While home charging infrastructure is well established in many countries, the landscape for 2Ws is markedly different. Stock and sales of 2Ws continue to increase in India and the ASEAN countries. These growing markets also see growing momentum in battery swapping technologies, especially in India. In 2023, the Chinese Taipei-based battery-swapping company Gogoro announced a USD 2.5 billion partnership with the Indian State of Maharashtra. Gogoro intends to invest more than USD 1.5 billion in deploying smart battery infrastructure, which will include their battery swapping stations. Other Indian start-ups such as Sun Mobility and Battery Smart raised USD 50 million and USD 33 million, respectively, for further expansion of battery swapping infrastructure. Elsewhere, Africa has also seen increased investment in battery-swapping technologies for 2Ws. Ampersand, a Rwanda-based company, currently performs 140 000 monthly battery swaps to more than 1 700 customers that together travel 1.4 million km every week in Kigali and Nairobi. Spiro, an African electric 2W start-up, secured around USD 60 million in 2023 in order to expand its electric fleet and fund more than 1 000 swap stations.

[13] Assuming a fuel economy of 20 kWh/100 km and charger power of 1 kW, 10 hours of lower-voltage overnight charging can provide 50 km range to an electric car, whereas electric 2/3Ws have battery capacities of under 8 kWh and consume approximately 3 kWh/100 km, and can therefore fully charge in the same time.

[14] Dedicated chargers allow for AC charging above 3.7 kW and up to 22 kW.

Installed public and private light-duty vehicle charging points by power rating (public) and by type (private), 2015-2023



Notes: "Private – other" refers to charging points that are neither publicly accessible nor charging points at private residences. Home charging stock is estimated based on electric light-duty vehicle stock and regional assumptions on electric vehicle supply equipment (EVSE)/electric vehicle (EV) ratios.
Sources: IEA analysis based on country submissions.

Governments are strengthening support for public charging infrastructure

Although there are many more private chargers, public charging and the interoperability of its infrastructure is key to enabling more widespread adoption of and more equitable access to EVs. The public charging stock increased by more than 40% in 2023, and the growth of fast chargers – which reached 55% – outpaced that of slow chargers.[15] At the end of 2023, fast chargers represented over 35% of public charging stock.

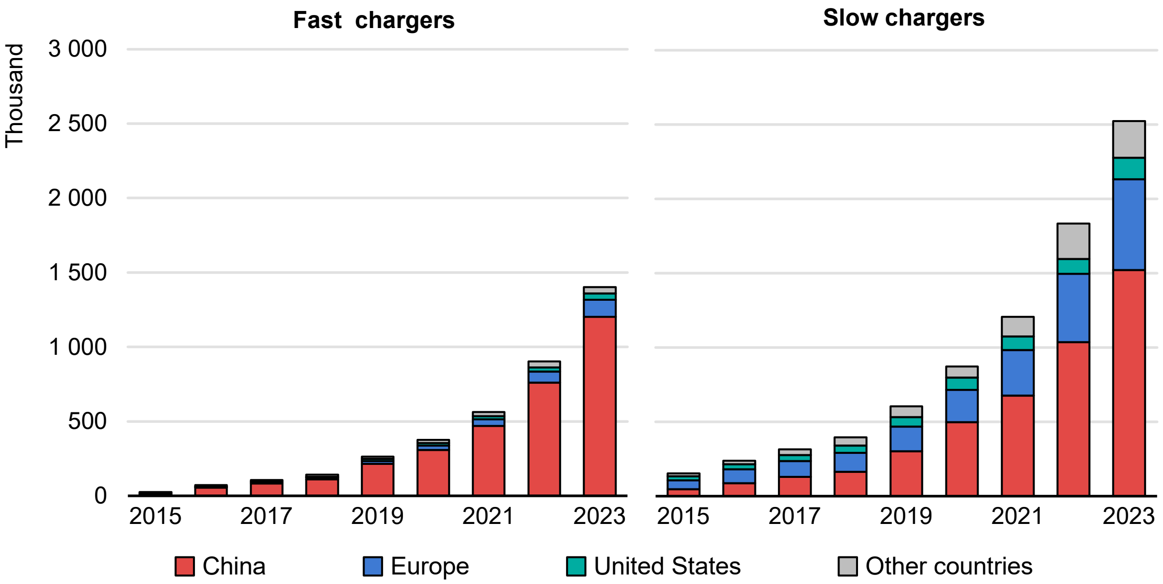
Overall, China leads electric vehicle supply equipment (EVSE) deployment, with more than 85% of the world's fast chargers, and around 60% of slow chargers. Having achieved an electric car sales share of over 35%, thus already surpassing their policy ambition for 2025, China is shifting focus to charging infrastructure development, targeting full coverage in cities and on highways by 2030, as well as expanded rural coverage. China has also begun to support more sustainable charging behaviour, with the aim that 60% of EV charging occurs off-peak by 2025, starting with five pilot cities.

[15] Slow chargers have power ratings less than or equal to 22 kW, whereas fast chargers have a power rating of more than 22 kW and up to 350 kW. "Charging points" and "chargers" are used interchangeably and refer to the individual charging sockets, reflecting the number of EVs that can charge at the same time.

In late 2023, the European Union agreed on the text of the alternative fuels infrastructure regulation (AFIR), which will require public fast chargers every 60 km along the European Union's main transport corridors (Trans-European Transport Network [TEN-T]). This will ensure that 1.3 kW of publicly accessible chargers are available for each registered BEV, and another 0.8 kW for each registered PHEV.

Other developed markets are also expanding support for EVSE while reducing funding for vehicle incentives. The United Kingdom has ended subsidies for private cars, but maintained incentives for private and public charging installations, with more than 53 600 installed as of 2023, and 300 000 public chargers expected by 2030. New regulations relating to payments and reliability also aim to improve the customer experience. Elsewhere, Korea has reduced the value of its EV subsidy while committing funding to EVSE. This has attracted additional private investment to the sector, and allowed for the installation of over 200 000 public chargers to date.

Installed publicly accessible light-duty vehicle charging points by power rating and region, 2015-2023



Note: Values shown represent number of charging points.
Source: IEA analysis based on country submissions.

In other countries, EVSE targets are being adopted alongside vehicle targets. New Zealand released its charging strategy in 2023, targeting one charging hub[16] every 150-200 km on main highways, and at least 600 charging stations installed in rural areas by 2028. The United States announced funding for new EVSE

[16] A charging hub is a centralised location equipped with multiple charging stations specifically designed for EVs.

projects, and has already installed more than 180 000 public chargers towards the goal of 500 000 by 2030, as well as funding the repair or replacement of existing chargers. Canada is currently on track to meet its target of 33 500 charging ports by 2026. Developing markets are also increasingly recognising the importance of EVSE, such as India, which provided funding for over 7 000 fast chargers in 2023.

As the number of public chargers grows, attention is also turning to the interoperability of charging infrastructure. In the United States, SAE International announced it would use Tesla's charging connector (J3400) as the standard across North America under the North American Charging Standard (NACS). The aim is to ensure that any supplier or manufacturer is able to use and deploy the connector, providing EV drivers with more options for reliable, convenient charging across North America.

Both the AFIR regulation in Europe, and the NACS in North America, are examples of legislation enacted to enhance interoperability of the charging infrastructure. Achieving greater interoperability across more regions will require enhanced collaboration amongst all stakeholders in order to agree common standards and protocols.

Public charging roll-out needs to keep pace with electric vehicle sales

Deployment of EV chargers should be co-ordinated with power grid developments to ensure that new connections are consistent with the wider grid-planning horizon. When not managed appropriately, charging can lead to a surge in peak demand, meaning that it is increasingly important to ensure that transmission and distribution grids are appropriately sized and equipped.[17] Strategies to manage charging, such as through time-of-use tariffs and smart-charging, will become more necessary as EV deployment grows.

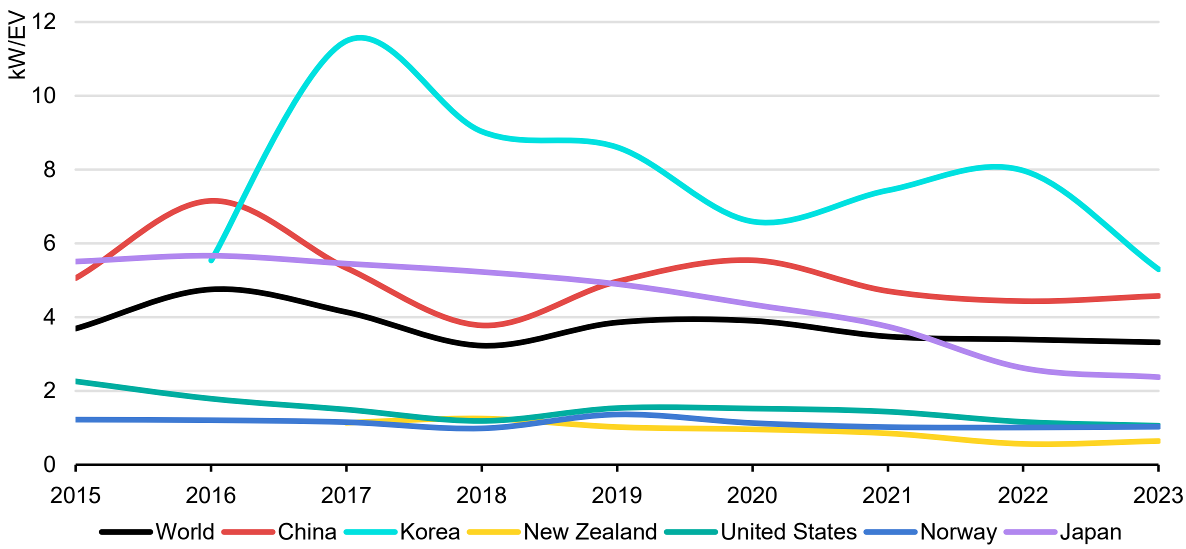
High ratios of publicly available charging capacity to EVs in use are crucial in regions where home charging is less accessible, and can help improve the consumer experience more widely. Sufficient coverage reduces concerns about range, and can allow for vehicles with lower battery capacity, thereby reducing costs and critical material demand. Accurately planning for the most appropriate ratio can prove challenging due to the varying supply and demand dynamics within individual countries. Insufficient public charging infrastructure (high EV:EVSE ratio) could lead to considerable customer inconvenience, while excessive

[17] Further information on the impact of EV charging on the electricity grid can be found in the IEA's Electricity Grids and Secure Energy Transitions report.

infrastructure (low EV:EVSE ratio) may prove uneconomical. Finding an appropriate balance is important to ensuring optimal utilisation and satisfaction among EV users.

It may be more relevant to consider the total charging capacity per EV rather than EV:EVSE ratio, given that fast chargers can serve more EVs per day than slow chargers. In the initial phases of infrastructure development, the ratio of charging capacity to EV is generally high, given that charger usage will likely be low until the market matures. As the market matures and utilisation increases, the capacity per EV tends to decrease.

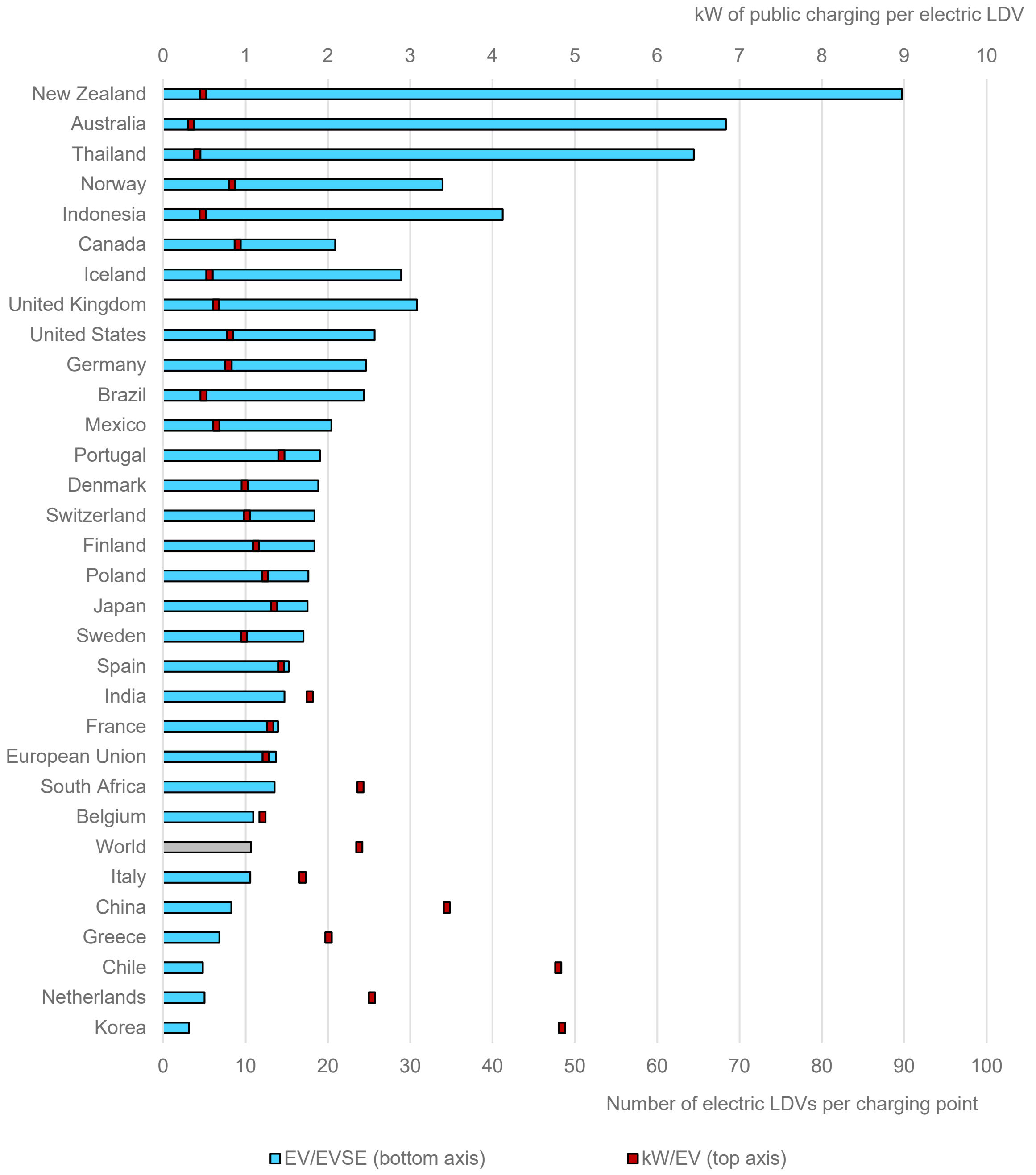
Charging capacity per electric light-duty vehicle, 2015-2023



Notes: Kilowatts per EV are estimated assuming 11 kW for slow and 50 kW for fast chargers. Official national statistics, which benefit from access to more granular data, may differ from these values.
Sources: IEA analysis based on country submissions.

Connecting cities through EVSE along motorways is a priority for a number of governments. In 2023, the Australian Government announced that it will provide AUD 39.3 million (Australian dollars) to the National Roads and Motorists' Association, through the Driving the Nation Fund, to build EV chargers along national highways. This proposal (like that of New Zealand) aims to install chargers every 150 km along eligible routes.

Number of electric light-duty vehicles per public charging point and kilowatt per electric light-duty vehicle, 2023

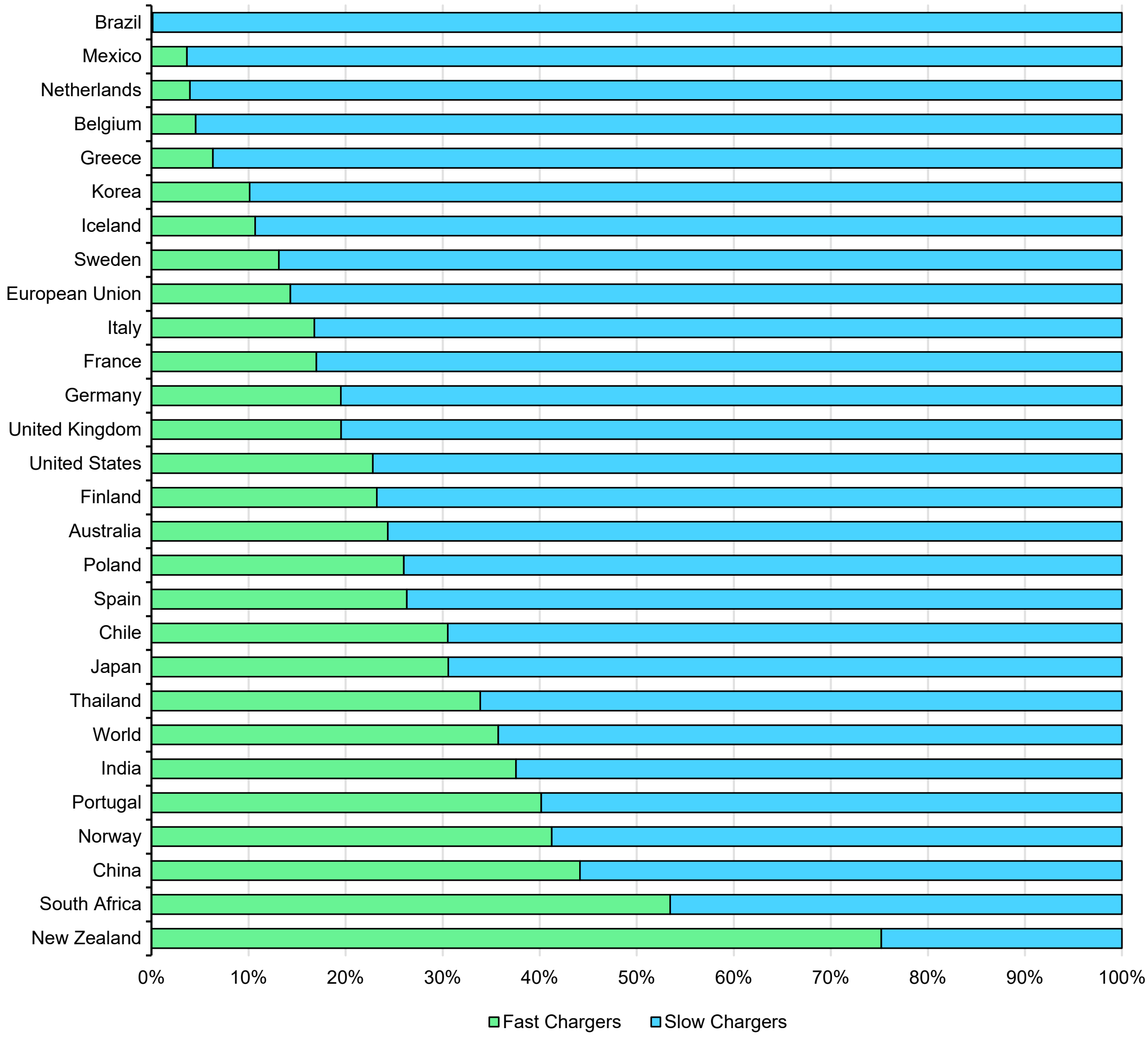


Notes: EV = electric vehicle; EVSE = electric vehicle supply equipment; LDV = light-duty vehicle. Kilowatts per EV are estimated assuming 11 kW for slow and 50 kW for fast chargers. Official national statistics, which rely on more granular data, might differ from these values.

Sources: IEA analysis based on country submissions

Charging ratios also illustrate the differing priorities of governments with regards to slow versus fast charging. Although New Zealand has the most vehicles per charger, it is ahead of countries such as Australia and Thailand when considering charging capacity per EV. This can be attributed to New Zealand prioritising fast public chargers over slow, resulting in the highest proportion of fast chargers to slow chargers globally, standing at 75%. Similarly, the next highest proportions globally are observed in South Africa, China, and Norway, with 53%, 44% and 41%, respectively. At the other end of this spectrum lie countries such as Brazil, the Netherlands and Korea, which have installed more slow public chargers, with the share of fast public chargers representing 0.1%, 4% and 10%, respectively.

Proportion of fast and slow public chargers in total public chargers, 2023



Notes: Assuming 11 kW for slow and 50 kW for fast chargers. Official national statistics, which rely on more granular data, might differ from these values.
Sources: IEA analysis based on country submissions.

Charging for electric heavy-duty vehicles

Dedicated charging for heavy-duty vehicles is the next frontier

Electric HDVs can generally use the same charging points as LDVs, but the larger size of both the vehicle and battery, and the resulting longer charging times required can disrupt normal operations, ultimately creating a need for dedicated equipment and facilities. HDV charging facilities of this kind are still in the early stages of large-scale development and deployment.

Progress is being made globally on developing standards for megawatt-scale chargers, with the aim of achieving maximum interoperability for electric HDVs. This will be essential to enable a fast roll-out of the charging technology, and mitigate any potential risks and challenges faced by vehicle manufacturers, importers, international operators and equipment providers. In 2023, the European Union and United States produced a set of recommendations for charging infrastructure, including the harmonisation of standards between the two regions. In essence, this provided recognition of the adoption of the megawatt charging system (MCS) – which allows charging capacity up to 3.75 MW – by international standardisation organisations such as SAE International and the International Organization for Standardization (ISO). Some companies such as Kempower, who mainly operate in Europe but are expanding globally, are expected to introduce chargers designed to operate at up to 1.2 MW in 2024, ahead of the formal standardisation of the MCS, though this is not expected to cause issues of divergence. In Asia, predominantly in China and Japan, the ChaoJi-2 began demonstration in late 2023. Although ChaoJi-2 has a lower power rating than the MCS (up to 1.2 MW), it allows for compatibility with existing standards in the region.[18]

In March 2024, the United States released the National Zero-Emission Freight Corridor Strategy. This sets out a phased approach to electrifying road freight, starting with establishing charging hubs at locations such as rail yards and airports, before expanding the network with the aim of achieving full coverage sometime between 2035 and 2040. Smaller demonstrations have also been undertaken, such as the Run on Less – Electric DEPOT scheme, through which around 140 charging points were installed at 10 depots across the United States. According to data collected by the Atlas EV Hub, a further 210 charging points are already operating in the United States to serve electric trucks, and another 1 020 are planned, around 75% of which are due to be completed in 2024. The weighted

[18] Maximum powers are based on specifications of 1 250 V and 3 000 A for MCS, and 1 500 V and 800 A for ChaoJi.

average capacity of chargers whose power was included in the database is 180 kW, with almost 95% being direct current fast chargers.

To date, there are around 160 truck-specific charging points deployed in Europe. In early 2023, Europe's first truck charging corridor was launched along a 600 km stretch of the Rhine-Alpine corridor, one of the busiest road freight routes in Europe. All 6 public charging locations are fitted with 300 kW charging points. The company behind the corridor, BP pulse, is also electrifying one of the largest truck stops in the United Kingdom.

Looking forward, the EU AFIR details the progressive roll-out of minimum coverage and capacity for HDV charging stations, specifying that each station must include at least one charger of at least 350 kW power output by the end of 2025. Alongside national policies, AFIR has sparked the creation of several pilot programmes dedicated to charging HDVs using MCS charging, such as HoLa, ZEFES, HV-MELA-BAT, and a joint ABB and Scania project. In late 2023, Milence, an independent joint venture established by Traton, Volvo and Daimler, presented their HDV charger. In collaboration with Hitachi Energy, they plan to build 1 700 public charging points across Europe by 2027, based on the MCS.

Although high-powered charging can enable the decarbonisation of freight, it may also present challenges for the electricity grid, like fluctuations in power quality or supply-demand imbalances. These imbalances can cause grid congestion at the local level, and could affect entire regions where there is a large electric HDV fleet. Some countries, such as the Netherlands, are already developing policies to anticipate these issues. One way to mitigate challenges and avoid peak demand is through stationary storage batteries that are co-located with high-powered chargers. This solution would require significant capital expenditure (CAPEX) for the installation of large, stationary batteries, but it could also offer new revenue streams to charging station owners, such as through electricity price arbitrage or grid services provision. Co-locating renewable sources close to charging hubs can also decrease the stress on the local power grid. The electricity grid is a key enabling technology for HDV electrification, and careful planning and investment will be required in order to accommodate new loads. For further analysis of the impacts of HDV charging on the electricity grid, see the Outlook for electric vehicle charging infrastructure later in this report, as well as the recently published Electricity Grids and Secure Energy Transitions.

More innovative solutions, such a battery swapping and electric road systems, can also play a role

Alternative solutions for HDV charging may reduce uncertainty about the system-level costs associated with high-powered charging, and can already compete favourably in terms of total capital and operating costs. Two such solutions are battery swapping and electric road systems, both of which can potentially offer significant advantages compared to high-powered charging.

Battery swapping can be completed in as little as five minutes, can help to extend battery life through more controlled charging, and can spread power demand over a longer period, thus reducing pressure on the electricity grid. Battery swapping is currently most developed in China, where it has been encouraged by national and local governments since 2020. As many as half of electric heavy-duty trucks sold in 2023 were enabled with battery-swapping technology. In late 2022, SAIC launched a joint venture to set up around 40 battery swapping stations in cities such as Beijing, Guangzhou, Shanghai and Shenzhen, with the aim of installing 3 000 stations by 2025. In 2023, CATL, the world's largest producer of EV batteries, launched QIJI Energy, an all-in-one heavy-duty truck chassis battery-swapping solution, which aims to reduce costs by building upon existing battery technology.

Electric road systems (ERS) allow vehicles to charge while they are driving, using one of three main technologies: induction between the vehicle and the road, conduction connections between the vehicle and road, or catenary lines.[19] With increased access to charging through ERS, vehicles would require less battery capacity, leading to reduced battery demand and a more equal distribution of power demand throughout the day, with the trade-off being a greater and more distributed overall infrastructure requirement. ERS have significantly progressed in countries including Sweden, France, Germany, Italy, Israel and the United States. In 2023, Sweden became the first country in the world to commit to turning a highway into a permanently electrified road. Though the exact charging method has yet to be decided, the planned road should open to the public by 2025, with up to 3 000 km of further road expansion by 2045. In France, a study for the Ministry of Transport on the impact of ERS concluded that it could reduce CO_2 emissions by 86% for road freight trucks that currently run on diesel. The installation of nearly 5 000 km of ERS by 2030 has been proposed, and the first stage of this project is expected in 2024 with a proof of concept being installed on 2 km of motorway to the southwest of Paris. In Germany, a catenary system was installed over 10 km of motorway in 2019 as part of a pilot trial, and a further 7 km have since been added , with long-term aspirations for the entire A5 motorway to be fitted with ERS. Other countries such as Italy and Israel have already completed proof-of-concept trials run by Electreon.

[19] Catenary lines can only be used for HDVs due to the suspension of overhead wires for delivering electricity. Conductive charging works for both HDVs and LDVs where there is a conductive system embedded in the road.

5. Trends in electric vehicle batteries

Battery supply and demand

Demand for batteries and critical minerals continues to grow, led by electric car sales

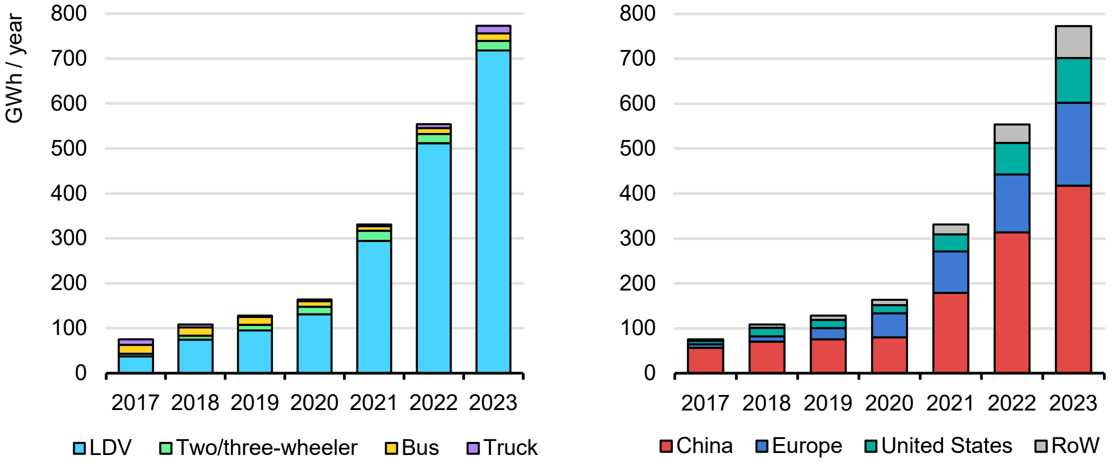
Increasing EV sales continue driving up global battery demand, with fastest growth in 2023 in the United States and Europe

The growth in EV sales is pushing up demand for batteries, continuing the upward trend of recent years. Demand for EV batteries reached more than 750 GWh in 2023, up 40% relative to 2022, though the annual growth rate slowed slightly compared to in 2021-2022. Electric cars account for 95% of this growth. Globally, 95% of the growth in battery demand related to EVs was a result of higher EV sales, while about 5% came from larger average battery size due to the increasing share of SUVs within electric car sales.

The United States and Europe experienced the fastest growth among major EV markets, reaching more than 40% year-on-year, closely followed by China at about 35%. Nevertheless, the United States remains the smallest market of the three, with around 100 GWh in 2023, compared to 185 GWh in Europe and 415 GWh in China. In the rest of the world, battery demand growth jumped to more than 70% in 2023 compared to 2022, as a result of increasing EV sales.

In China, PHEVs accounted for about one-third of total electric car sales in 2023 and 18% of battery demand, up from one-quarter of total sales in 2022 and 17% of sales in 2021. PHEV batteries are smaller than those used in BEVs, thereby contributing less to increasing battery demand. In recent years, Chinese carmakers have also been marketing more extended-range EVs (EREVs), which use an electric motor as their unique powertrain but have a combustion engine that can be used to recharge the battery when needed. EREVs typically have a battery size about twice that of a PHEV, enabling a real-world electric range of around 150 km compared to 65 km for traditional PHEVs. With an ICE on board, EREVs can reach ranges of around 1 000 km when needed. In 2023, EREVs accounted for 25% of PHEV sales in China, up from about 15% in 2021-2022. Negligible EREV sales are recorded in other regions.

Electric vehicle battery demand by mode and region, 2017-2023



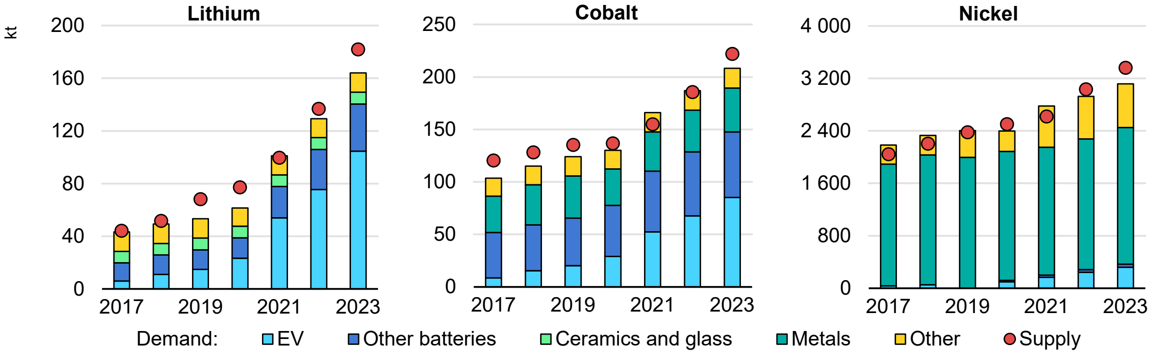
Notes: LDV = light-duty vehicle, including cars and vans; RoW = rest of the world.
Source: IEA analysis based on data from EV Volumes.

More batteries means extracting and refining greater quantities of critical raw materials, particularly lithium, cobalt and nickel

Rising EV battery demand is the greatest contributor to increasing demand for critical metals like lithium. Battery demand for lithium stood at around 140 kt in 2023, 85% of total lithium demand and up more than 30% compared to 2022; for cobalt, demand for batteries was up 15% at 150 kt, 70% of the total. To a lesser extent, battery demand growth contributes to increasing total demand for nickel, accounting for over 10% of total nickel demand. Battery demand for nickel stood at almost 370 kt in 2023, up nearly 30% compared to 2022.

High levels of investment in mining and refining in the past 5 years have ensured that global supply can comfortably meet demand today, not only for EVs but also in historical markets including portable electronics, ceramics, metals and alloys. In 2023, the supply of cobalt and nickel exceeded demand by 6.5% and 8%, and supply of lithium by over 10%, thereby bringing down critical mineral prices and battery costs. While low critical mineral prices help bring battery costs down, they also imply lower cash flows and narrower margins for mining companies. Compared to just a few years earlier, overcapacity means that many companies are now struggling to stay afloat (see later section on trends in the EV industry). Mining and refining will need to continue growing quickly to meet future demand, to avoid supply chain bottlenecks and make supply chains more resilient to potential disruptions. Doing so will also require striking a balance between remaining profitable while competing on prices. Innovative technologies such as sodium-ion batteries can potentially mitigate demand for critical minerals, together with the rise of mature battery chemistries requiring lower amounts of critical metals, such as lithium iron phosphate (LFP).

Supply and demand of battery metals by sector, 2017-2023



Notes: EV = electric vehicle. The metals category includes alloying applications. Supply refers to refinery output and not mining output.
Sources: IEA analysis based on data on lithium and cobalt global supply-demand balance (January 2024) and nickel global supply-demand balance (January 2024) from S&P Global, USGS Mineral Commodity Summary 2023, and World Metal Statistics Yearbook by the World Bureau of Metal Statistics.

Battery production is located close to demand centres, with international partnerships playing an important role in global expansion

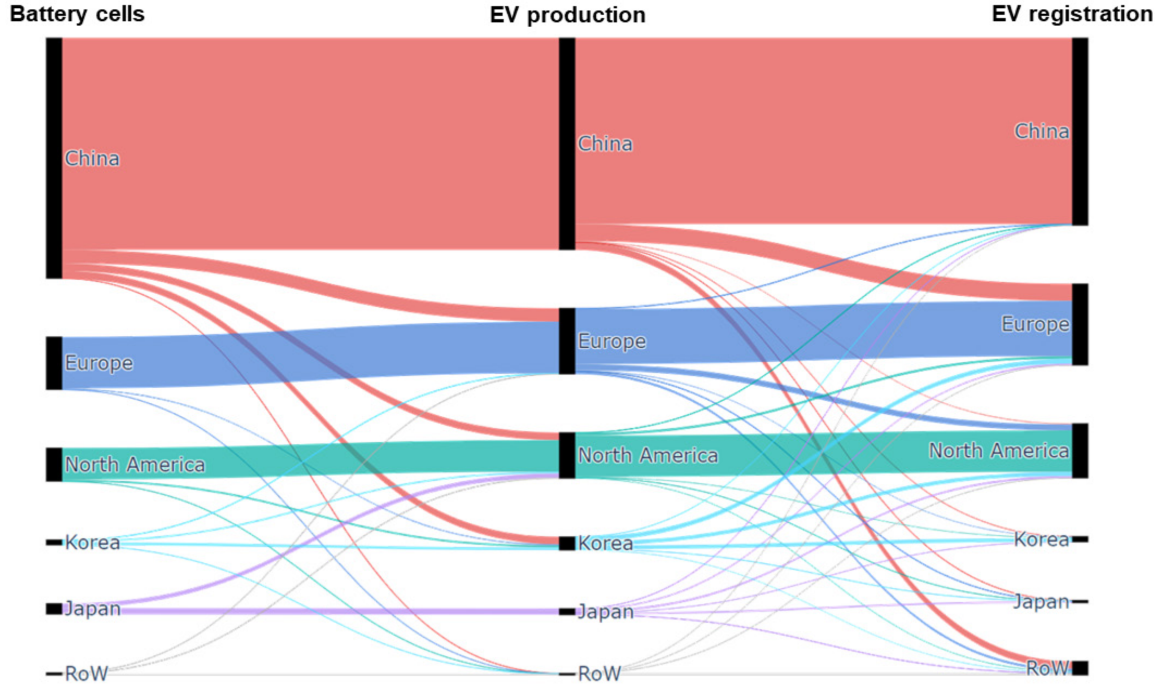
The majority of battery demand for EVs today can be met with domestic or regional production in China, Europe and the United States. However, the share of imports remains relatively large in Europe and the United States, meeting more than 20% and more than 30% of EV battery demand, respectively. China is the world's largest EV battery exporter, with around 12% of its EV batteries being exported.

Production in Europe and the United States reached 110 GWh and 70 GWh of EV batteries in 2023, and 2.5 million and 1.2 million EVs, respectively. In Europe, the largest battery producers are Poland, which accounted for about 60% of all EV batteries produced in the region in 2023, and Hungary (almost 30%). Germany leads the production of EVs in Europe and accounted for nearly 50% of European EV production in 2023, followed by France and Spain (with just under 10% each).

Battery production in China is more integrated than in the United States or Europe, given China's leading role in upstream stages of the supply chain. China represents nearly 90% of global installed cathode active material manufacturing capacity and over 97% of anode active material manufacturing capacity today. The only countries with significant shares of cathode active material manufacturing capacity outside of China today are Korea (9%) and Japan (3%). Different supply chains are, however, required for different chemistries. China is home to almost 100% of the LFP production capacity and more than three-quarters of the installed lithium nickel manganese cobalt oxide (NMC) and other nickel-based chemistries production capacity, compared to 20% in Korea. LFP is the most prevalent chemistry in the Chinese electric car market, while NMC batteries are more common in the European and American electric car markets.

China's current leading role in battery production, however, comes at the cost of high levels of overcapacity. In 2023, excluding portable electronics, China used less than 40% of its maximum cell output,[20] and cathode and anode active material installed manufacturing capacity was almost 4 and 9 times greater than global EV cell demand in 2023. To take advantage of some of this excess capacity, China is the biggest exporter of EV cells, cathodes and anodes globally. However, this has significantly decreased producers' margins, which may put some at risk if they do not find enough customers outside of China.

Global trade flows for lithium-ion batteries and electric cars, 2023



Notes: EV = electric vehicle; RoW = Rest of the world. The unit is GWh. Flows represent battery packs produced and sold as EVs. Battery net trade is simulated accounting for the battery needs of each region for each battery manufacturer, and assuming that domestic production is prioritised over imports. The eventual gap between domestic production and battery needs is filled through imports, which is assigned as a function of the unused manufacturing capacity of the other regions after satisfying their internal demand. This analysis does not consider battery production for stationary or portable electronics applications or stockpiling.

Sources: IEA analysis based on data from Benchmark Mineral Intelligence and EV Volumes.

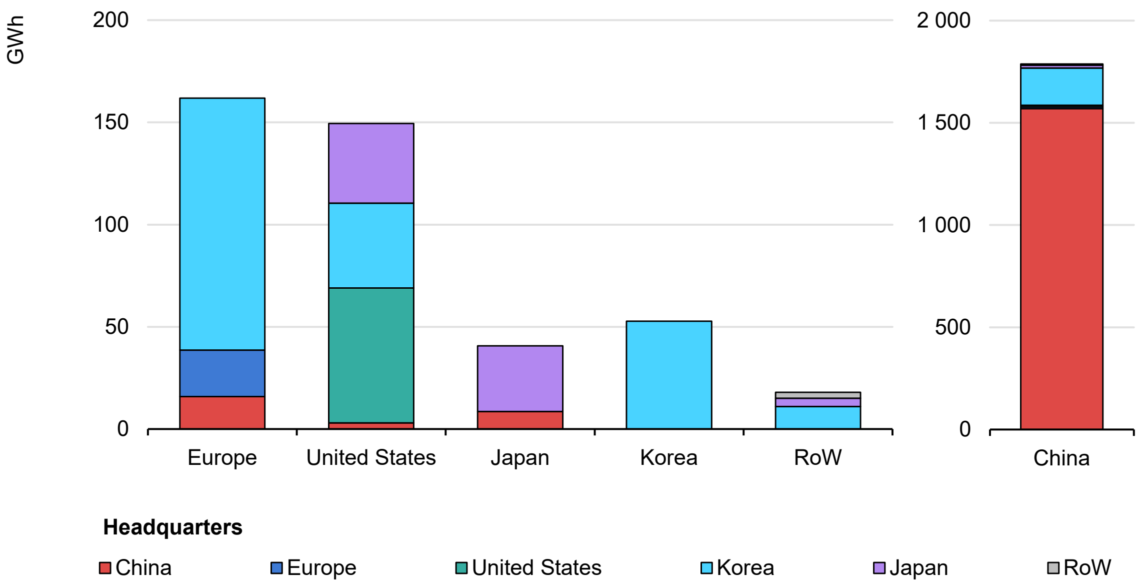
In 2023, the installed battery cell manufacturing capacity was up by more than 45% in both China and the United States relative to 2022, and by nearly 25% in Europe. If current trends continue, backed by policies like the US IRA, by the end

[20] Maximum output refers to an average utilisation factor of 85%.

of 2024, capacity in the United States will be greater than in Europe. As manufacturing capacity expands in the major electric car markets, we expect battery production to remain close to EV demand centres through to 2030, based on the announced pipeline of battery manufacturing capacity expansion as of early 2024.

At the same time, international co-operation and trade in battery technologies will continue to underpin EV market expansion. Just as for current capacity, announcements for additional EV battery manufacturing capacity in Europe and the United States are primarily made by foreign companies headquartered in Asia. Korean companies, for example, account for over 350 GWh in manufacturing capacity outside Korea, Japanese companies for 57 GWh outside Japan, and Chinese companies for just under 30 GWh outside China. About 75% of existing European manufacturing capacity is owned by Korean companies, with LG's plant in Poland accounting for 50% alone. Capacity in the United States is currently led by four companies: Tesla, Panasonic, SKI and LG. China's capacity is slightly more fragmented across different manufacturers, but the three largest producers – CATL, BYD and Gotion – account for nearly 50% of domestic capacity.

Installed regional lithium-ion battery cells manufacturing capacity by location of manufacturer headquarters, 2023



Notes: RoW = Rest of the world. Lithium-ion battery manufacturing capacity in China, Europe, United States, Japan, Korea, and other countries sorted as a function of the company headquarters location. Installed manufacturing capacity refers to EV-batteries only.

Sources: IEA analysis based on data from Benchmark Mineral Intelligence.

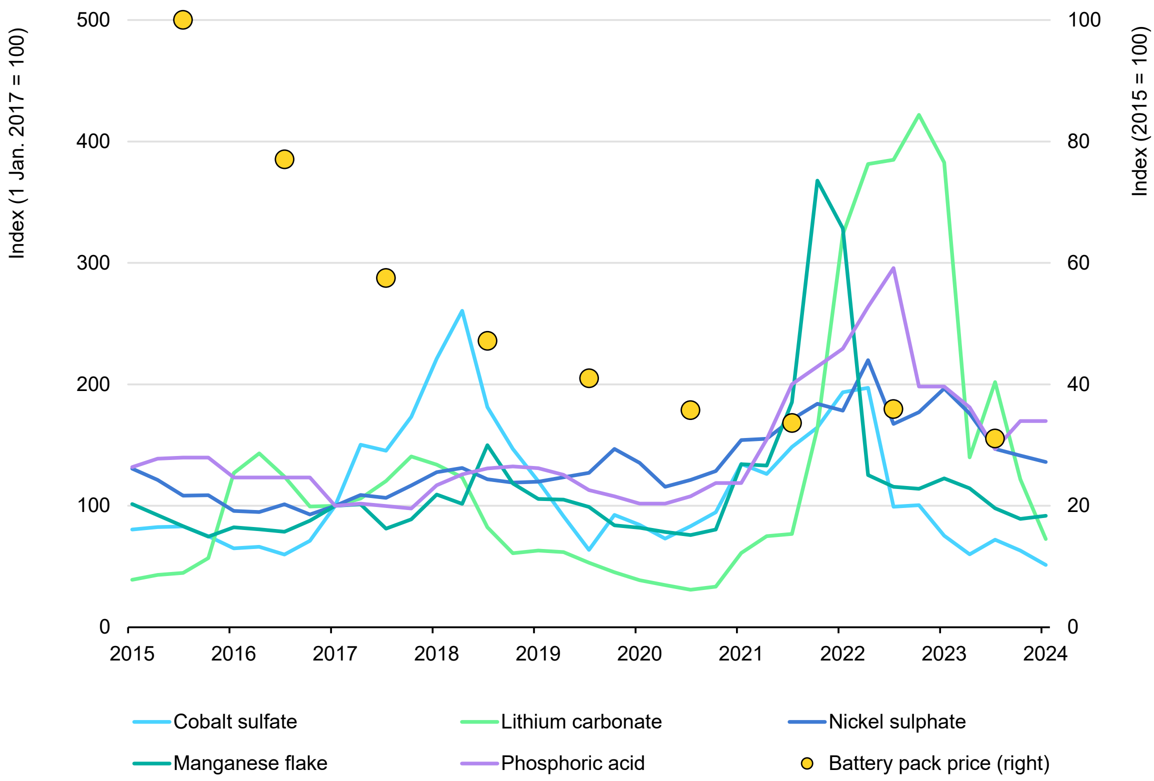
Battery prices

Electric vehicle battery prices start falling again

Stabilising critical mineral prices led battery pack prices to fall in 2023

Turmoil in battery metal markets led the cost of Li-ion battery packs to increase for the first time in 2022, with prices rising to 7% higher than in 2021. However, the price of all key battery metals dropped during 2023, with cobalt, graphite and manganese prices falling to lower than their 2015-2020 average by the end of 2023. This led to an almost 14% fall in battery pack price between 2023 and 2022, despite lithium carbonate prices at the end of 2023 still being about 50% higher than their 2015-2020 average. The last year in which battery price experienced a similar price drop was 2020.

Price of selected battery metals (left) and lithium-ion battery packs (right), 2015-2024



Note: "Battery pack price" refers to the volume-weighted average pack price of lithium-ion batteries over all sectors.
Sources: IEA analysis based on data from Bloomberg and Bloomberg New Energy Finance Lithium-Ion Price Survey (2023).

In relative terms, the LFP chemistry was most affected by the surge in battery mineral prices in the last two years. Lithium is the only critical mineral in LFP, and its price grew more than that of other minerals, and remained above historical averages for longer. In comparison, NMC batteries were less than 25% more expensive than their LFP equivalents in 2023, down from a premium of 50% in 2021. LFP batteries remain significantly cheaper than NMC, and their price has recently decreased rapidly.

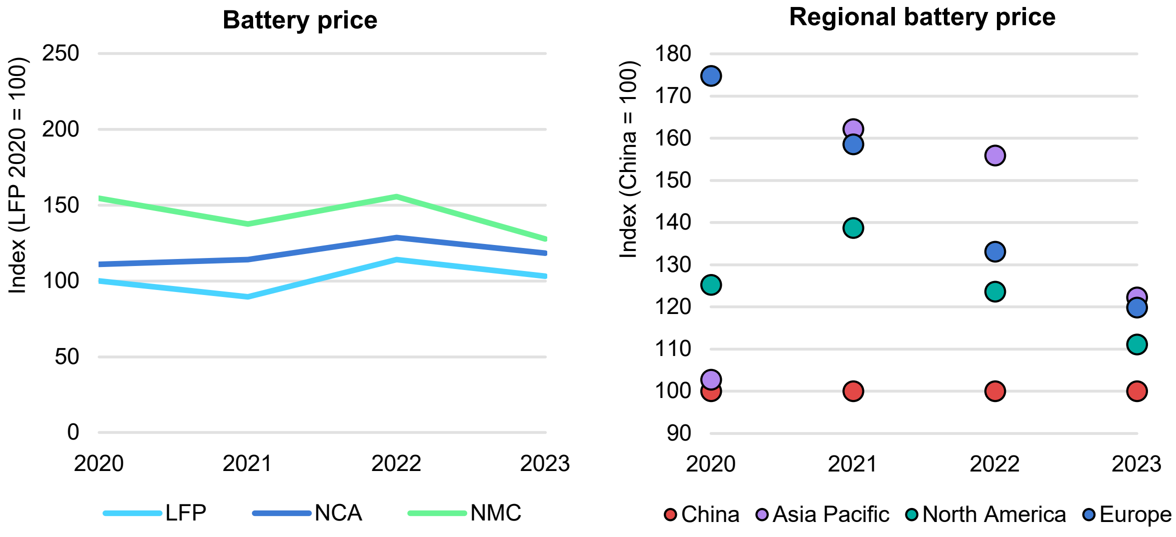
Further innovation-driven improvements are foreseen for both chemistries through recent battery pack configurations, such as cell-to-pack[21] (already being adopted for LFP) and cell-to-chassis. In addition, continued innovation in manufacturing is helping to achieve improved battery performance, for example through multi-layer electrodes enabling ultra-fast charging. Efforts to increase the manganese content of both NMC and LFP are also underway, with the aim of either increasing energy density while keeping costs low (LFP) or reducing cost while maintaining high energy density (NMC).

In terms of regional competitiveness, batteries are cheapest in China, followed by North America, Europe and other Asia Pacific countries. However, battery prices across regions, including both batteries produced locally and imports, have been converging in the past few years, indicating that EV batteries are moving towards becoming a truly globalised product.

Nonetheless, battery manufacturing in Europe and the United States remains more expensive than in China. For example, producing a battery cell in the United States is nearly 20%[22] more expensive than in China, even when assuming that material costs do not vary regionally. In reality, Chinese manufacturers are likely to benefit from preferential prices from local material producers and a more integrated supply chain within China, which could mean the manufacturing cost gap is even larger. Moreover, contrary to the United States and Europe, most Chinese batteries are LFP, which is more than 20% cheaper to produce than NMC.

[21] Battery packs used in EVs are typically made of a series of modules, each containing several battery cells. In the cell-to-pack configuration, battery cells are assembled to build a pack without using modules, which reduces the need for inert materials and increases energy density. In cell-to-chassis concepts, battery cells are used as part of the EV structure without being assembled into a battery pack beforehand.
[22] Calculations from the BNEF BattMan 3.1.0 model using NMC811 as cathode and graphite as anode.

Average battery price index by selected battery chemistry and region, 2020-2023



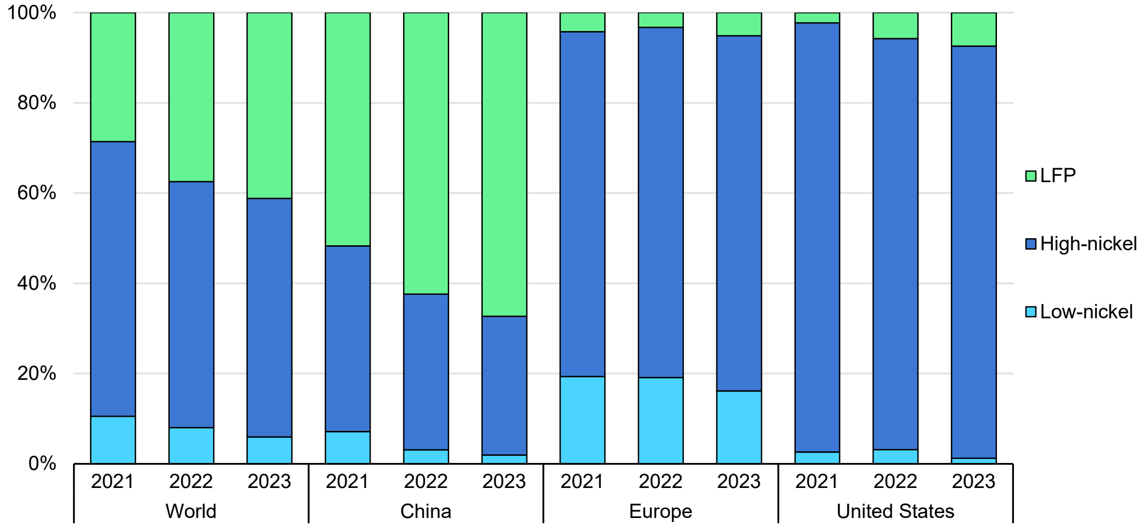
Notes: LFP = lithium iron phosphate; NMC = lithium nickel manganese cobalt oxide; NCA = lithium nickel cobalt aluminium oxide. Asia Pacific excludes China. Each year is indexed with respect to China price (100). Battery prices refer to the average battery price in a given region, including locally produced batteries and imports.
Sources: IEA analysis based on data from Bloomberg New Energy Finance.

The battery industry is accelerating plans to develop more affordable chemistries and novel designs

Over the last five years, LFP has moved from a minor share to the rising star of the battery industry, supplying more than 40% of EV demand globally by capacity in 2023, more than double the share recorded in 2020. LFP production and adoption is primarily located in China, where two-thirds of EV sales used this chemistry in 2023. The share of LFP batteries in EV sales in Europe and the United States remains below 10%, with high-nickel chemistries still most common in these markets.

LFP was first invented in the United States in 1997, and further developed in Canada through the early 2000s, but thanks to a favourable intellectual property agreement, China has been the only country mass-producing LFP batteries since the 2010s. In 2022, the core LFP patents expired, sparking interest in production outside of China. The recent surge in interest in LFP chemistries has led to major investments in Morocco, which is home to the world's largest phosphate reserves and, importantly, holds free-trade agreements with the United States and Europe. In 2022, Morocco saw almost as many announced investments to as in the five previous years combined, reaching USD 15.3 billion. Many of these investments were made by battery industry players (e.g. Gotion, LG, CNGR Advanced Material).

Share of battery capacity of electric vehicle sales by chemistry and region, 2021-2023



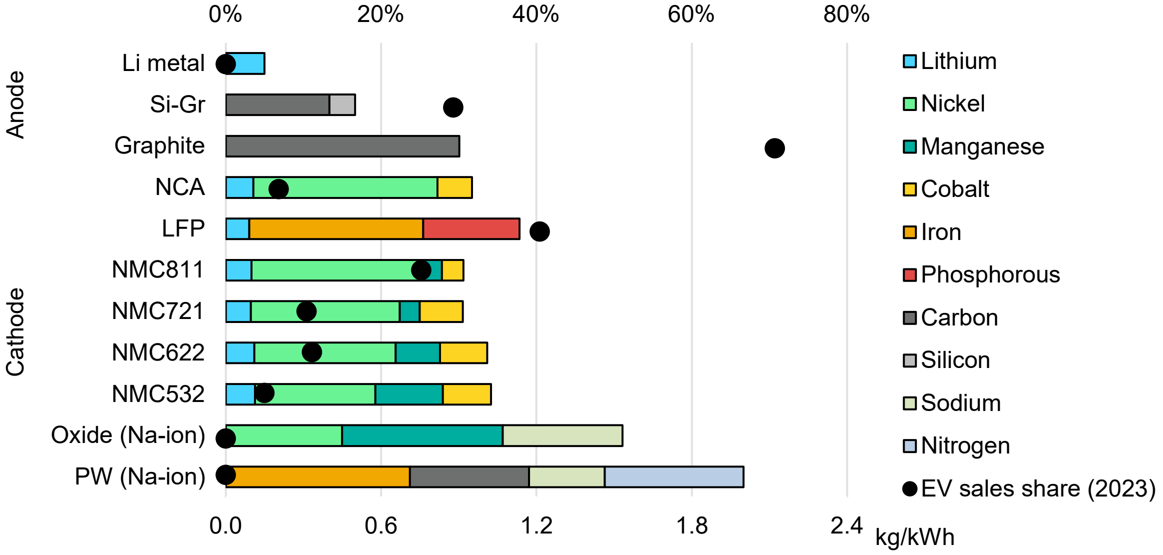
Notes: LFP = lithium iron phosphate. Low-nickel includes lithium nickel manganese cobalt oxide (NMC) 333, NMC442, and NMC532. High-nickel includes NMC622, NMC721, NMC811, lithium nickel cobalt aluminium oxide (NCA), and lithium nickel manganese cobalt aluminium oxide (NMCA). Cathode sales share is based on the battery capacity of EVs registered in the different regions. This calculation assumes that 90% of electric trucks and buses sold in China use LFP, and that 70% of electric trucks and electric buses sold outside of China uses high-nickel chemistries. Two/three-wheelers are excluded from the analysis.
Sources: IEA analysis based on data from EV Volumes and China Automotive Battery Industry Innovation Alliance.

Further declines in battery cost and critical mineral reliance might come from sodium-ion batteries, which can be produced using similar production lines to those used for lithium-ion batteries. The need for critical minerals like nickel and manganese for sodium-ion batteries depends on the cathode chemistry used, but no sodium-ion chemistries require lithium. Similarly to LFP, sodium-ion batteries were initially developed in the United States and Europe, but today the announced sodium-ion manufacturing capacity in China is estimated to be about ten times higher than in the rest of the world combined. Manufacturing capacity outside China is still at the laboratory or pilot scale.

In 2023, leading battery manufacturers announced expansion plans for sodium-ion batteries, such as BYD, Northvolt and CATL, which initially sought to reach mass production by the end of the same year. If brought to scale, sodium-ion batteries could cost up to 20% less than incumbent technologies and be suitable for applications such as compact urban EVs and power stationary storage, while enhancing energy security.

The development and cost advantages of sodium-ion batteries are, however, strongly dependent on lithium prices, with current low prices discouraging investments in sodium-ion and delaying expansion plans. Supply chain bottlenecks, such as for high-quality cathode and anode materials specific to sodium-ion batteries, could also hinder near-term expansion.

Material content in anodes and cathodes, by chemistry, 2023



Notes: EV = Electric vehicle ; Li metal = lithium metal anode; Si-Gr = silicon-graphite anode; Graphite = pure graphite anode; Na-ion = sodium-ion; LFP = lithium iron phosphate; NMC = lithium nickel manganese cobalt oxide; NCA = lithium nickel cobalt aluminium oxide; PW = Prussian white; Oxide (Na-ion) = $Na_{0.83}Ni_{0.32}Mn_{0.47}Mg_{0.1}Ti_{0.12}O_2$, for which magnesium (Mg) (0.06 kg/kWh) and titanium (Ti) (0.14 kg/kWh) are not displayed for simplicity. Other chemistries for sodium-ion batteries are being developed as well, most of them based on layered-oxide. The oxygen content of the different chemistries is not displayed for simplicity. Materials composing the battery casing and the electrolyte, separator, and current collectors are excluded. Chemistry shares are based on demand. The shares of NMC811 includes all NMC having a higher nickel content than NMC622, and Si-Gr share includes every degree of silicon-graphite mix. Hard carbon, used as anode in Na-ion batteries, is composed of carbon only, similarly to graphite.

Sources: IEA analysis based on data from EV Volumes, Bloomberg New Energy Finance, Argonne Laboratory, BatPaC, and Wood Mackenzie (2023), Sodium-ion batteries: disrupt and conquer?.

6. Trends in the electric vehicle industry

Electric vehicle company strategy and market competition

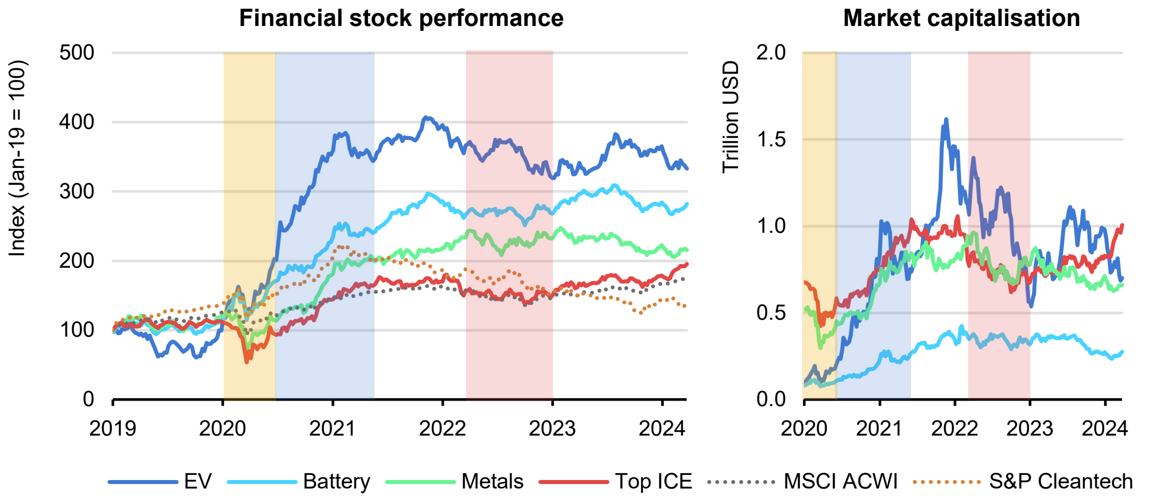
Electric vehicle companies perform well in financial markets, but volatility and competition raise concern

Since 2019, the stocks of EV companies – including vehicle and battery manufacturers and companies involved in the extraction or processing of battery metals – have consistently outperformed general stock markets, major traditional carmakers, and other segments of clean technology. Return on investment has increased more over the 2019-2023 period for these companies than it has for others, in relative terms. The combined market capitalisation of pure play EV makers boomed from USD 100 billion in 2020 to USD 1 trillion at the end of 2023, with a peak over USD 1.6 trillion at the end of 2021, though this trend was primarily driven by Tesla. The market capitalisation of battery makers and battery metal companies also increased significantly over the same period.

Behind this overall upward trend, however, there has been significant volatility. Supply chain disruptions and battery metal price fluctuations – notably in the wake of Russia's invasion of Ukraine – as well as increasing competition, price wars among OEMs and expectations of slower relative annual growth as major EV markets mature, and of possible consolidation, are having an important downward impact on investor confidence and EV stocks.

For example, Tesla's shares were on average 15% lower in 2023 than in 2021-2022; BYD's average stock also fell 15% in 2023 relative to 2022; and the combined market capitalisation of pure play EV carmakers fell by nearly 20% on average relative to 2022, while that of major incumbent carmakers remained flat. Many emerging EV players – such as VinFast from Viet Nam, Polestar from Europe, and Canoo, Fisker, Lucid and Nikola from the United States – are missing sales targets and trading low. Fiercer competition and shrinking profits also have an impact upstream, among EV battery makers: in the first weeks of 2024, CATL was trading near a three-year low, with a market capitalisation at its lowest point since the end of 2020. In the first quarter of 2024, the combined market capitalisation of pure play EV players fell below that of major incumbents, even if their financial stock performance remained robust.

Key financial indicators for major car, battery, mining and cleantech companies



Notes: EV = electric vehicle; ICE = internal combustion engine; ACWI = All Country World Index. Data through Q1 2024 included. Performance is measured via arithmetic returns, which refer to the sum of quarterly returns on a given stock (capital gains and dividends). The area highlighted in yellow represents a credit crisis, and in blue, a recovery period for capital markets followed by the pandemic-induced credit shock in Q1 2020. The red highlight shows the months following Russia's invasion of Ukraine. Weekly financial performance of selected EV, battery and battery mineral and metal companies is plotted against the major conventional carmakers, the broader public equity market benchmark (MSCI ACWI), and the S&P Renewable Energy and Clean Technologies benchmark, at an index level. The major conventional carmakers index is equal-weighted, giving equal importance to each constituent company regardless of market capitalisation or share (BMW, Ford, GM, Honda, Hyundai, Kia, Mercedes-Benz, Nissan, Renault, Stellantis, Toyota, and Volkswagen). The EV index consists of ten pure play EV companies (BYD, Fisker, Leap, Li Auto, Lucid, Nikola, NIO, Rivian, Tesla, and XPeng), and the battery index of eight battery and component manufacturing companies (Contemporary Amperex Technology, Ecopro BM, Eve Energy, Gotion High-tech, L&F, LG Energy Solution, Panasonic Holdings, and Samsung SDI), weighted based on the shares of these companies within the Bloomberg EV Price Return Index. The battery mineral and metal index includes over 40 companies selected in the S&P Global Core Battery Metals Index. Financial performance and market capitalisation do not necessarily reflect actual profits or losses, but rather investor expectations of future returns.
Source: IEA analysis based on Bloomberg.

As we reported last year in GEVO-2023, companies and investors are exploring new opportunities upstream in EV supply chains, especially as competition intensifies. Carmakers are seeking to secure direct deals with battery makers and companies involved in the mining and processing of critical minerals. Investors including large banks and funds are pouring capital into the metal industry.

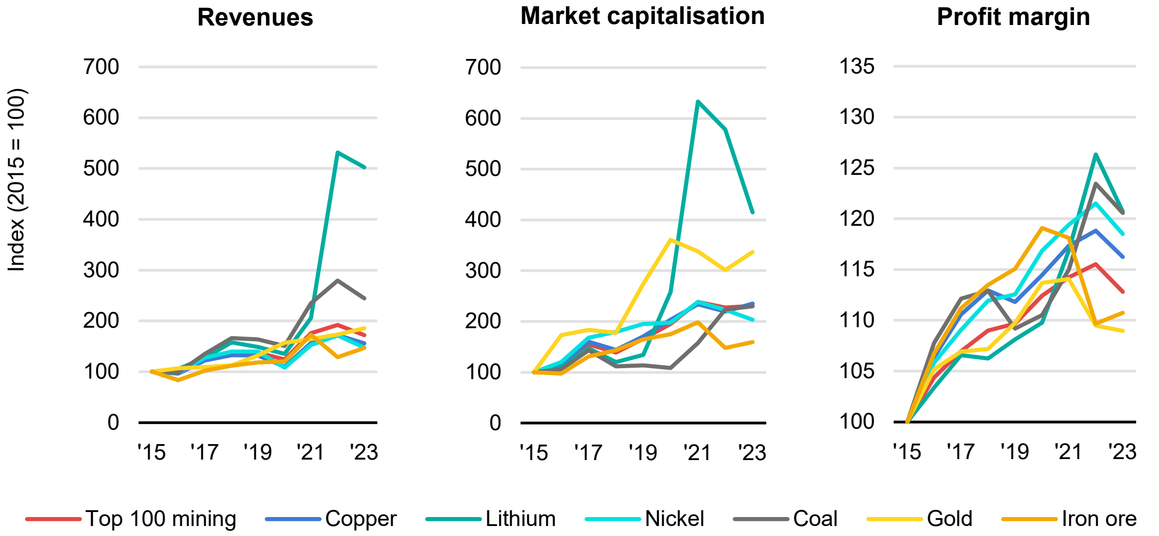
In 2023, Stellantis announced a partnership in Argentina to secure projected copper demand, investing USD 155 million. Volkswagen, Glencore and Chrysler each invested USD 100 million in a Special Purpose Acquisition Company operating nickel and copper assets, supported by several global investment banks for an overall USD 1 billion deal. In 2024, Tesla and several Korean battery makers, including LG and SK, met with Chilean government agencies regarding lithium supply, primarily with the aim of supplying the US market with the support of IRA tax credits. AustralianSuper, Australia's largest pension fund, announced plans to double its exposure to lithium stocks over the next five years, with investments in 2023, such as in Pilbara Minerals, worth AUD 560 million (USD 370 million).

As a result of increasing investor appetite and growing EV markets, the valuation of critical mineral companies has increased significantly in the last few years. Over the 2015-2022 period, the market capitalisation of companies involved in the extraction and processing of lithium increased sixfold. The margins for lithium, nickel and copper companies typically outperformed those of the top 100 mining companies over the same period, including relative to gold or iron ore.

However, the picture in 2023 and the first quarter of 2024 is changing. The volatile metal prices seen in the past few years, the increasing competition and pressure to drive down EV and battery prices, and the current overcapacity for several critical minerals (see earlier section on batteries), mean that major mining companies are revisiting growth and performance forecasts. After several years of important cash flows as a result of high prices and increasing volumes, many companies are now starting to struggle to finance both existing and new projects with their own revenues, suggesting external sources will be needed for large-scale capital expenditure.

In Australia, for example, Albemarle, Core Lithium, Liontown Resources and Pilbara Minerals announced project spending reductions, lower dividends, and job cuts in 2024. Albermarle expects capital expenditures to drop by around USD 500 million from USD 2.1 billion in 2023 to USD 1.6-1.8 billion in 2024, and plans to reduce annual costs by nearly USD 100 million. Pilbara Minerals expects annual exploration spending to be cut by up to AUD 100 million (USD 66 million). Nickel and cobalt projects in Australia have also been delayed or halted, involving companies like BHP, First Quantum Minerals and Wyloo Metals. First Quantum Minerals expects a 30% staff cut as a result of reduced operations. In the United States, Piedmont Lithium Inc. is letting go of 25% of staff. Over the 2024-2026 period, we could see progressive consolidation of critical mineral extraction and refining projects and businesses around lowest-cost producers.

Key financial indicators of top mining companies, 2015-2023



Notes: Top 100 mining refers to companies with the highest market capitalisation in 2022 and with a share of revenues from mining of more than 70% of total revenues. The same rules apply to selected coal companies. For copper, lithium and nickel mining, each sample contains about 15-20 companies, and 30 for iron ore, with over 50% of revenues from corresponding mining activities. Revenues and market capitalisation are respectively cumulative over the sample of companies, in current US dollars. Three-year moving non-weighted averages over the sample of companies are used for profit margin, excluding single outlier data points. Data as of mid-April 2024.

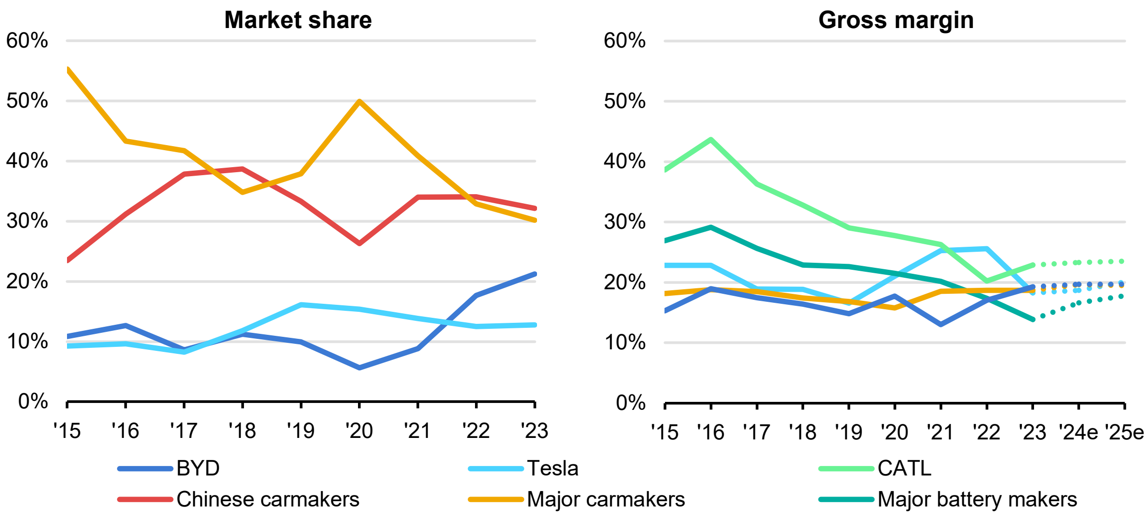
Sources: IEA analysis based on Bloomberg data.

Global competition is getting tougher, pushing down company margins

Road transport electrification is reshuffling cards in global markets, as carmakers compete fiercely to capture their share of a growing pie. BYD and Tesla remain far ahead of the curve, together accounting for 35% of all electric car sales in 2023. This is more than all the major carmakers outside China combined (just above 30%), and more than all the other Chinese carmakers (just under 30%). BYD and Tesla's rise as global front-runners has primarily dented the market share of major incumbents, which accounted for 55% of global electric car sales in 2015 but have been falling behind ever since.

In 2022, BYD had already overtaken Tesla as the world's best-selling EV company when accounting for plug-in hybrid cars. In the second half of 2023, BYD also became the world's best-selling battery electric car company. Counting both BEV and PHEV models, BYD's share of global electric car markets was just over 20%. In China, BYD also became the top-selling car company with over 2.4 million new registrations or 11% of the domestic market, ahead of Volkswagen, which had been China's best-selling brand for over 15 years. BYD's worldwide sales exceeded 3 million, making it one of the world's top 10 car sellers.

Share of global electric car markets by selected carmakers (left) and gross margin of selected companies (right), 2015-2023



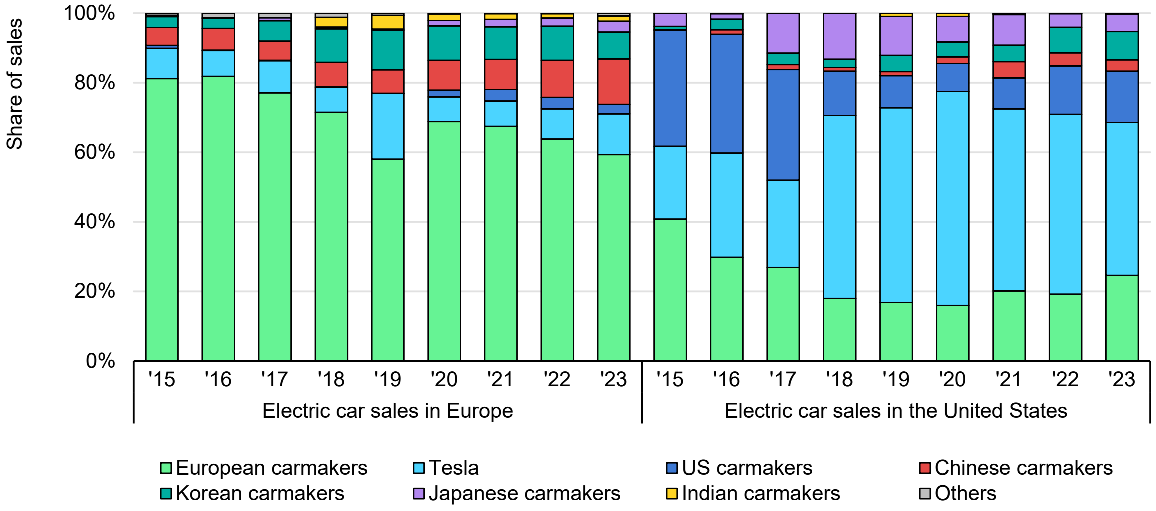
Notes: Market share in terms of global electric car sales, including battery electric and plug-in hybrid electric cars. Major incumbent carmakers include BMW, Ford, GM, Honda, Hyundai, Kia, Mercedes-Benz, Nissan, Renault, Stellantis, Toyota, and Volkswagen. Chinese carmakers include 33 companies excluding BYD. Gross margin for 2024 and 2025 estimated by companies in their annual reporting.

Sources: IEA analysis based on Bloomberg and EV Volumes.

In China, since the end of 2022, greater competition among front-runners has led electric car prices to fall quickly. The price of compact electric cars and SUVs dropped by up to 10% in 2023 relative to 2022. In the first quarter of 2024, Tesla once again slashed prices, by up to 6% or CNY 15 000 for its Models 3 and Y, forcing competitors to follow by squeezing margins. BYD proceeded with a 10-20% cut on model prices, such as a CNY 10 000 reduction on its flagship Qin Plus; XPeng with a CNY 20 000 cut on its G6 series; and the GM-SAIC-Wuling joint venture with a CNY 6 000 cut on its Xingguang sedan.

Tesla has been able to afford such a strategy thus far thanks to a focus on high-end models and greater profits per car sold, around USD 10 000 to USD 15 000 per electric car sold in 2022-2023 against around USD 6 000 for BYD, which also explains why Tesla's market value in 2023 remained 7 times higher than that of BYD. BYD's preferred strategy has been to sell cheaper models and protect margins by developing in-house battery supply chains. Other Chinese makers are now actively seeking to catch up by announcing new models. For example, XPeng announced new models for 2024 priced at around CNY 100 000-150 000, far more affordable than the premium models typically priced in the range of CNY 300 000. However, just one-third of Chinese carmakers (e.g. Li Auto, BYD, Geely) met their sales targets in 2023, while others (e.g. Nio, Xpeng, Leap, Great Wall) fell short for the second straight year.

Breakdown of electric car sales in Europe and the United States, by company or country of headquarters, 2015-2023



Notes: Market share in terms of regional electric car sales, including battery electric and plug-in hybrid electric cars. Geely-Volvo is counted as headquartered in China. The Renault-Nissan-Mitsubishi Alliance is counted as headquartered in Europe.
Source: IEA analysis based on data from EV Volumes.

Competition is also getting tougher outside China. In the United States, Tesla accounted for over 45% of all the battery electric cars ever sold as of 2023. However, Tesla's share in new US electric car sales has been shrinking, from over 60% in 2020 to 45% in 2023. Hyundai-Kia overtook GM and Ford in 2023, and now accounts for 8% of US electric car sales, second only to Tesla. Hyundai-Kia plans to start manufacturing operations at a Georgia-based factory in 2024, qualifying for IRA benefits. European carmakers accounted for 25% of US electric car sales, their highest share since 2017, led by Stellantis. About 15% of BMW's sales were electric, meeting its 2023 sales target, and in the same year the company went on record as saying that a tipping point for ICE cars had been reached, and that EVs would lead future growth. Meanwhile, other US carmakers accounted for 15% of electric car sales, half their share back in the 2015-2017 period, and GM and Ford announced a step back from their earlier sales objectives (see later section on Industry Outlook).

In Europe, the share of electric car sales by local carmakers has been falling since 2015. In 2023, European carmakers accounted for 60% of electric car sales in the region, compared to over 80% in 2015. Volkswagen, Stellantis and BMW aggregated to 45% of European electric car sales in 2023, but competition is getting tougher among front-runners. The share of Stellantis jumped from under 2% in 2015 to nearly 15% in 2023, while Volkswagen's fell from 27% to 20%. Renault-Nissan-Mitsubishi Alliance accounted for nearly 40% of European electric car sales in 2015, but just 7% in 2023. Tesla's share has stagnated around 10%

between 2015 and 2023, while Chinese carmakers have seen important growth, from 5% in 2015 to just under 15% in 2023.

Global competition is expected to further intensify in the coming years, especially as Chinese carmakers look to export in the context of battery and EV oversupply. Just as for steel and solar PV, China's subsidised industrial strategy for EVs, which was initiated 15 years ago, has led to significant excess capacity. Capacity utilisation stood below 70% among the top 10 sellers in the first months of 2023. There are also far more EV companies in China than can possibly survive in a competitive market. In 2014 alone, ten years ago, over 80 000 companies registered in China entered the electromobility sector. In 2023, over 80% of electric car sales in China were concentrated in just over 30 companies. In 2024, the Chinese Ministry of Industry and Information Technology noted its concern that too many carmakers remain unprofitable. Nio, for example, recorded net losses of USD 3 billion in 2023.

As shrinking margins push the least profitable out of the race, China's EV industry is consolidating around a smaller number of robust champions – and they are looking abroad for expansion. Chinese auto exports grew steeply in 2023, up 60% relative to 2022, making China the world's largest car exporter, ahead of Japan and Germany. Despite high import taxes (e.g. 27% in the United States and 10% in the European Union) and tight regulatory scrutiny (e.g. the anti-subsidy EU investigation on EV imports since October 2023 and possible introduction of new tariffs from July 2024), Chinese OEMs often remain more competitive than incumbents. They could be well-placed to capture market share in the near term, especially in the small car segment. In early 2024, for example, BYD chartered its first cargo ship, with a capacity of 7 000 cars sailing to Europe.

European and US carmakers are under growing pressure as Chinese carmakers start to export at scale, and are adjusting corporate strategy accordingly. In February 2024, for example, Ford and GM expressed that they could even be open to partnering to compete against Chinese carmakers, and BYD in particular. Ford estimates losses on EV investments of up to USD 5.5 billion in 2023, and expects even tougher future competition from more affordable Tesla models and Chinese carmakers. Another example comes from Stellantis, which – considering the growing importance of Chinese pure play EV manufacturers on the global market – recently became an important shareholder of China's Leapmotor brand.

Electric vehicle and battery start-ups

Venture capital investments in electric vehicle start-ups dropped in 2023, following the global trend

Venture capital (VC) funding to EV start-ups has boomed in the past decade. Financial investors such as banks and VC or private equity funds see in EV start-ups a potential for significant future returns. Many companies – including major incumbent carmakers – also use corporate VC to fund start-ups to develop new technology, or to acquire concepts developed by new entrants. Whereas in the past century, most carmakers typically developed ICE technology and manufacturing through in-house R&D, investing in start-ups has now become a notable trend. This allows incumbents to bolster their own position and maintain a competitive edge in quickly evolving markets and regulatory environments.

In 2023, however, global VC investments in clean energy start-ups fell considerably relative to 2022, and EVs and batteries were no exception. Early-stage investments (i.e. seed and series A, referring to the first rounds of financing and the earlier stages of development) in start-ups developing EV and battery technologies dropped 20% to USD 1.4 billion in 2023. Meanwhile, growth-stage investments (i.e. series B and growth equity, which refer to the later rounds of financing as start-ups increase activity) dropped 35% to USD 10.1 billion.

Several important factors are contributing to this downward trend. As competition intensifies in EV and battery markets, and as incumbents ramp up their own investments and manufacturing plans, barriers to entry for new actors get higher, and so do investor perceptions of risk. The front-running start-ups that raised funds over the 2015-2020 period are now maturing and transitioning to other sources of capital, leaving fewer alternatives for newcomers – early-stage VC for electric carmakers dropped radically in 2023. Geopolitical tensions, supply chain disruptions, high energy prices, and rising inflation and interest rates limit the availability of higher-risk capital. We also observe a cooldown following the post-Covid-19 boom of 2021-2022, which was fuelled by investment restraint during the pandemic and the expectation of significant economic recovery packages afterwards.

Despite the drop, investments remain far greater than in 2019, prior to the Covid-19 pandemic. Start-ups developing EV charging technology attracted over USD 400 million in early-stage VC, and battery and battery component makers USD 260 million, together accounting for half of early-stage VC. There was also a surge for two- and three-wheeler start-ups, which raised USD 200 million in early-stage VC in 2023, up from below USD 100 million in previous years. While early-stage funding for electric carmakers has dried up, and in 2023 fell far short of the

2018-2022 rounds, investors continue to show interest in upstream and downstream segments of EV supply chains, as well as other EV types, especially if these can scale quickly.

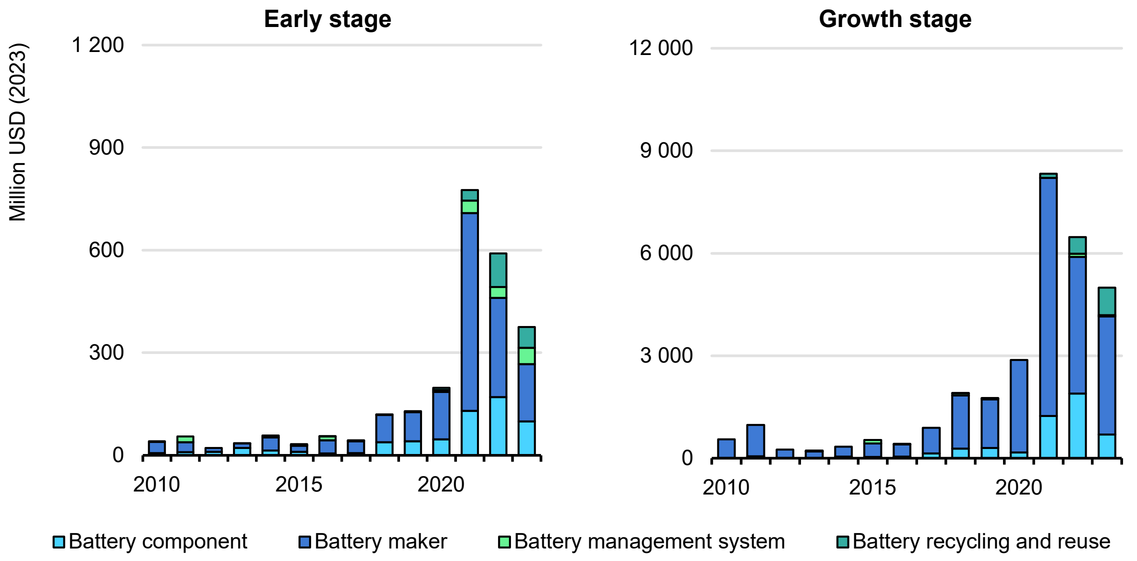
Notable deals in 2023 included Germany-based Jolt Energy's first round of VC funding, which raised USD 160 million. The company seeks to bring its fast-charging technology to urban areas of Europe and the United States, and claims to provide 100 km of driving range in just 5 minutes. Similarly, German EV charging start-up Numbat raised USD 75 million in series A funding through the European Infrastructure Fund, as well as another USD 75 million in loans. Indian start-up Charge Zone also raised nearly USD 55 million to develop nearly 300 charging stations.

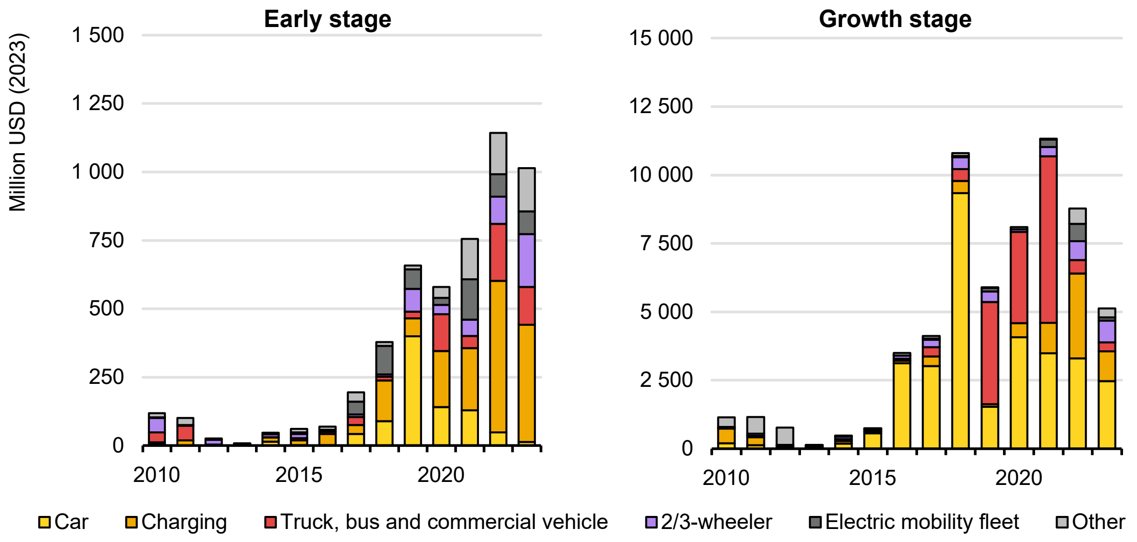
Chinese electric truck maker DeepWay raised USD 110 million in series A funding to start mass production, after having raised USD 70 million in 2022 to fund R&D and early-stage manufacturing. In the 2/3W space, Benin-based start-up Spiro raised USD 60 million, Indonesian Maka Motors raised over USD 37 million and Volta Indonesia USD 35 million, Brazilian Vammo raised USD 30 million, and Indian Simple Energy India raised USD 20 million, illustrating the importance of this segment in EMDEs. In India, Evera, a provider of all-electric cab services and management, raised USD 7 million to expand operations in Delhi, and Zyngo, an operator of electric last-mile delivery fleets, raised USD 5 million.

At the growth stage, battery technology developers attracted USD 5 billion, and electric carmakers USD 2.5 billion, with significant support from public investors, indicating interest from governments to help new entrants ramp up manufacturing capacity or accelerate expansion and deployment. However, growth-stage investor appetite for electric trucks and EV charging dried up relative to previous years.

Notable deals include French battery maker Verkor, which raised USD 900 million in growth equity from investors including public-private EIT InnoEnergy and BPI France, and major incumbent carmaker Renault. The company also received a nearly USD 700 million grant from the French Government and another USD 650 million in debt from the European Investment Bank to develop a 16 GWh gigafactory project in Dunkirk. To support its global expansion, Swedish battery maker Northvolt raised USD 400 million from Ontario's asset manager, USD 1.2 billion and then another USD 150 million in debt from public Canadian investors and private banks, a USD 740 million grant from the German Government, and a USD 5 billion loan from the European Investment Bank and Nordic Investment Bank. Chinese lithium-ion battery maker Hithium also raised over USD 600 million.

Early-stage (left) and growth-stage (right) venture capital investments in start-ups developing battery (top) and electric mobility (bottom) technology, 2010-2023





Notes: Early-stage deals refer to seed and series A; growth-stage to series B and growth equity deals. “Battery maker” refers to manufacturers of battery packs and cells or associated technology. “Battery component” refers to components within batteries, such as cathodes and anodes. Battery technologies may also include applications for stationary storage. “Other” includes EV components and manufacturing (excluding electric motors that are not specific to road transport), digital and software products otherwise excluded, hybrid carmakers, EV project development and operation, and EV finance. Each year, the IEA team improves methodology and expands coverage, which can explain absolute value differences compared to GEVO-2023.

Source: IEA analysis based on Cleantech Group i3 database.

Chinese electric carmakers continued raising money in 2023, such as Hozon and Rox Motor, which each raised around USD 1 billion. Like other Chinese new entrants, Hozon Automobile is looking to expand in overseas markets as well as domestically, and could go public in Hong Kong. Rox Motor launched its first model in 2023, an electric SUV priced under USD 50 000. Premium electric carmaker Avatr raised USD 400 million, after having raised a similar amount in series A funding in 2022.

In the electric taxi fleet space, India-based BluSmart, a start-up providing ride-hailing services, raised two rounds of USD 42 million and USD 24 million in growth equity in 2023, and another USD 25 million in 2024. However, there has been fierce competition with larger taxi fleet apps and operators in the past few years in EMDEs. In 2023, for example, electric ride-sharing app Beat, owned by Free Now, withdrew from Latin America.

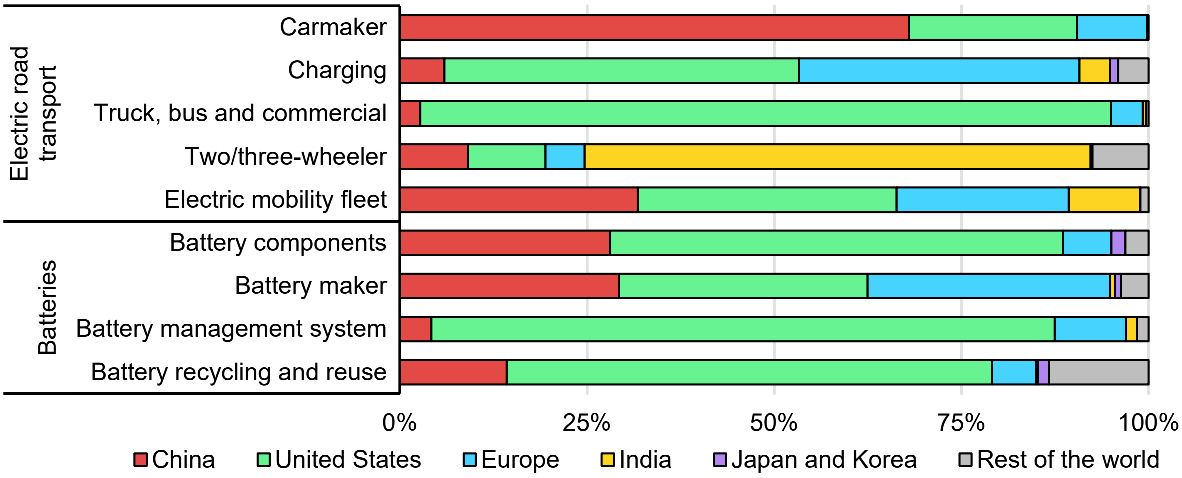
Leading electric vehicle start-ups and venture capital investments are geographically concentrated

Similarly to for other clean energy technologies, start-ups for EVs are predominantly headquartered in the United States, Europe or China. There is, however, significant variability across different EV technology areas. Over the 2018-2023 period, in cumulative terms, about 70% of the VC investments in start-ups developing electric cars were made in China, 20% in the United States and 10% in Europe. Meanwhile, about 95% of the VC investments in electric trucks, buses, and commercial vehicles were made in the United States.

India, the only EMDE other than China that has a significant share in global VC markets, accounted for 70% of the investments in start-ups developing electric 2/3Ws. Over the 2018-2023 period, Indian EV start-ups raised USD 2.7 billion, of which over 70% was for electric 2/3Ws. Policy support has contributed to building investor appetite for the EV sector, and the high investment levels seen in 2022 and 2023 will warrant further examination in 2024 and beyond if the FAME subsidies are reduced or phased out. The investment potential in India's EV sector is estimated at around USD 200 billion, suggesting there are still considerable opportunities ahead for Indian entrepreneurs and start-ups.

With regards to batteries, start-ups based in the United States attracted most VC investments – from 30% to over 80% of global investments over the 2018-2023 period. Investments in battery makers, however, were split evenly among major VC markets, with 30% each for China, Europe and the United States. It is noticeable that battery VC remains extremely limited in historic battery-producing countries such as Japan and Korea, where technology innovation through start-ups is generally less common.

Cumulative venture capital investment, by technology, country or region, 2018-2023



Notes: Includes both early- and growth-stage deals. The country or region is determined based on company headquarters and not the origin of investors. “Europe” includes European Union member states, Norway, Switzerland and the United Kingdom.
Source: IEA analysis based on Cleantech Group i3 database.

Investors look to new battery chemistries, recycling, and critical mineral extraction and refining technologies

As VC investors look for new opportunities across EV supply chains, novel battery concepts and critical mineral extraction and refining are gaining momentum. Over the 2018-2020 period, cumulative early-stage VC flowing to battery and component makers stood around USD 430 million, nearly 75% of which was for lithium-based battery chemistries. Over the 2021-2023 period, cumulative investments for batteries not only more than tripled, to nearly USD 1.4 billion, they also diversified. Lithium chemistries accounted for just 60% of the total, while the share of emerging concepts such as metal-hydrogen, redox-flow, solid state and sodium-ion batteries rose, growing from less than 15% to more than 25%.

Not all the start-ups active in the battery space today will eventually serve EV supply chains. In fact, many companies in our sample have so far announced that long-duration power storage is their primary target market. However, there are important spillover opportunities between those two closely related technology fields. For example, sodium-ion batteries can be used for both grid-level storage and EVs, and learnings in one sector can inform technology development in the other.

Notable early-stage VC deals in novel battery chemistries in 2023 included rounds by Chinese WeView (USD 90 million), United States-based Noon Energy (USD 30 million) and XL Batteries (USD 10 million), and Singapore’s VFlow Tech (USD 10 million), all of which are developing redox-flow batteries. Peak Energy, based in Colorado, was established in 2023 and raised USD 10 million in seed money to develop sodium-ion batteries. Similarly, Inlyte Energy raised USD 8 million in seed funding, after having received at least USD 250 000 in grants from the US Department of Energy (DoE) Advanced Research Projects Agency–Energy (ARPA-E) in 2022.

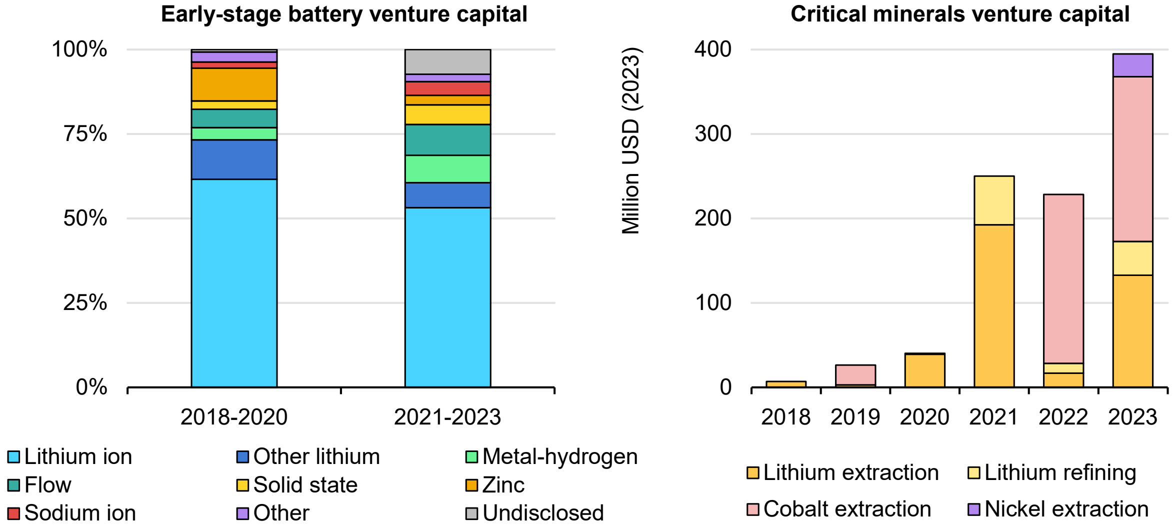
In the battery recycling space, notable deals in 2023 included a USD 540 million round of growth equity funding to US-based Ascend Elements, a start-up that also received two grants from the DoE totalling USD 480 million in 2022. The company, which raised another USD 160 million in 2024, aims to build North America's first cathode precursor manufacturing facility using black mass, the typical output of lithium-ion battery recycling. Chinese Tianneng New Materials raised a series A of USD 140 million, and French MECAWARE USD 40 million.

As reported last year, critical minerals VC is also expanding, standing just under USD 400 million in 2023, or nearly twice as much as in 2021 or 2022. This technology field attracted under USD 75 million in cumulative VC over the 2018-2020 period. Cobalt extraction attracted nearly USD 200 million in 2023, just like in 2022. Lithium extraction and refining attracted USD 135 million, much higher than the dip of 2022 but still below the record year of 2021. We now observe deals for nickel extraction, suggesting investors are also looking for opportunities beyond cobalt and lithium.

In 2023, several governments have also launched critical raw material funds. For example, France committed EUR 500 million to the EUR 2 billion private equity Critical Metals Fund managed by InfraVia, as part of France 2030. Similarly, EIT InnoEnergy launched the European Battery Alliance's Strategic Battery Raw Material Fund, targeting investments of EUR 500 million. Other announcements and projects are mentioned in the later section on Industry Outlook in this report.

Notable critical mineral deals in 2023 included a series A of USD 50 million by Canada-based Summit Nanotech to scale its more sustainable lithium extraction technology, after it received grants from public investors such as Sustainable Development Technology Canada and Natural Resources Canada. In the United States, Kobold Metals raised USD 195 million in growth equity to expand cobalt extraction, Energy Exploration Technologies raised USD 50 million for direct lithium extraction from GM Ventures, and Atlas Materials raised USD 27 million in seed money to develop nickel extraction technologies.

Venture Capital investments in start-ups developing battery technologies by chemistry (left), and for the extraction and refining of critical minerals (right), 2018-2023



Notes: "Other lithium" includes lithium metal-based and lithium-sulphur batteries. "Flow" includes redox flow (including vanadium-based) as well as other flow batteries (e.g. iron-based, hydrogen-bromine). "Other" includes lead acid, metal-air, organic materials, and polymer batteries. Critical minerals venture capital is not exclusive to electric mobility applications. Each year, the IEA team improves methodology and expands coverage, which can explain absolute value differences compared to GEVO-2023.

Source: IEA analysis based on Cleantech Group i3 database.

7. Outlook for electric mobility

Scenario overview

In this part of the report, we focus on pathways to electrify road transport over the period to 2035, expanding the time horizon by five years compared with previous editions of the Global EV Outlook. A scenario-based approach is used to explore the outlook for electric mobility, based on recent market trends, policy drivers and technology developments.

The purpose of the scenarios is to assess plausible futures for global electric vehicle (EV) markets and their potential implications. The scenarios do not make predictions about the future. Rather, they aim to provide insights to inform decision-making by governments, companies and other stakeholders about the future of EVs.

The projections in the Stated Policies Scenario (STEPS) and Announced Pledges Scenario (APS) consider historical data through the end of 2023, as well as stated policies and ambitions as of the end of March 2024. The Net Zero Emissions by 2050 Scenario (NZE Scenario) is consistent with the 2023 update to the IEA Net Zero Roadmap and the World Energy Outlook 2023.

Deployment of electric vehicles is projected by road transport mode and by region. Regional results are presented for the STEPS and APS, while the discussion of the projections in the NZE Scenario focuses on global results. These projections are then compared to announcements by original equipment manufacturers (OEMs) and battery manufacturing capacity expansion announcements. These scenario projections incorporate GDP assumptions from the International Monetary Fund and population assumptions from the United Nations.

Stated Policies Scenario

The Stated Policies Scenario (STEPS) reflects existing policies and measures, as well as firm policy ambitions and objectives that have been legislated by governments around the world. It includes current EV-related policies, regulations and investments, as well as market trends based on the expected impacts of technology developments, announced deployments and plans from industry stakeholders. The STEPS aims to hold up a mirror to the plans of policy makers and illustrate their consequences.

Announced Pledges Scenario

The Announced Pledges Scenario (APS) assumes that all announced ambitions and targets made by governments around the world are met in full and on time. With regards to electromobility, it includes all recent major announcements of electrification targets and longer-term net zero emissions and other pledges, regardless of whether these have been anchored in legislation or in updated Nationally Determined Contributions. For example, the APS assumes that countries that have signed on to the Conference of the Parties (COP 26) declaration on accelerating the transition to 100% zero emissions cars and vans will achieve this goal, even if there are not yet policies or regulations in place to support it. In countries that have not yet made a net zero emissions pledge or set electrification targets, the APS considers the same policy framework as the STEPS. Non-policy assumptions for the APS, including population and economic growth, are the same as in the STEPS.

The difference between the APS and the STEPS represents the “implementation gap” that exists between the policy frameworks and measures required to achieve country ambitions and targets, and the policies and measures that have been legislated.

Net Zero Emissions by 2050 Scenario

The Net Zero Emissions by 2050 Scenario (NZE Scenario) is a normative scenario that sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. The scenario is compatible with limiting the global temperature rise to 1.5°C with no or limited temperature overshoot, in line with reductions assessed by the Intergovernmental Panel on Climate Change in its Special Report on Global Warming of 1.5°C. There are many possible paths to achieve net zero CO_2 emissions globally by 2050 and many uncertainties that could affect them. The NZE Scenario is therefore a path and not the path to net zero emissions.

The difference between the NZE Scenario and the APS highlights the “ambition gap” that needs to be closed to achieve the goals under the 2015 Paris Agreement.

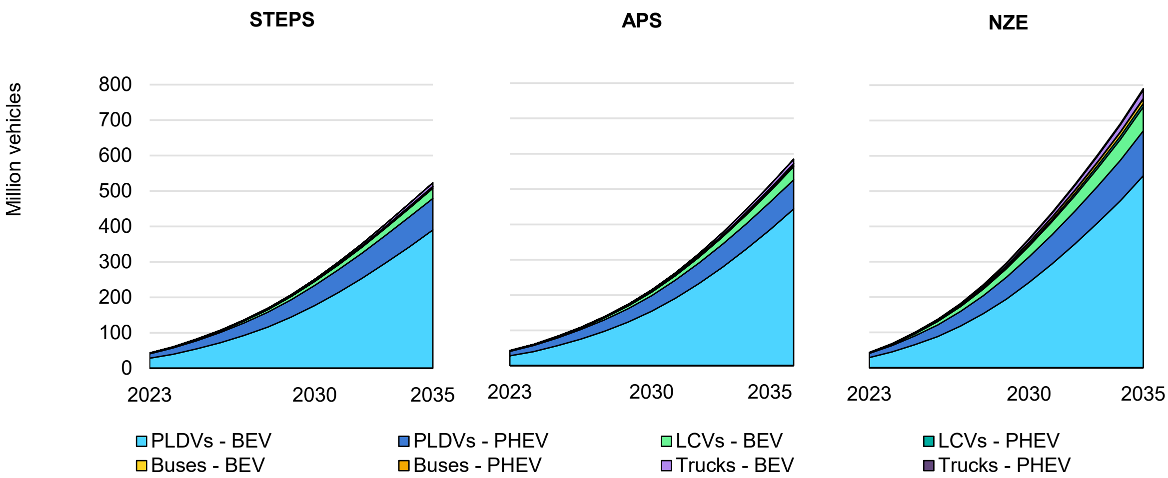
Vehicle outlook by mode

The global electric vehicle fleet is set to grow twelve-fold by 2035 under stated policies

In the STEPS, the stock of EVs across all modes except for two/three-wheelers (2/3Ws),[23] grows from less than 45 million in 2023 to 250 million in 2030 and reaches 525 million in 2035. As a result, in 2035, more than one in four vehicles on the road is electric. On average, the EV stock grows by 23% annually from 2023 to 2035.

In the APS, the stock of EVs (excluding 2/3Ws) reaches 585 million in 2035, over 10% higher than in the STEPS, and 30% of the vehicle fleet (excluding 2/3Ws) is electric. Compared to the STEPS, the average annual growth in the EV fleet is only slightly higher, with an average 24% growth between 2023 and 2035. In the NZE Scenario, the fleet of EVs grows even more quickly, at an average annual rate of 27% to 2035, reaching 790 million (excluding 2/3Ws).

Electric vehicle stock by mode and scenario, 2023-2035



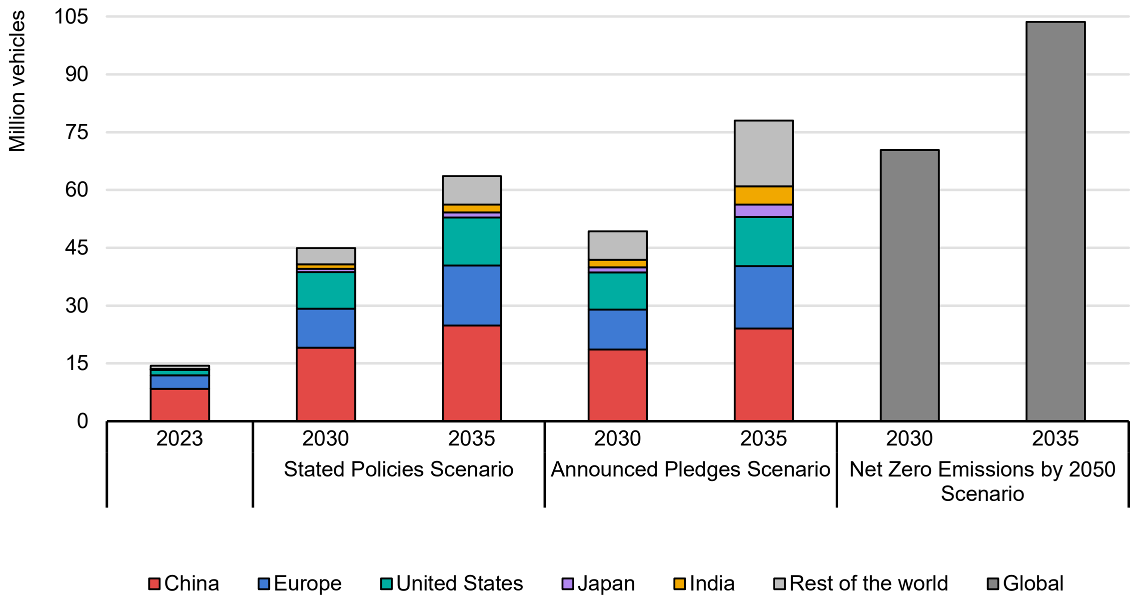
Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; PLDV = passenger light-duty vehicle; LCV = light commercial vehicle.

In the STEPS, EV sales (excluding 2/3Ws) reach almost 45 million in 2030 and close to 65 million in 2035, up from around 14 million in 2023. The sales share of EVs grows from around 15% in 2023 to almost 40% in 2030 and over 50% in 2035 in the STEPS. In the APS, the sales shares are higher, approaching 45% in 2030

[23] In this report, "two/three-wheelers" refer to vehicles aligned with the following UNECE classifications: L1, L2, L3, L4 and L5.

and two-thirds in 2035. In the NZE Scenario, EV sales shares accelerate over the next few years, reaching about 65% in 2030 and 95% in 2035.

Electric vehicle sales by region and scenario, 2030 and 2035



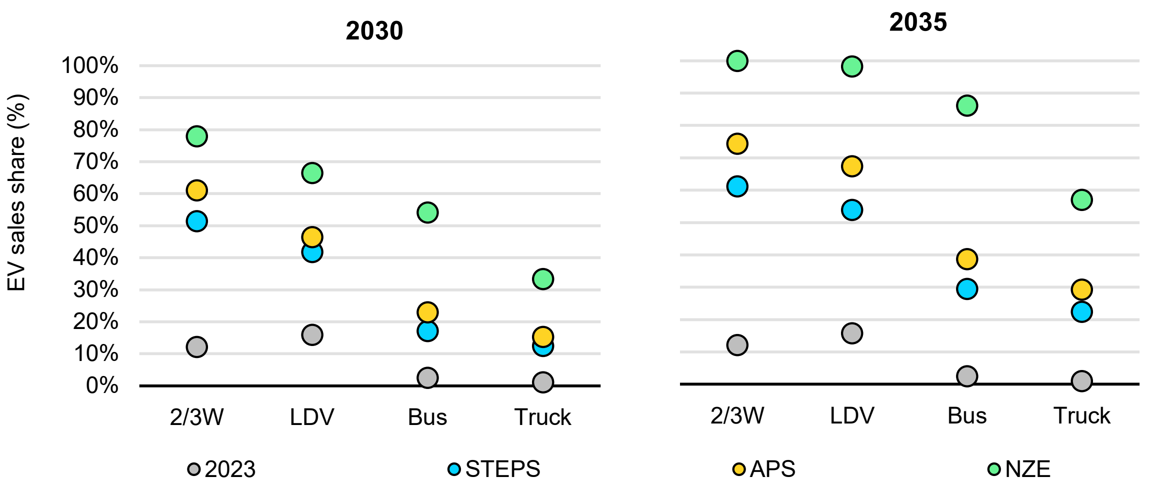
Note: Regional EV sales projections can be explored in the interactive Global EV Data Explorer.

The global sales shares of electric light-duty vehicles (LDVs), buses and trucks are fairly similar in both the STEPS and APS to 2030, suggesting that the gap between policy implementation and announced ambitions is small over the near term. This gap grows to 2035, given that many policies are focused on the near- to medium term, while strategy documents outlining ambitions tend to be longer-sighted.

Further, the gap between announced ambitions and a global trajectory to achieving net zero emissions by 2050 is larger than the policy implementation gap. In the NZE Scenario, 100% of light vehicle sales, including 2/3Ws, cars and vans, are zero-emission vehicles by 2035. This compares to an EV sales share of only around 75% of 2/3Ws and 70% of LDVs in the APS. Ambition for heavy-duty vehicles (HDVs), in particular, is lagging behind the net zero by 2050 pathway.

There are, however, differences by region. China, Europe and the United States, – the largest vehicle and EV markets today – all have both ambitious targets and ambitious policies to achieve those targets. This is well illustrated by the extremely small gap between electric car sales in the STEPS and in the APS in 2030. In fact, electric car sales in 2030 in the STEPS in China, Europe and the United States together reach a sales share of over 60%, close to the global electric car sales share in the NZE Scenario. For other countries with less developed markets, the gap between projected sales in 2030 under the STEPS, APS and NZE Scenario is larger (with less than 20% electric car sales in aggregate in the STEPS and 30% in the APS), suggesting a need to both further expand the EV industry and to share policy learnings on implementation.

Electric vehicle sales share by mode and scenario, 2030 and 2035



Notes: 2/3W = two/three-wheeler; LDV = light-duty vehicle; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.

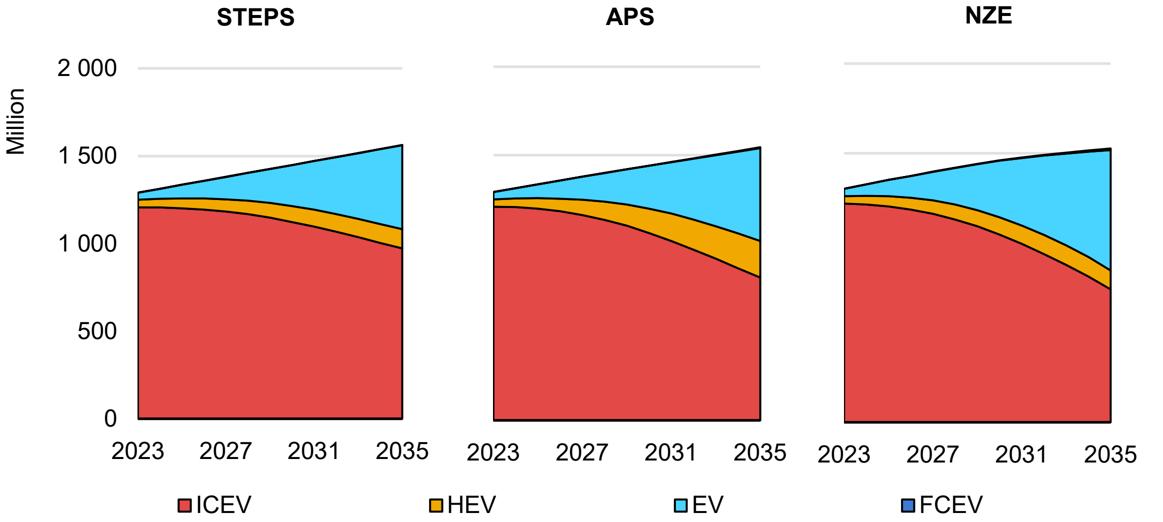
Global electric light-duty vehicle sales are set to reach 40% in 2030 and almost 55% in 2035 based on current policy settings

Light-duty vehicles (LDVs), including passenger light-duty vehicles (PLDVs) and light commercial vehicles (LCVs), are expected to continue to make up the majority of EVs (excluding 2/3Ws) through 2035. This is a result of strong policy support, including light-duty vehicle fuel economy and CO_2 standards, as well as the availability of EV models and, more generally, the sheer size of the LDV market. For example, over the past year, Canada and the United Kingdom implemented policies to increase zero-emission vehicle (ZEV) sales in 2030, targeting 60% and 80% of PLDVs, respectively.

As a result, electric LDV sales are projected to triple to over 43 million in 2030 in the STEPS, accounting for 40% of total LDV sales. By 2035, sales reach 60 million, representing a share of almost 55%.

In this scenario, the number of internal combustion engine (ICE) cars on the roads worldwide is set to decline over time as the number of electric cars grows. The stock of electric LDVs reaches about 245 million in 2030, meaning that almost one in six LDVs on the road is electric. In 2035, electric LDV stock increases to 505 million: approximately one out of three LDVs on the road.

Passenger light-duty vehicle stock by powertrain and scenario, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; EV = electric vehicle (including battery electric and plug-in hybrid electric vehicles); FCEV = fuel cell electric vehicle.

In the APS, sales of electric LDVs reach 47 million in 2030 and 75 million in 2035, representing two-thirds of sales in 2035. This reflects government electrification ambitions and net zero pledges, such as the Zero Emission Vehicles Declaration to achieve 100% zero-emission LDV sales by 2040, and by 2035 in leading markets, which has been signed by 40 national governments spanning six continents. The fleet of electric LDVs reaches more than 565 million in 2035, representing one in three LDVs. Of these, 525 million are electric PLDVs, with only 7% being LCVs.

China is set to remain the leading region for electric LDV sales in the STEPS, though its share in global sales is expected to shrink from almost 60% in 2023 to around 40% in 2030 and 2035. The relative decline in China's global share is due in part to the United States nearly doubling its share of global electric LDV sales to around one-fifth in both 2030 and 2035, thanks to a combination of policy efforts and industry ramp-up (see below). Despite strong growth in electric LDV sales in the STEPS, Europe's share of global sales remains broadly stable through 2035, at around 25%.

Full electrification of two/three-wheelers is within reach but requires more policy support

The stock of 2/3Ws is currently the most electrified among all road transport segments, with around 65 million electric 2/3Ws on the road today, representing about 8% of the fleet. In the STEPS, the number of electric 2/3Ws reaches 210 million by 2030 and 360 million in 2035, over one-third of the total fleet.

This trend has been supported by policy measures such as purchase subsidies in countries including India and Indonesia, and targets for electrifying the 2/3W fleet, predominantly in emerging and developing economies, which represent 90% of the global conventional 2/3Ws stock today. For example, the Dominican Republic aims for 5% of the private motorcycle fleet to be electric by 2030, Pakistan targets 50% electric 2/3W sales by 2030, and Rwanda targets a 30% fleet share of electric 2/3Ws. In the APS, the stock grows to 430 million in 2035, meaning 40% of all 2/3Ws on the roads are electric. The sales share of electric 2/3Ws in 2035 reaches 60% in the STEPS and 75% in the APS. China is the front-runner, with a sales share of around 90% by 2035 in both scenarios.

In the NZE Scenario, the global electric 2/3W sales share reaches close to 80% by 2030 and 100% by 2035. Getting on track with the NZE Scenario is achievable with no technological breakthroughs or major market adaptations. Given the light weight and limited daily driving distance of 2/3Ws, electrification is relatively easy and already makes economic sense on a total cost of ownership basis in many countries. However, unlike for cars, vans and HDVs, there are currently no global initiatives to reach 100% zero-emission 2/3W sales. Strengthening regulations on emissions (or even noise pollution) from 2/3Ws can play a key role in increasing the adoption of electric 2/3Ws, along with purchase subsidies to ease any barriers for lower-income households presented by higher purchase prices compared to ICE 2/3Ws.

Electric buses are projected to represent 30% of buses sold globally by 2035 based on existing policies

In recent years, a number of governments have announced new funding for electric and zero-emission buses. For example, the United Kingdom has launched a second iteration of its zero emission bus programme that will provide GBP 129 million (almost USD 160 million) to support deployment over the next few years. As announced in late 2023, India is targeting 50 000 electric buses on its roads by 2027. There are also longer-standing programmes, such as the Zero Emission Bus Rapid-deployment Accelerator partnership that was launched in 2019 to accelerate the deployment of zero-emission buses in major Latin American cities.

Funding programmes of this kind, and heavy-duty vehicles regulations, including the European Union's revised CO_2 emission standards for HDVs and California's Advanced Clean Fleets, are expected to increase the sales shares of electric buses. In the STEPS, electric bus sales increase fourteen-fold from 2023 levels, to about half a million in 2035, representing 30% of bus sales. The stock reaches 4.5 million in 2035 in the STEPS, or 20% of the total.

There are also ambitious targets for electrifying bus fleets, including Chile (100% zero-emission vehicle sales for public transport by 2035), Colombia (100% zero-emission bus sales by 2035), Chinese Taipei (full conversion of the urban bus fleet to electric by 2030), Ecuador (100% electric new public transport vehicles by 2025), and Israel (all new municipal buses to be electric by 2025). Further, the Philippines and Solomon Islands recently joined countries including the Dominican Republic, Nepal, Pakistan and Panama in setting specific targets for decarbonising their bus fleets.[24] Perhaps the biggest push for electric buses in emerging markets and developing economies (EMDEs) has been at the city level. Jakarta, Indonesia, aims to electrify its fleet of 10 000 buses by 2030, with the first 100 purchased in late 2023. Uzbekistan aims to purchase 300 electric buses in its capital Tashkent and in Samarkand. Buenos Aires is targeting a 50% zero-emission bus fleet by 2030, and a wider study of 32 Latin American cities expects that 25 000 electric buses will be deployed by 2030, and 55 000 by 2050.

Such targets mean that in the APS, sales of electric buses in 2035 are almost 40% higher than in the STEPS, reaching almost 1 million sales. One in four buses on the road in 2035 is electric. In the NZE Scenario, electric bus sales reach significantly higher levels: by 2035, almost 90% of bus sales are electric.

Trucks continue to be slowest to electrify, but country commitments could help boost progress

Zero emissions vehicles could achieve total cost of ownership parity in many HDV applications this decade, including long-haul trucks, according to recent research. And the adoption of stringent emissions standards could also help to make electric options more attractive by increasing the cost of ICE buses and trucks. Nevertheless, medium- and heavy-duty trucks may prove more difficult to electrify than other segments, in part due to the size and weight of their batteries, as well as charging requirements.

Recent emissions standards in the United States and European Union will support electric HDV adoption in the coming years. In the STEPS, sales increase more than 30-fold by 2035, albeit from around 54 000 in 2023. As a result, more than 20% of medium- and heavy-duty truck sales are electric in 2035.

At COP 28, six countries[25] joined the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles (Global MOU), bringing the total to 33 nations[26] committed to reaching 100% zero-emission sales in 2040 and 30% by 2030. In aggregate, these signatories currently represent almost 25% of

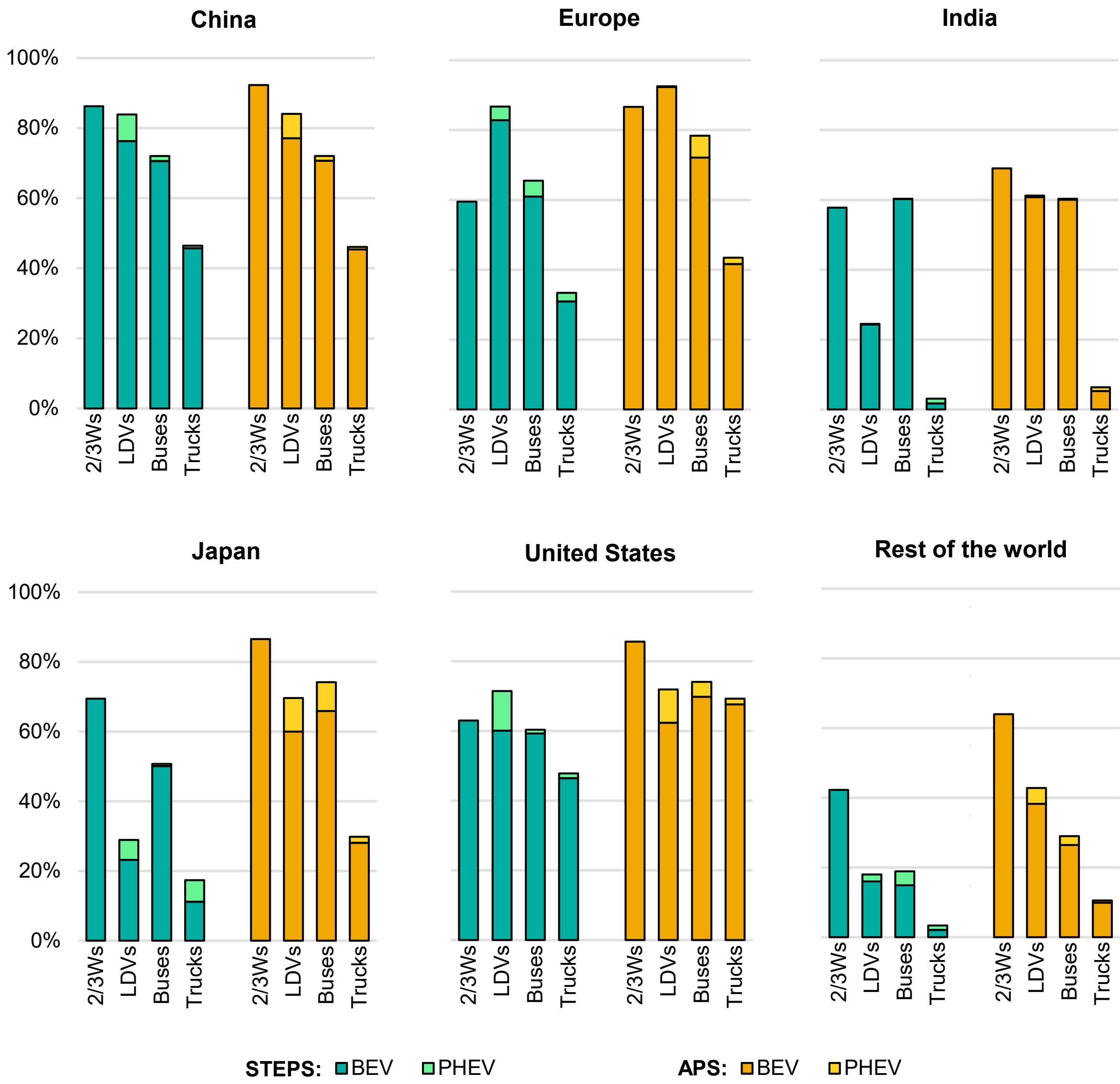
[24] See the Global EV Policy Explorer for a more comprehensive list of countries and policies.
[25] New signatories were Cape Verde, Colombia, Ghana, Iceland, Israel and Papua New Guinea.
[26] Previous signatories comprise Aruba, Austria, Belgium, Canada, Chile, Croatia, Curaçao, Denmark, Dominican Republic, Finland, Ireland, Liechtenstein, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Scotland, Sint Maarten, Switzerland, Türkiye, Ukraine, United Kingdom, United States, Uruguay and Wales.

the global medium- and heavy-duty truck market. This brings the global electric truck sales share in the APS close to 30% in 2035.

In the NZE Scenario, electric truck sales represent over 55% of total medium- and heavy-duty truck sales in 2035.

Vehicle outlook by region

Electric vehicle sales share by mode and region, 2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; 2/3Ws = two/three-wheelers; LDVs = light-duty vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle. See the annex for regional groupings. Regional projected EV sales and sales shares data can be explored in the interactive Global EV Data Explorer.

China is expected to surpass a 50% electric car sales share in the next few years

The current momentum in electric car sales has led to anticipation in China that passenger new energy vehicle (NEV) sales could reach a 50% share as soon as 2025, as stated in the recent Automotive Industry Green and Low-Carbon Development Roadmap 1.0 developed under the supervision of China's Ministry of Industry and Information Technology. If this materialises, it would be a decade ahead of the 50% sales in 2035 target laid out in the Energy-saving and New Energy Vehicle Technology Roadmap 2.0 published just a few years ago. Moreover, it would be well above the official target of 20% new energy car sales by 2025, and would even exceed the recently announced 45% NEV sales share target for 2027.

After achieving this milestone, the sales share of electric cars and vans continues to grow in the STEPS, exceeding two-thirds of total sales in 2030 and almost reaching 85% in 2035. Given that the current trend is tracking ahead of government targets, the electric LDV sales shares are the same for STEPS and APS through 2035. However, it will be critical for China to roll out public charging infrastructure in a timely manner to enable such growth. Electric LDVs are generally cost-competitive in China even at purchase, and so the phasing out of EV purchase subsidies in 2023 is unlikely to affect further growth. Announced EV battery manufacturing capacity is well above projected sales share (see below), with an eye to potential exports, and so even higher shares are theoretically achievable.

China is also the global leader in terms of electric share of the 2/3W fleet, with over one-third of all 2/3Ws being electric today, and is expected to remain the leader in electric 2/3W sales in both the STEPS and APS. In the STEPS, the sales share of electric 2/3Ws reaches nearly 90% in 2035; in the APS, the share is slightly above that by 2035.

China also has one of the highest stock shares of electric buses, with more than one in four buses being electric. By 2035, the sales share of electric buses increases to over 70% in both scenarios, up from 50% in 2023. While sales of electric medium- and heavy-duty trucks are significantly lower than other road modes, China held over 90% of the world's total global electric truck stock in 2023. Electric truck sales are projected to reach a sales share of almost 50% in 2035 in both scenarios.

The sales share of EVs across all road transport modes (excluding 2/3Ws) reaches around 80% in 2035 in both scenarios. Across all modes, the current market dynamics, and the policy landscape as considered in the STEPS to 2035, are sufficient to bring EV sales shares into line with China's ambition of climate neutrality by 2060, as well as with provincial electrification targets. As such, in China there is no gap between existing policy frameworks and future targets, and even more ambition is conceivable.

The European Union's HDV CO_2 standards brighten the outlook for electric heavy-duty vehicles

Europe remains one of the most advanced EV markets under stated policies. Last year, the United Kingdom passed the Vehicle Emissions Trading Schemes Order 2023, which mandates certain sales shares of zero-emission cars and vans, setting a target for annual ZEV sales shares for cars to increase from 22% in 2024 to 80% in 2030. Considering the policy landscape across Europe, including the UK ZEV mandate and the EU CO_2 standards for cars and vans, the sales share of electric LDVs in Europe reaches nearly 60% in 2030 and 85% in 2035 in the STEPS. The ZEV sales share in 2035 does not reach 100% for a couple of reasons. First, in the United Kingdom, the annual ZEV targets for 2031-2035 have not yet been set out in the legislation and thus the 100% ZEV sales target for 2035 is not reflected in the STEPS. Secondly, the European car market includes national markets that are not covered by such strong regulations as in the European Union and the United Kingdom.

Given that the European Union has legislated to the level of its climate and EV ambitions (resulting in zero-emission LDV sales reaching 100% in 2035), and since the United Kingdom has also passed legislation for zero-emission LDVs, at least through 2030, the EV sales shares in the APS are similar to in the STEPS. Electric LDVs represent over 60% of sales in 2030 and over 90% of sales in 2035 in the APS.

For buses and trucks, the revised EU HDV CO_2 standards drive up electric HDV sales in the STEPS. The standards will require 100% of city bus sales to be zero-emission from 2035, and other HDVs to reduce CO_2 emissions by at least 45% in 2030, 65% in 2035 and 90% from 2040, compared to 2019 levels. A number of European countries also offer grants and other financial support for the purchase of electric buses and trucks. For example, the second round of Zero Emission Bus Regional Areas (ZEBRA) funding in the United Kingdom is expected to add an additional 955 zero-emission buses to the UK fleet. In the STEPS, the sales shares of electric buses and trucks reach around 65% and 35% in 2035 in Europe. Within the European Union, sales are higher, reaching shares of 80% for buses and around 50% for trucks in 2035.

The APS takes into account the ambitions of the 18 European national governments who have signed the Global MOU on Zero-Emission Medium- and Heavy-Duty Vehicles, committing to reach 30% zero-emission HDV sales shares in 2030 and 100% in 2040. Other targets are also included in the APS, such as the UK aim to phase out the sale of any heavy goods vehicles weighing 26 tonnes and under that are not zero emissions by 2035. As a result, in Europe in the APS, electric bus sales reach around 80% in 2035 and electric truck sales almost 45%.

In Europe, the EV sales share across all modes (excluding 2/3Ws) is 85% in 2035 in the STEPS. In the APS, Europe has a combined EV sales share of over 90% in 2035 (for electric LDVs, buses and trucks), which is in line with the global trajectory in the NZE Scenario.

In the United States, new emissions standards will boost electric car and truck sales

Electric car sales are expected to continue growing in the United States, thanks to successive policies that are driving up adoption. The Corporate Average Fuel Economy Standards for Model Years 2024-2026 Passenger Cars and Light Trucks requires fuel economy improvements that are likely to increase the share of EV sales in just the next few years. From 2026, California's Advanced Clean Cars II regulations, which have been adopted by twelve other states and Washington DC,[27] will begin to further increase zero-emission PLDV sales, with the stated aim of reaching 100% by 2035. Combined, these states represent around one-third of light-duty vehicle sales in the United States, with a significant impact on overall electric car sales and, therefore, on OEM strategy. This could create a ripple effect across the wider market, as OEMs harmonise around the regulations in order to bring down production costs through standardisation. In addition, in March 2024, the US Environmental Protection Agency (EPA) also released the final rulemaking for Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles, which it estimates could bring electric PLDV sales to around 70% of total sales in 2032.

The United States is also supporting an expansion of charging infrastructure to support increased EV adoption. At the end of 2023, construction of the first EV chargers funded under the National Electric Vehicle Infrastructure programme had begun, with around USD 100 million already awarded to projects. There is now around USD 2.5 billion available to states to be allocated to EV charging projects (about 60% of the total programme funding).

The policy landscape in the United States, combined with already-committed industry investments (see below), is boosting confidence in EV market expansion. As a result, electric LDV sales reach approximately 55% in 2030 in the STEPS,

[27] The California Air Resources Board has requested a waiver from the US Environmental Protection Agency for the regulation to be enforceable; a waiver has not yet been granted. Given that such a waiver was granted for the previous Advanced Clean Cars regulation, this regulation is included in the STEPS. Note also that three states have only partially adopted the Advanced Clean Cars II regulation, keeping the ZEV sales shares targets only through 2032 without including the 100% sales target for 2035.

higher than the Administration's previously announced target, and hit more than 70% in 2035. Due to the recent policy developments, the electric LDV sales in the STEPS match government ambition and thus are the same as in the APS.

Funded by the Bipartisan Infrastructure Law, the US EPA has awarded almost USD 2 billion to fund approximately 5 000 school bus replacements, with another USD 3 billion to be provided to 2026, as part of the Clean School Bus Program. Under stated policies, the US electric bus sales share is expected to increase from around 1% in 2023 to 35% in 2030 and 60% in 2035. With respect to trucks, 11 states, representing around one-quarter of HDV sales in the country, have adopted California's Advanced Clean Trucks regulation, which sets ZEV sales requirements for trucks that range from 40-75% in 2035. Bringing the national standards more in line with the Californian regulation, the US EPA finalised GHG standards for HDVs for model years 2028-2032, which aims to reduce emissions from trucks and heavy buses by 25-60% in 2032 compared to 2026. In the STEPS, the electric truck sales share across the United States reaches around 50% in 2035.

The United States is also a signatory of the Global MOU, which targets 30% zero-emission M/HDV sales shares by 2030 (on aggregate, across bus and truck sales) and 100% by 2040. In the APS, the US electric bus sales share reaches around 75% in 2035 and the electric truck sales share reaches almost 70% in 2035.

The EV sales share across all modes (excluding 2/3Ws) reaches more than 70% in both the STEPS and the APS in 2035.

Japan's policies in support of electric vehicles remain unchanged

Japan has fuel economy standards for both light- and heavy-duty vehicles, and offers purchase subsidies for EVs. Historically, Japan has also had a relatively high sales share of hybrid (non-plug-in) vehicles, as one way to reduce emissions from cars and improve the average fuel economy.

In the STEPS, the electric LDV sales share increases from about 3% in 2023 to around 20% in 2030, and 30% in 2035. In Japan's Green Growth Strategy, the government sets a target for 100% of new car sales to be electrified by 2035 – for which their definition includes BEVs, PHEV, FCEV and hybrid electric vehicles (HEVs). In the APS, which reflects this target, about 70% of LDV sales in 2035 are electric (BEV or PHEV).

With respect to HDVs, electric bus sales reach about 25% in 2030 and increase to 50% in 2035 in the STEPS. In the APS, electric bus sales increase to 75% in

2035 to support climate targets. However, electric medium- and heavy-duty truck sales lag behind, approaching 20% in 2035 in the STEPS and about 30% in the APS.

In Japan, the EV sales share across all modes (excluding 2/3Ws) is 30% in 2035 in the STEPS and about 70% in the APS.

In India, the outlook for electric car sales brightens as domestic supply chains are built

India's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) II scheme, which provided subsidies for EVs and funding for EV charging, ended on 31 March 2024. The Ministry of Heavy Industries announced in March 2024 a limited scheme for the period between 1 April 2024 and 31 July 2024, which outlays over INR 4.9 billion (Indian rupees) (almost USD 60 million) to subsidise electric 2/3W purchases. This may be a stopgap until the announcement of a FAME III scheme, which is expected to detail new subsidy provisions for EVs. In addition, the government's Production Linked Incentive scheme for Automobile and Auto Components and for manufacturing of Advanced Chemistry Cell Battery Storage aims to attract investments in domestic EV and battery manufacturing.

Based on the current policy landscape, electric LDVs represent one in four LDVs sold in India in 2035. The APS takes into account that India signed the COP 26 declaration to transition to 100% zero-emission LDV sales by 2040. As such, electric LDV sales in 2035 reach over 60% in the APS.

India has the largest stock of two-wheelers of any country and represents almost 30% of the global stock of three-wheelers. Electrifying the 2/3W segment will therefore be important for decarbonising India's road transport system. India has made good progress to date, and almost a quarter of the country's three-wheelers are electric. The sales share of electric 2/3Ws increases from around 8% in 2023 to almost 60% in 2035 in the STEPS. In the APS the electric sales share reaches 70% in 2035.

As announced at COP 28, India is aiming to reach a stock of 50 000 electric buses by 2027, backed by a USD 390 million fund supported by both the Indian and US governments to provide loans to expand electric bus manufacturing. In both the STEPS and the APS, electric bus sales shares increase to about 35% in 2030 and 60% in 2035. Electric truck sales remain low in both scenarios to 2035, at under 10%.

Across all modes (including 2/3Ws), the EV sales share in India is about 50% in 2035 in the STEPS (and closer to 25% if 2/3Ws are excluded). In the APS, EV sales shares in India scale up to over 65% in 2035 across all road vehicle modes (and to almost 60% excluding 2/3Ws).

Many emerging and developing economies set their sights on electrification of two- and three-wheelers and public transport

Each year, more and more countries around the world are setting out a clear vision or targets for electromobility. However, in emerging and developing economies, in particular, adoption of EVs can be hindered by limited funding available for fiscal incentives and other measures to overcome purchase price hurdles. Importantly, there are still some 750 million people without access to electricity, mainly in sub-Saharan Africa, and others with grid reliability issues, which also affects the prospects for charging EVs. However, efforts are being made to support governments in EMDEs to advance deployment of EVs, such as through the Global Electric Mobility Programme, as well as proposed reforms that could improve financing options from Multilateral Development Banks.

In many EMDEs, the main targets of vehicle electrification initiatives are 2/3Ws and public transport. In Colombia, for example, there has been a major focus on electrifying mass transportation systems (buses), cargo vehicles and taxis. Targets for electric 2/3Ws have been set in countries as diverse as Cambodia, Morocco and the Dominican Republic.

In the STEPS, the average EV sales share across regions and countries outside of those described in the preceding sections is about 45% for 2/3Ws, 20% for buses, 18% for LDVs and 3% for trucks in 2035. In the APS, sales across these other regions reach 65% of 2/3Ws, 40% of LDVs, 30% of buses and 10% of trucks.

The countries that have adopted EV-related policies and set ambitions tend to have higher EV sales shares than these averages. In particular, Canada tends to align with the most ambitious standards in North America. In December 2023, Canada amended its GHG regulations to include new requirements to increase the availability of zero-emission passenger cars and light trucks, targeting at least 20% zero-emission vehicle sales by 2026, at least 60% by 2030 and 100% zero-emission vehicle sales by 2035.

The industry outlook

The ten largest carmakers are set to sell over 20 million electric cars in 2030, exceeding current policy targets

As of 2023, the ten largest global automakers all have established clear electrification targets. Together, these automakers sold over 40 million cars in 2023, representing about 55% of global sales. Although some manufacturers have missed or postponed near-term targets – often pointing to underwhelming consumer demand – they have not scaled back their longer-term ambitions. If each company in the top ten meets their target, over 20 million new electric cars could be sold in 2030. Notable examples include BMW's target of 50% of deliveries in 2030 to be BEVs; Toyota's 3.5 million BEV sales target in 2030; Stellantis's 5 million BEV sales target in 2030; and GM's target of a global EV manufacturing capacity of 2 million per year by 2025. In addition, Tesla is targeting production of 20 million electric cars in 2030, which – combined with the targets of the top ten – would be roughly equivalent to the projected sales in the STEPS in that year.

In total, more than 20 OEMs, together representing over 90% of car sales in 2023, have set some sort of target for future EV deployment. The global electric car sales envisaged in announcements by manufacturers have increased by several percentage points based on developments over the past year. If all manufacturers' targets on vehicle electrification are combined, between 42% and 58% of car sales in 2030 could be electric. This range encompasses the sales share for cars in the STEPS (almost 45%) and the share implied by government ambitions in the APS (almost 50%).

Regional examples include:

- In China, major carmakers, including incumbents, have increased their electrification ambitions. For example, SAIC and Geely are targeting 50% NEV sales by 2025.
- In Europe, more ambitious targets announced by majors such as Volkswagen, Ampere (a spin-out of Renault), Nissan and Suzuki have increased the overall OEM electrification targets relative to last year's range. For example, Volkswagen increased its BEV delivery target from 70% to 80% by 2030. On the other hand, Mercedes-Benz has delayed its goal of 50% electrified car sales by 5 years, to 2030.
- In the United States, both Ford and GM missed their 2023 targets or abandoned those for 2024, citing profitability concerns, though they are maintaining longer-term targets. Ford missed its targeted manufacturing rate of 600 000 EVs per year in 2023, but now aims to achieve that in 2024. GM had previously planned to manufacture 400 000 electric cars in North America by mid-2024, but has now

dropped that target, and yet has retained a US manufacturing capacity target of 1 million electric cars by 2025. Meanwhile, Volkswagen increased their BEV delivery target in the United States from 50% to 55% by 2030. As a result of missed near-term targets but robust longer-term ambition, the outlook for the United States based on OEM targets has remained stable over the past year.

- In Japan too, new announcements have increased the aggregate OEM target range. Suzuki aims to reach 20% BEV sales in 2030. Subaru announced a new and more ambitious target of 50% BEV sales out of a total of 1.2 million car sales in 2030, with a production capacity of 400 000 BEVs in Japan and even a new BEV production line in the United States before 2030. Subaru plans to introduce a total of 8 new BEV models, and to sell 400 000 BEVs in the United States by 2028.
- In India, Tata is targeting a 50% EV sales share by 2030 and net zero GHG emissions by 2045.

Newly announced and updated electrification targets for light-duty vehicles

Automaker	Target	Region	Group / Brand
Volkswagen	Increased BEV delivery target from 50% to 55% in 2030	United States	Brand
Volkswagen	Increased BEV delivery target from 70% to 80% in 2030	Europe	Brand
Ampere	Announced target of 300 000 BEV sales in 2025 and 1 million in 2031	Europe	Brand
Togg	Targets delivery of 1 million electric cars by 2030	Europe	Brand
Toyota	Accelerated production target to 20% EV by 2026	Europe	Brand
Nissan	Announced 100% BEV sales from 2030	Europe	Group
Suzuki	Presented strategy to reach 80% BEV sales share in 2030	Europe	Group
Suzuki	Presented strategy to reach 15% BEV sales share in 2030	India	Group
Suzuki	Presented strategy to reach 20% BEV sales share in 2030	Japan	Group
Subaru	Announced more ambitious target of 50% BEV sales in 2030	Global	Group

Automaker	Target	Region	Group / Brand
Hyundai	Raised ambition to sell 2 million EVs annually by 2030	Global	Brand
Kia	Increased 2030 EV sales target to 1.6 million	Global	Brand
Tata	Announced plan to sell 50% EVs by 2030	Global	Brand
SAIC	Increased ambition from 40% to 50% ZEV sales by 2025	Global	Group
Geely	Increased ambition from 40% to 50% ZEV sales by 2025	Global	Group

Note: Data on targets announced or updated since the publication of GEVO-2023.
Source: IEA analysis based on company announcements as linked in the automaker column.

Several important car makers have also announced a phase-out date for ICE vehicle sales. For example, ICE phase-outs have been announced by Jaguar from 2025, Mini and Rolls-Royce from the beginning of the 2030s, Lexus from 2035, Land Rover from 2036, and Honda from 2040.[28] Combined, these brands represented over 5% of global car sales in 2023. Even more automakers have pledged to phase out ICE vehicle sales in the European market specifically, including include Ford, Volkswagen, Stellantis, Lancia, Renault and Nissan.

Policy is boosting investment in manufacturing capacity, building confidence for a rapid electrification pathway

Battery and EV manufacturers have faced new challenges and opportunities as major markets including the United States and the European Union introduced new industrial policies. Domestic content requirements introduced by these policies have supported the expansion plans of major battery and EV manufacturers, with billions in investments already committed as of early 2024. Worldwide, reported investment announcements from 2022 and 2023 alone exceed USD 275 billion in EVs and USD 195 billion in batteries, with around USD 190 billion of the total already committed. The level of investments observed in the past 2 years boosts confidence in the electrification of road transport.

In **China**, committed battery manufacturing capacity is well above what is needed to supply domestic electric car sales in 2030. In fact, just two-thirds of the already-committed battery cell manufacturing capacity would be sufficient to cover 100% of electric car sales in China in 2030. This excess capacity, which is today driving

[28] Mercedez-Benz had previously announced the end of ICE car sales this decade but has recently delayed that target.

down margins, implies that battery producers are banking on export markets, at least in part. This will bring both opportunities and challenges. Countries that have electrification targets but lack sufficient battery manufacturing capacity could reach these targets through imports from China, whereas companies outside of China will see increased competition from the arrival of Chinese manufacturers. Governments will seek to find the right balance between supporting local producers at the same time as ensuring consumers can benefit from the low prices offered by Chinese manufacturers, which would accelerate road electrification.

In the **United States**, the Inflation Reduction Act (IRA) revised the requirements for the Clean Vehicle Tax Credit. Now, to qualify for the tax credit of up to USD 7 500, vehicle assembly must take place in North America and meet the critical minerals and battery components requirements.[29] In December 2023, guidance was released defining the "Foreign Entities of Concern" as part of the tax credit exclusions: vehicles with batteries containing components manufactured or assembled by a foreign entity of concern (which includes China) cannot qualify for the tax credit. The number of eligible electric car models has therefore fallen from more than 40 in the second half of 2023 to around 27 from the beginning of January 2024.[30] In 2025, restrictions may be expanded such that EVs cannot qualify if their batteries contain any critical minerals that were extracted, processed, or recycled by a foreign entity of concern.

From September 2022 to the end of 2023, after the IRA was signed into law, investments of more than USD 60 billion were announced to support the EV industry, in EV manufacturing, charging and batteries in the United States.[31] The vast majority – about 80% – of these investments are for batteries; with just around USD 5 billion announced for EVs, though there are, of course, strong links between battery manufacturing and EV manufacturing. For example, in February 2024, Volkswagen-backed Scout Motors started building a USD 2 billion electric sports utility vehicle (SUV) manufacturing plant in South Carolina. In mid-2023, BMW broke ground on their high-voltage battery manufacturing plant (USD 700 million) to supply batteries for their announced EV production lines (USD 1 billion) in South Carolina. Hyundai-Kia, which in 2023 overtook GM and Ford in terms of electric car sales share, plans to manufacture EVs in the state of Georgia by October 2024 to qualify for IRA benefits.

Announced battery manufacturing expansions in the United States, in part resulting from signals sent by the IRA, would be more than enough to satisfy carmaker electrification targets and government ambitions in 2030. Of course, the

[29] The critical minerals requirement refers to minimum percentages of critical mineral extraction or processing (by values) in the United States or in a country which has a free trade agreement with the United States. The battery component requirement refers to minimum percentages of battery component manufacturing or assembly (by value) that takes place in North America.
[30] Based on model trim eligibility from the US government website.
[31] Another USD 5 billion has been invested in battery manufacturing in Canada since the IRA was passed.

announced investments in battery manufacturing will first need to be realised, and we estimate that it would require around USD 100 billion in capital expenditures[32] to reach the level of battery manufacturing capacity necessary to meet demand for electric cars in 2030 in the APS. According to the Clean Investment Monitor, actual expenditures in EV battery manufacturing from 2020 to 2023 totalled around USD 45 billion. Around 45% of the capital expenditure (CAPEX) needed for battery manufacturing has therefore already been spent.

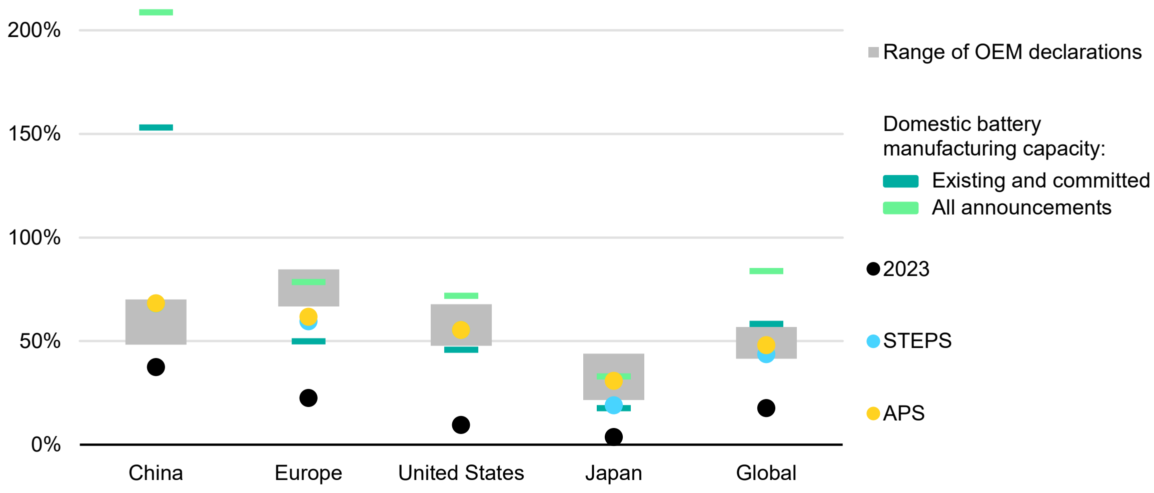
In the **European Union**, the Net Zero Industry Act and the subsequent relaxing of state aid rules in March 2023 are boosting public support for road transport electrification. For example, in January 2024, Swedish battery maker Northvolt received approval for EUR 700 million in direct grant and EUR 200 million in guarantee from Germany, which was described as “proportionate and limited to the minimum necessary to trigger the investment in Europe”. Northvolt’s project is expected to require a total investment of EUR 4.5 billion, creating 3 000 jobs and starting battery manufacturing in 2026. The company also secured a USD 5 billion green loan – touted as the largest green loan in Europe to date – with the support of European and Korean banks and export credit agencies. The loan will enable further expansion for the production of cathodes, cell manufacturing and a recycling plant in northern Sweden.

As of 2024, the market signals provided by the Net Zero Industry Act have been sufficient to attract enough committed investments in battery manufacturing capacity in the European Union to satisfy government electrification targets out to 2030. Across the whole of Europe, committed investments come close to meeting these targets.

While investments that are already committed today tend to be more heavily geared towards battery than to EV manufacturing, it is important to note that battery manufacturing and EV expansion plans typically go hand in hand, often being situated close to demand centres to create integrated supply chains. This close collaboration is important in order to deliver on targets, avoid bottlenecks and decrease costs. In addition, in the event that committed EV battery manufacturing capacity outpaces demand from EV manufacturers, it is unlikely that it would find alternative outlets, as other key battery markets such as consumer electronics are already well supplied and have different technical specifications. Failure to deliver on EV manufacturing capacity and sales therefore creates a risk of massive sunk investment in battery manufacturing, if manufacturers are unable to export significant quantities.

[32] CAPEX of 2023 USD 107 million per GWh of battery manufacturing capacity is assumed.

Equivalent electric car sales shares targets by battery and car manufacturers, and electric car sales shares in the Stated Policies and Announced Pledges Scenarios, 2030



Notes: OEM = original equipment manufacturer; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. OEM pledges cover the European Union and the European Free Trade Association (i.e. Iceland, Liechtenstein, Norway and Switzerland). Committed refers to plants that have reached a final investment decision and are starting or have already started construction works. Battery manufacturing capacity refers to the mobility sector only and assumes utilisation factors of 85%.

Sources: IEA analysis based on companies announcements and data from Benchmark Mineral Intelligence, Bloomberg New Energy Finance and EV Volumes.

For example, in Europe, Volkswagen benefits from close co-operation with two of the biggest regional battery manufacturers, LG Energy Solutions and Samsung, which together provide batteries for 95% of Volkswagen's European electric car sales. In China, on the other hand, Volkswagen works with CATL, which provides almost all the batteries for its Chinese electric car sales. Similarly, Tesla works with Panasonic's Nevada plant in the United States, but with CATL and LG Energy Solutions in China. When considering expansion plans, battery manufacturers often seek to bring operations closer to the production facilities of partner OEMs. CATL is currently developing manufacturing facilities in Hungary to provide regional car makers like Stellantis, which sources nearly 50% of its European EV batteries from CATL and the other half from LG and Samsung SDI. A similar trend is already observable outside of the biggest EV markets, such as in Türkiye, where the Turkish brand Togg and Farasis Energy created a joint venture in April 2023. During 2023 the Togg T10X model reached almost 20 000 registrations in Türkiye, becoming the fourth most sold car model in November 2023.

Continued co-operation between EV and battery makers is expected to continue to support road transport electrification into the future. As of early 2024, half of the committed battery manufacturing capacity in the United States will be delivered by joint ventures between an EV and a battery manufacturer (e.g. LG-GM, LG-

Honda, LG-Hyundai, Samsung-GM, Samsung-Stellantis, Panasonic-Tesla, LG-Toyota, SKI-Ford, SKI-Hyundai). Many similar joint ventures are seen in Europe (e.g. Northvolt-Volvo, Envision-Nissan). There are even joint ventures for battery components, such as between Volkswagen and Umicore to produce battery cathodes.

Globally, on the basis of industry announcements, committed battery manufacturing capacity in 2030 would be sufficient to support the electric car sales share reaching more than 55%, higher than the sales shares implied by automaker targets and both the STEPS and APS projections. In fact, the committed and existing battery manufacturing capacity would meet over 90% of the EV battery demand in the NZE Scenario in 2030.

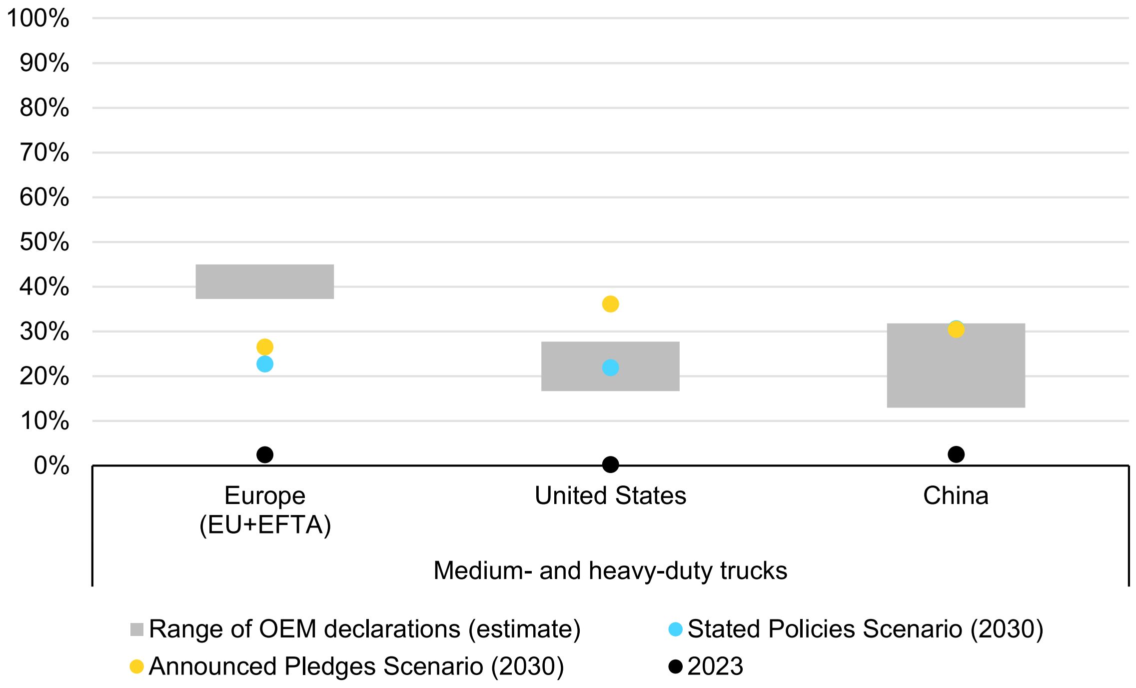
Heavy-duty original equipment manufacturers are most ambitious in the European market, driven by proposed CO_2 standards

A few new announcements on zero-emission vehicle strategies have been seen in the HDV market, such as the agreement signed by Hino Motors Sales USA that could result in the delivery of up to 10 000 electric trucks by 2030. For the United States, the range of OEM targets in 2030 encompasses the zero-emission vehicle sales shares in the STEPS (around 20%).

Chinese OEM Foton has also announced a target of 50% NEV sales by 2030. Similarly, BAIC Trucks also plans to sell 50% new energy trucks by 2030 and 80% by 2035. On aggregate, OEM targets would imply that zero-emission truck sales represent 13-32% of Chinese truck sales in 2030.

There have been no big announcements from truck makers in Europe over the past year, but OEM targets for this market still exceed what would be necessary under the EU HDV CO_2 standard, as reflected in the STEPS sales share.

Zero-emission heavy-duty vehicle sales shares implied by original equipment manufacturer targets and projected in the Stated Policies and Announced Pledges Scenarios, 2030



Notes: OEM = original equipment manufacturer. OEM pledges cover the European Union and the European Free Trade Association whose members are Iceland, Liechtenstein, Norway and Switzerland. The figure compares OEM targets for heavy-duty vehicles (HDVs) (which for some OEMs include buses) relative to IEA projections for zero-emission medium- and heavy-duty truck sales (including fuel cell electric vehicles). Since annual sales of trucks substantially outnumber sales of buses, achieving HDV targets will require selling zero-emission trucks, which is currently more challenging than selling electric buses. The regional average market share in 2030 is calculated by collating announcements that explicitly mention zero-emission vehicles (ZEV) market shares or ZEV sales by the top 10-25 OEMs in each region. Electric bus and truck registrations and stock data can be interactively explored via the Global EV Data Explorer.

8. Outlook for electric vehicle charging infrastructure

Light-duty vehicle charging

Public charging could increase sixfold by 2035, helping mass-market consumers switch to electric

Large-scale adoption of EVs hinges on the simultaneous roll-out of accessible and affordable charging. The early adopters of electric cars have tended to live in single-family detached homes with affordable and convenient access to home charging. As a result, most charging to date has been private (at home and other private locations). At the same time, public chargers have tended to be installed in urban areas, where utilisation rates are likely to be higher. Looking forward, however, chargers must also be installed outside of urban areas to enable continued adoption beyond cities and suburbs.

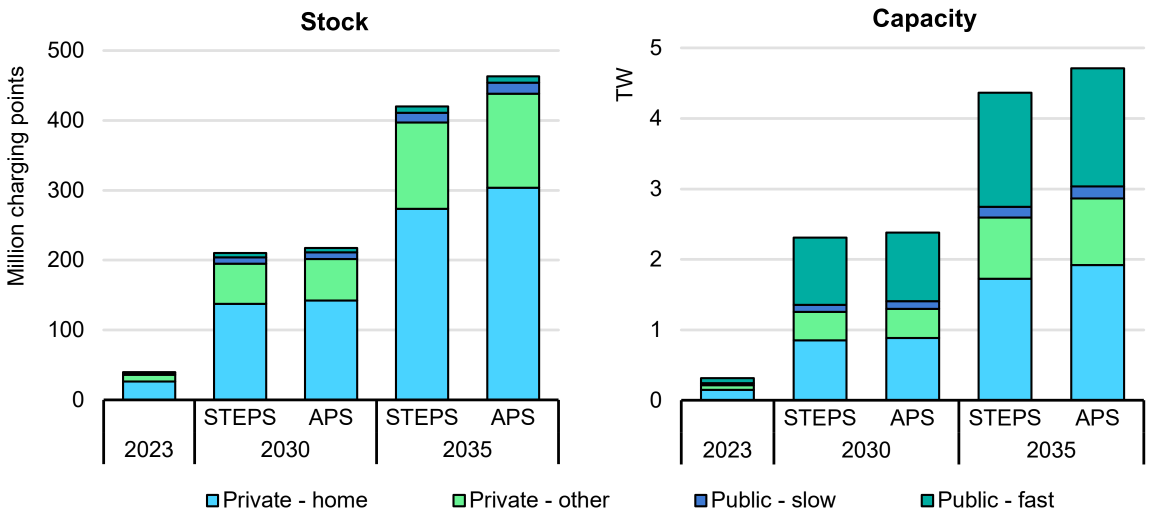
In a 2021 survey of EV drivers in the United Kingdom, over 90% of the respondents reported having access to home chargers, whereas a 2023 study showed that only 55% of Indian consumers had such access. The build-out of charging in workplaces and publicly accessible areas will be key for increasing adoption among groups without access to home charging. Charging speed – slow or fast – is also an important consideration for consumers looking to switch to electric, especially when considering a vehicle for long journeys. Charging services should also be easy to use, reliable and transparently priced. Further, ensuring interoperability is important when making investments in charging infrastructure and services, so that a wide customer base is able to benefit.

In the STEPS and APS, the global number of public charging points exceeds 15 million by 2030, up four-fold compared to the almost 4 million operating in 2023. By 2035, this number reaches almost 25 million in the APS, a sixfold increase relative to 2023.

Among today's major EV markets, China is where the population's access to home charging is most limited and where public charging has been most widely rolled out as a result. China accounted for 70% of global public LDV charging in 2023 and is expected to remain a leader with a similar share in 2035 in the STEPS. While the current availability of public chargers in China already appears to be above the global average (<10 electric LDVs per public charging point), the government recently issued new guidelines for deploying high-quality charging infrastructure. The number of electric LDVs per public charging point increases from around 10 in 2023 to around 15 in 2035 in the APS, remaining lower than other major markets.

Currently, China has one of the highest shares of fast chargers out of total public charging stock, at around 45%. In both the STEPS and APS, the stock of public fast chargers reaches around 7.5 million in 2035, almost six times 2023 levels. The number of slow chargers reaches 8.2 million in 2035 in the APS.

Global light-duty vehicle charger stock and capacity, 2023-2035



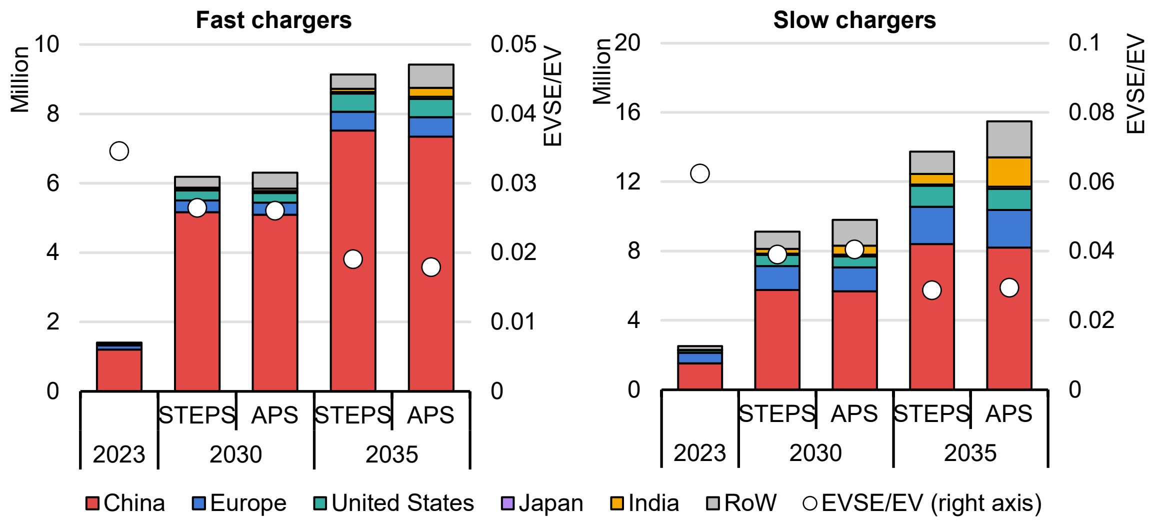
Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. "Private – other" refers to charging points that are neither publicly accessible nor charging points at private residences. Home charging stock in 2023 is estimated based on electric light-duty vehicle stock and regional assumptions on electric vehicle supply equipment (EVSE)/electric vehicle (EV) ratios. Regional projected EVSE stock data can be explored via the interactive Global EV Data Explorer.

In Europe, the stock of public LDV chargers increases to around 2.7 million in 2035 in both the STEPS and APS, up from about 730 000 in 2023. In both scenarios, roughly 80% of the European public charging stock is in the European Union, or around 2.3 million chargers in 2035.

Policies focused on charging infrastructure play an important role in increasing the number of charging points per EV. Specifically, the EU Alternative Fuels Infrastructure Regulation (AFIR) requires member states to ensure publicly accessible charging stations offer in aggregate at least 1.3 kW of power output per BEV and 0.8 kW per PHEV. The capacity requirements can be relaxed once 15% battery electric stock share has been reached. In the APS, the average charging capacity per EV is close to 1 kW, despite over 80% of electric LDVs being battery electric, given that battery electric LDVs reach a 30% stock share. The AFIR regulation also requires that from 2025 onward, DC fast charging (at least 150 kW) be installed every 60 km along the EU Trans-European Transport Network (TEN-T). As such, the share of fast chargers is set to increase from the 2023 share of approximately 15%.

The United Kingdom expects to install at least 300 000 public chargers by 2030. In the APS, the roll-out of public chargers is slightly slower but maintains adequate coverage in terms of charging capacity available, with the stock reaching only 220 000 in 2030, with 1.2 kW of charging capacity per electric LDV available, and reaching 300 000 5 years later in 2035. Considering the stock of electric LDVs approaches 20 million in 2035 in the APS, this corresponds to over 60 electric LDVs per public charging point, up from around 30 in 2023.

Number of public light-duty vehicle chargers installed by region, 2023-2035



Notes: RoW = Rest of the world. STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; EV = electric vehicle; EVSE = electric vehicle supply equipment. Regional projected EVSE stock data can be explored via the interactive Global EV Data Explorer.

In the United States, the government has announced nearly USD 50 million to subsidise projects that aim to expand access to convenient charging, in line with its objective of building a national network of 500 000 public EV charging ports by 2030. In the APS, the number of public chargers reaches 900 000 in 2030 and 1.7 million in 2035, many of which will likely be funded by private investment and go beyond highway corridors. This translates to about 55 electric LDVs per charging point in 2035.

Japan's Green Growth Strategy aims to deploy 150 000 charging points by 2030, including 30 000 fast chargers, with the objective of reaching a comparable level of comfort as for refuelling conventional vehicles. In the APS, the number of LDV charging points reaches 160 000 by 2030, of which approximately 55 000 are fast chargers. By 2035, the number of public charging points reaches 190 000 in the APS. The number of electric LDVs per public charging point increases from around 18 in 2023 to over 80 in 2035 in the APS.

In India, FAME II has offered financial support and set targets for charging infrastructure, such as the requirement for chargers to be installed every 25 km along major highways. Additionally, in March 2023, the Ministry of Heavy Industries announced financial aid for the development of charging infrastructure. In the APS, the ratio of electric LDVs per public charging point remains low, like in China, with the number of charging points projected to reach almost 2 million by 2035 in order to supply around 25 million electric LDVs.

Recommendations for EV charging concessions to implement the EU Alternative Fuels Infrastructure Regulation

Following the formal adoption of the EU AFIR in 2023, EU member states are now implementing the regulation through the public and private entities that operate European motorway networks. This process is helping to build up the knowledge base on how to ensure that reliable charging points are deployed quickly and effectively through competitive tendering, thereby fostering the emerging market for EV charging infrastructure. Key learnings include:

1 – Collect information on state-of-the-art technologies and designs prior to issuing the tender

Carrying out a market consultation with charging point operators (CPOs) ahead of publishing a tender can help to ensure that the tenders are designed to encourage bids that follow best practices and use the latest technologies in this emerging sector.

2 – Include station design and reliability in the evaluation criteria of a tender

Tender evaluations should consider other criteria alongside rent (i.e. the amount that the CPO pays to operate the station), to ensure that CPOs also score highly on other factors relevant to the offer to customers.

Tenders should include criteria to ensure that EV charging stations are well designed and easily accessible. This includes making sure that charging stations have sufficient space to accommodate EVs of different sizes, including HDVs, camper vans and vehicles with caravans, as well as users with limited mobility, so that drivers are not required to perform potentially dangerous manoeuvres. Criteria can also be designed to ensure that chargers can service the newest generation of BEVs, as well as older models, and that sites have the potential to expand as the EV market increases.

For successful long-term operation and ensuring EV drivers are not dissuaded, CPOs need to be held accountable for providing a reliable service. Competitive tenders should set criteria for quality, with penalties for those that do not meet required standards, for example 99% uptime and regular charger maintenance.

Further, selection criteria can be used to ensure chargers are smart-ready, able to share data within the charging ecosystem, provide fair and transparent pricing, and meet interoperability obligations.

3 – Bundle more and less desirable sites to ensure full coverage

Charging stations located at sites with higher traffic often have a higher utilisation rate and thus are more profitable than those with lower traffic. In order to prevent CPOs from only bidding on the most desirable locations, tenders can bundle the motorway locations into several "lots" composed of higher- and lower-traffic sites.

4 – Ensure tender terms provide a viable business case

Given that the EV market is still relatively nascent, many EV charging stations will not be profitable for a number of years. ChargeUp Europe, an industry association, recommends that a contract duration of at least 15 years is necessary for CPOs to recover initial investments and for sites to become profitable. In general, the lower the current EV stock share, the longer the tender terms should be for CPOs to feel confident in the business proposition.

Further, to best enable CPOs to assess the business case for a tender, only one CPO should be selected to serve each service area, as is the case with conventional petrol stations. The presence of multiple CPOs makes it very difficult to predict revenues given low EV penetration rates. Different CPOs could be selected on consecutive service areas to provide greater customer choice and market competition. Local monopolies should be avoided.

5 – Prepare grid connections

Establishing a grid connection can be a lengthy, complex process, which can delay development of charging stations. To overcome this potential hurdle, motorway operators can request grid connections in advance of or in parallel to issuing a tender. Governments can also set requirements for grid operators to respond to requests within a set time and ensure there are no conflicts of interest between grid operators and parties requesting grid connections. In countries where grid operators also operate as CPOs, they can be in direct competition with operators requesting connections.

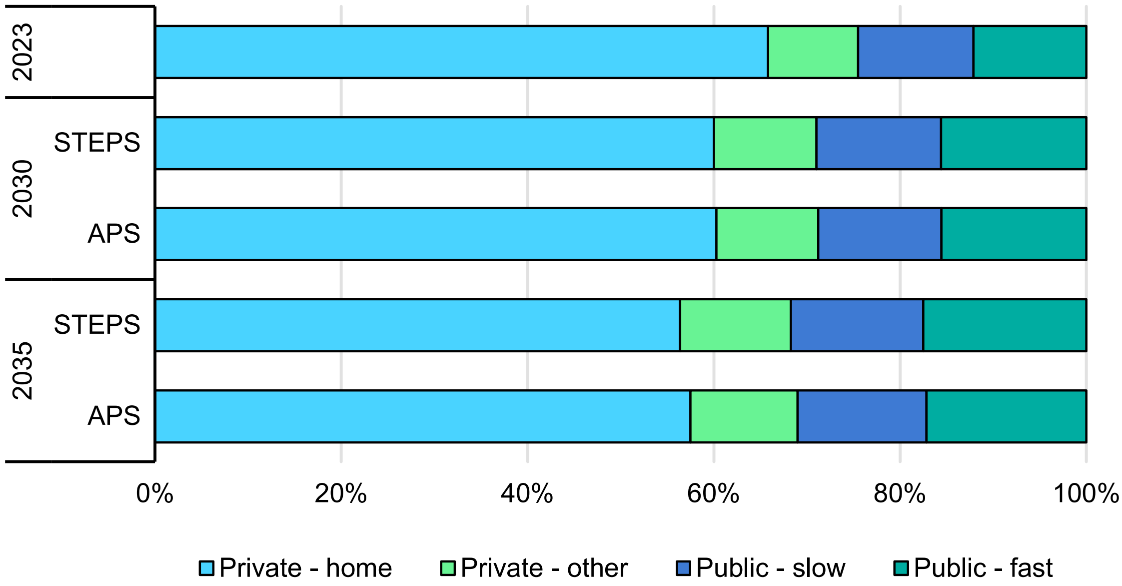
The share of public charging is expected to grow in the next decade, though most charging will still take place at home

Statistics on the availability of home chargers are scattered, and our analysis therefore assumes that access to home charging covers 50-80% of the electric LDV fleet, based on various surveys, depending on the share of population residing in dense urban areas.[33] We estimate that globally there were 27 million home chargers in operation in 2023, or 150 GW of charging capacity and 1.6 electric LDVs per home charger. The stock grows more than tenfold by 2035 in the STEPS to reach over 270 million. In the APS, the home charger stock reaches around 300 million in 2035.

The stock of other private chargers increases up to 14-fold by 2035 in the APS, while public chargers increase sixfold. In both scenarios, the charging capacity offered by public chargers in 2035 is higher than that offered by private chargers outside of homes. In total, there are an estimated 1.2 electric LDVs per charging point, including public and private, 2035 in the APS, up from just over 1 in 2023.

Even with access to home charging, EV owners rely to some extent on public charging. As EV adoption broadens, the share of charging from other private or public charging stations (in terms of electricity delivered to vehicles) is expected to grow over time. By 2035, the share of electricity coming from chargers other than home chargers reaches almost 45%, compared to less than 35% in 2023.

Electricity delivered to electric light-duty vehicles by charger type, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Home and other private chargers are considered to be slow chargers that provide power up to 22 kW; Fast chargers at over 22 kW.

[33] For example, a recent European EV driver survey showed that in 2023, 44% of respondents didn't have a charging point installed at home, up from 33% in the 2022 survey.

Heavy-duty vehicle charging

As more and more buses and trucks are electrified, charging capacity is set to grow twenty-fold by 2035

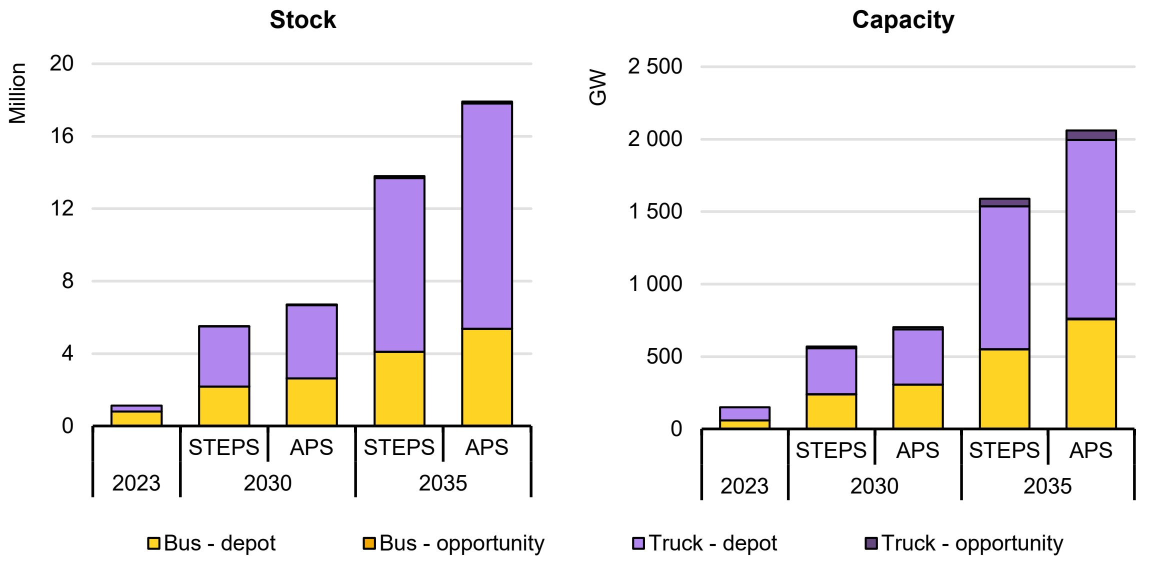
For commercial vehicle operators, similarly to owners of personal EVs, overnight charging of electric HDVs at depots offers a convenient way to charge stationary vehicles. Charging overnight also has the benefit of being able to charge at relatively low power rates given the amount of time available. This kind of charging strategy requires a close to one-to-one ratio of depot charger per electric HDV.

In the near term, it is expected that electrification of HDVs will proceed most quickly for segments with relatively short (under 200 km/day), predictable daily routes, such as city buses, urban and even some regional delivery services. Overnight depot charging could likely meet most of the needs of these fleets.

In addition, there will also be a role for opportunity chargers. Opportunity chargers can be at the end of a bus line or at a truck loading dock, where vehicles can take advantage of waiting time to charge without disrupting typical operations. Opportunity chargers also include public chargers along motorways that allow for en-route charging. For some HDVs, such as intercity buses and long-haul trucks, en-route fast charging may be needed to supplement depot charging in order to enable long-distance driving. While these segments could be slower to electrify, their relatively high share of activity today – and thus emissions – mean they will be important to decarbonise.

Options other than wired charging could also be used to support electric HDVs, such as electric road systems and battery swapping. In China in particular, battery swapping for trucks may become a widespread means of recharging. However, the current analysis of charger needs does not take into account non-wired charging options, as the future role of these alternative technologies remains uncertain.

Heavy-duty vehicle charger stock and capacity in the Stated Policies and Announced Pledges Scenarios, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Charger stock in 2023 is estimated based on the number of electric buses and trucks.

In the STEPS, over 99% of HDV chargers are depot chargers in 2030, though about 10% of electricity is provided by opportunity chargers. By 2035, there is greater deployment and utilisation of opportunity chargers, with the stock more than tripling compared to 2030 to reach 100 000 in 2035. In total, the installed capacity of chargers for HDVs reaches 2 000 GW in 2035 in the APS. For reference, the installed global renewable electricity capacity in 2022 was around 3 600 GW. Despite the average capacity of an opportunity charger being assumed to be around four times as high as a depot charger (especially considering the role of MW-scale charging), less than 5% of the total installed capacity for heavy-duty chargers in 2035 is from opportunity chargers.

Policy has an important role to play in fostering infrastructure roll-out. The EU AFIR, for example, includes requirements for coverage of HDV charging points with a power output of at least 350 kW along TEN-T Network by the end of 2025. In March 2024, the United States released the National Zero-Emission Freight Corridor Strategy, which aims to guide infrastructure deployment, catalyse public and private investment; and support utility and regulatory planning and action at local, state and regional levels. As of the end of 2023, cumulative private investment in medium- and heavy-duty vehicle charging infrastructure in the United States amounted to USD 4.2 billion. Industry will certainly also play a major role in HDV charging infrastructure development. For example, joint venture Milence plans to build and operate 1 700 HDV charging points in Europe by 2027.

The CharIN industry alliance is supporting the development of charging systems rated up to 3.75 MW, as well as the associated charging standards.

Special focus: examining the impacts of ramping up heavy-duty charging on power grids

A key challenge for rolling out charging infrastructure is ensuring that it can provide secure, low-emissions and affordable electricity. Decision makers will need to assess the impacts of HDV charging on the expansion and operation of power systems, and to plan accordingly. In this section, we explore the implications of different HDV charging strategies for power systems, through an analysis at the bulk power system level for three regions (China, the European Union and the United States) and a case study of a local high-voltage grid. We also discuss some strategies and technologies to mitigate the impacts of HDV charging on power grids.

EV charging creates both challenges and opportunities for electricity systems. Beyond local issues such as variations in power quality (e.g. harmonic distortion), EV charging can have an impact on electricity systems, mainly via demand-supply imbalances, either locally (e.g. by causing grid congestion) or – if there is a large enough fleet – at the system level. The electricity system impacts of EV charging can be principally understood by a combination of three dimensions: the **when** (at what time and for how long), the **where** (in which location of the grid), and the **how much** (the charging power that the vehicle is using).

As an example, EV charging could create stress on the electricity system if it takes place in an area of the grid that is already congested at that time. On the other hand, charging could become a beneficial opportunity if it is possible to charge the fleet at a different time of the day, when there is less congestion or greater renewable power availability, or if it is possible to charge in a different location.

This analysis is based on four cases that only differ with regards to the charging location and the power availability. There is no difference in technical parameters such as battery size or average daily mileage. All these cases represent feasible ways of meeting heavy-duty truck charging needs with different charging location options.

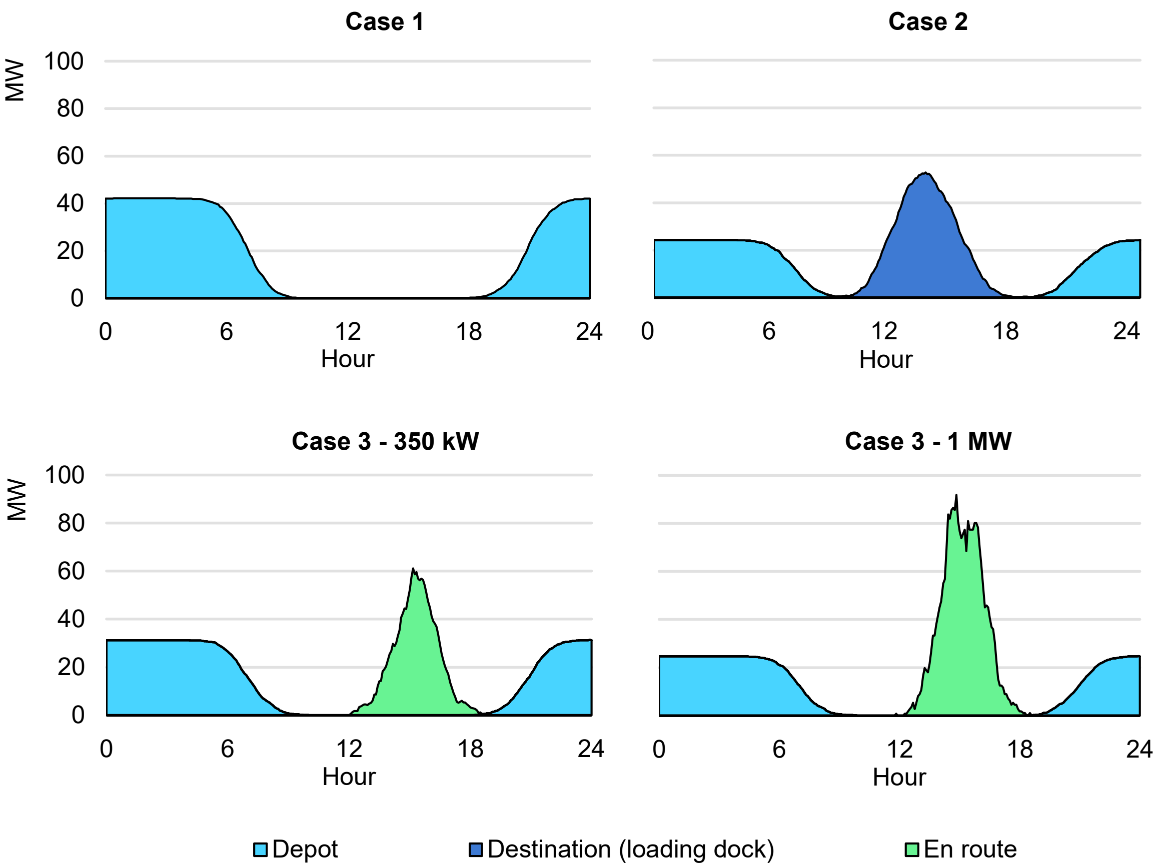
- **Case 1**. Heavy-duty trucks charge exclusively overnight at the depot, with a nominal capacity of 50 kW per charging point.
- **Case 2**. There is a 50/50 preference between charging overnight at the depot and charging at the truck loading dock, with a capacity of 150 kW in the latter destination.

En-route charging is studied under two different cases:

- **Case 3 - 350kW.** There is a 50/50 preference between charging at the depot overnight and stopping for around 45 minutes in the afternoon at a public charging spot (e.g. highway) where 350 kW fast chargers are available.[34]
- **Case 3 - 1 MW.** With the same behavioural profile, charging power stands at 1 MW instead of 350 kW.

These cases are similar to the charging taxonomy described in a recent European Network of Transmission System Operators (ENTSO-E) study on the impacts of heavy-duty EV charging on the power system.

Comparison of selected approaches to heavy-duty truck fleet charging and their effects on the electricity load of a 1 000-vehicle fleet



Notes: Case 1 represents charging overnight at a depot; Case 2 represents charging during the day at a loading dock in addition to overnight charging; Cases 3 represent en-route fast charging, for example along highways, in addition to overnight charging, with power ratings of either 350 kW or 1 MW. The values plotted are based on a simulation of 1 000 trucks over 24 hours using the IEA Electric Vehicle Charging and Grid Integration Tool. Fleet behaviour is represented by assuming that vehicles arrive, stay and depart at different times because of the underlying probabilistic distribution, resulting in a charging profile that is not fully simultaneous for all vehicles in the fleet. As part of the simulation inputs, it was assumed that each truck has a battery capacity of 500 kWh, consumes 1.4 kWh/km and travels 300 +/- 50 km per day.

[34] This case reflects EU regulations that require drivers to take a break of at least 45 minutes every 4.5 hours.

Daytime charging could support solar PV integration

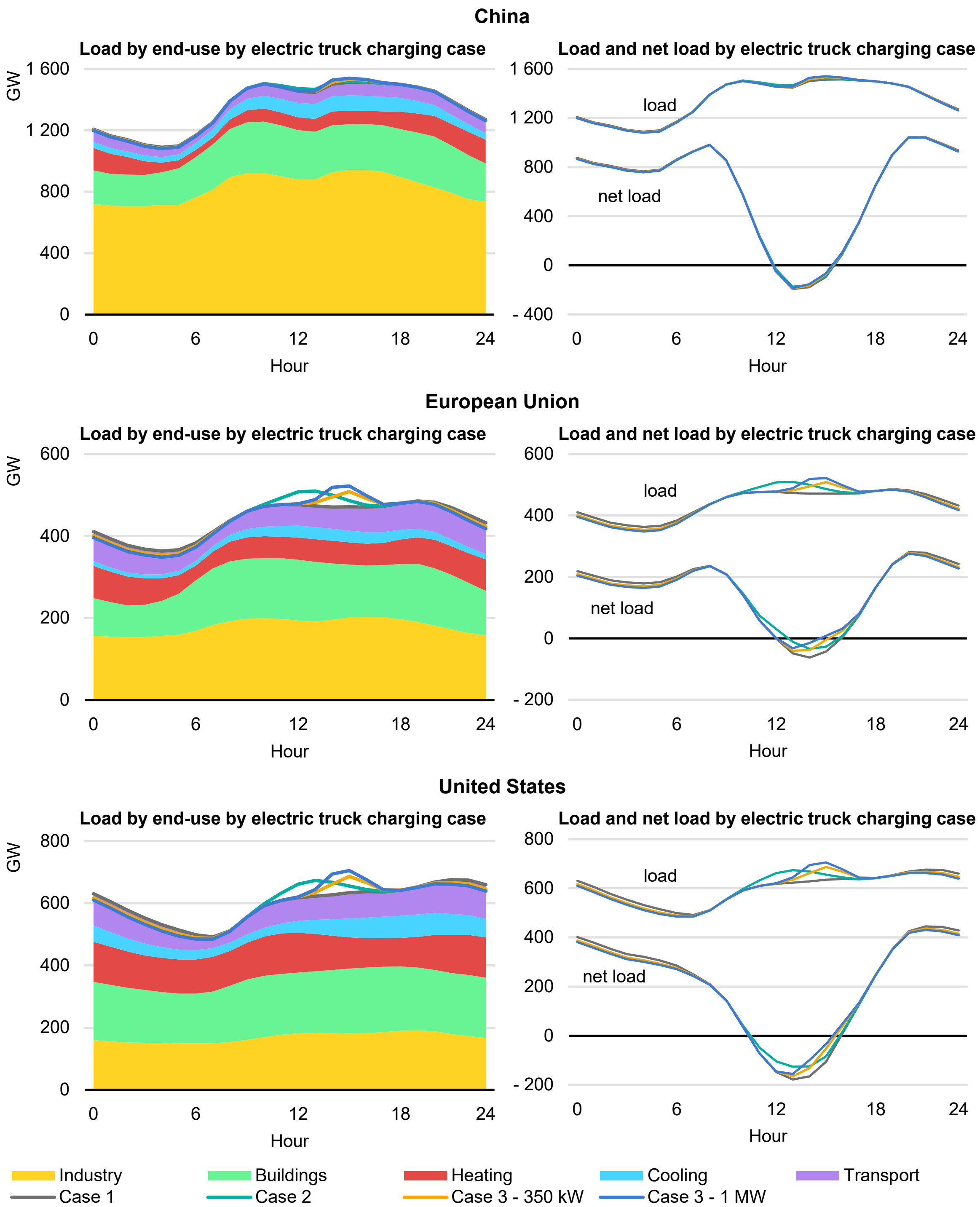
Electric truck charging adds to electricity demand from other end uses and can have a significant impact on the average daily load curve, depending on the structure of the underlying demand. For instance, in 2035 in the APS, the United States has an evening peak resulting in part from the charging of passenger cars, while in the European Union and China, midday demand is high because of significant industry consumption.

Across regions, the largest impacts by 2035 in the APS are in the European Union and the United States, where demand from electric trucks accounts for around 3% of total electricity demand. In China, truck charging has less of an impact on total electricity demand profiles in the APS (less than 1% by 2035), as other sectors such as industry play a much larger role.

Different charging behaviours can lead to peaks in total system power demand at different times throughout the day. Overnight charging at truck depots increases night-time demand and limits daily load variations, smoothing the truck charging load curve. Opportunity charging (at the loading dock) or en-route charging shifts power demand to the daytime, potentially creating new peaks in consumption. MW-scale chargers reduce charging times, producing high demand spikes that can be challenging for local grids. Fast chargers reinforce afternoon peaks, potentially overtaking the typical evening peak from residential consumers and passenger car charging.

Different charging approaches also lead to different results in terms of how well they support the integration of renewables. Daytime charging can more directly support solar PV integration, as loading dock or en-route charging increases demand between midday and the afternoon, when solar PV production is high, and electricity prices are potentially low. Increasing daytime power demand via charging could facilitate balancing supply and demand at the system level, and reduce the need for measures such as curtailment to manage excesses in solar PV output. Daytime charging can also be directly coupled with solar through the installation of solar panels on the roofs of charging depots. In contrast, while overnight charging at truck depots may (at times) coincide with high wind output, and could potentially benefit users if electricity prices are low at night, it does not directly contribute to solar PV integration.

Impact of different electric truck charging cases on total daily electricity load and net load in China, the European Union and the United States in the Announced Pledges Scenario, 2035



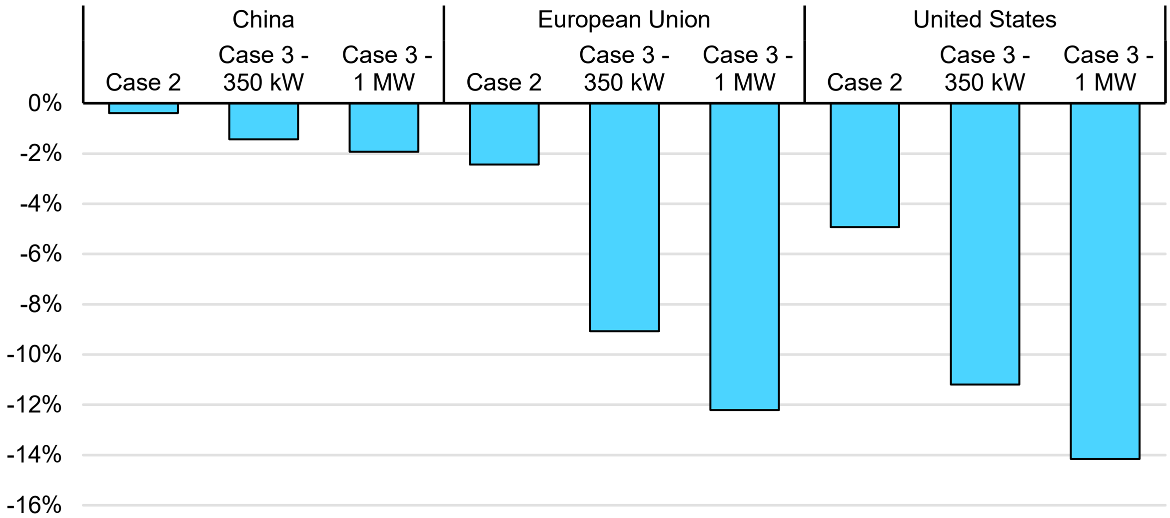
Notes: Heating includes space and water heating. Buildings excludes heating and cooling for buildings, which are shown separately; it includes power demand for cooking, lighting and appliances. Net load is defined as the electricity demand minus solar PV and wind generation.

Fast charging during the day could reduce the need for power system flexibility in the evening

Fast daytime charging of electric heavy-duty trucks could reduce the need for electricity system flexibility[35] in the early evening – typically the most challenging period of the day in terms of power system operation.

In the early evening, demand from several end uses tends to increase quickly, precisely when solar PV supply declines at sunset. As a result, the net load (i.e. total demand minus generation from solar PV and wind) ramps up, requiring higher short-duration flexibility – a need that will become all the more important as the share of solar PV increases in the overall system. This flexibility can be met by several sources, including dispatchable generation units, storage, or demand response. Additional flexibility needs can lead to operational challenges and higher costs, as maintaining a precise balance of electricity supply and demand requires either the use of power plants that have ramp-up constraints and start-up costs, or other measures that each have their own limitations (such as the state of charge of energy storage) and costs.

Average early-evening electricity system flexibility needs relative to a case of exclusively overnight charging at depot (Case 1) in selected regions in the Announced Pledges Scenario, 2035



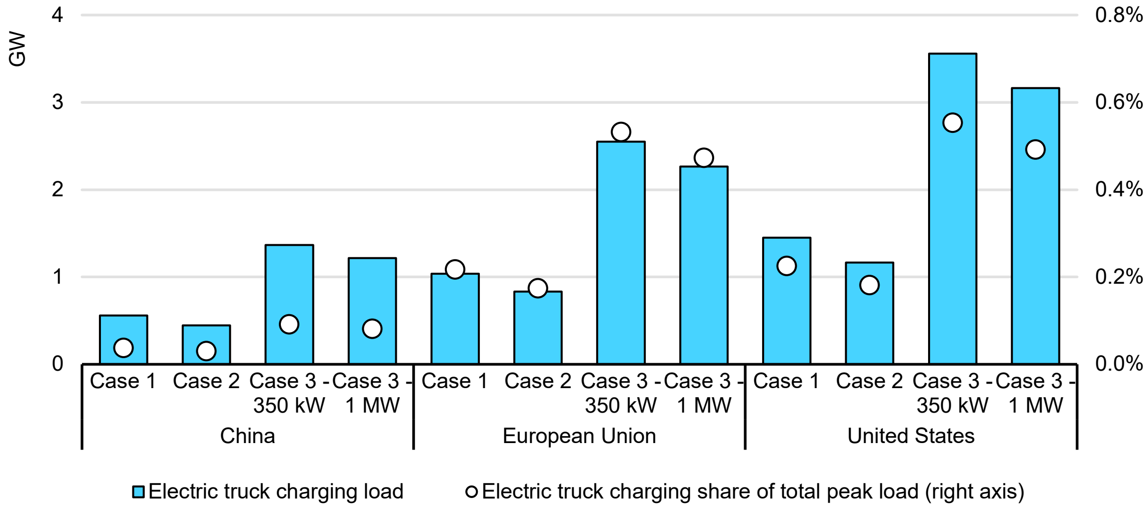
Note: The short-term system flexibility needs are computed as the average hourly net load increases in a three-hour period starting at 17:00.

Our analysis shows that, with daytime en-route charging in the APS, short-duration flexibility needs in the early evening could decrease by more than 10% in the

[35] Flexibility can be defined as the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of supply and demand across all relevant timescales. In this section, we focus on short-duration flexibility only (i.e. hourly changes within a day).

European Union and the United States in 2035, compared to a case where trucks charge exclusively overnight. In the APS, electric truck charging does not become a significant contributor to early-evening peak demand in China, the European Union nor the United States by 2035. In all of these regions, even if en-route fast charging behaviour is predominant (as in Case 3), electric truck charging reaches no more than 0.6% of average peak demand in the early evening, under the cases analysed.

Average electric truck charging contribution to early-evening electricity peak load by region and charging case in selected regions in the Announced Pledges Scenario, 2035



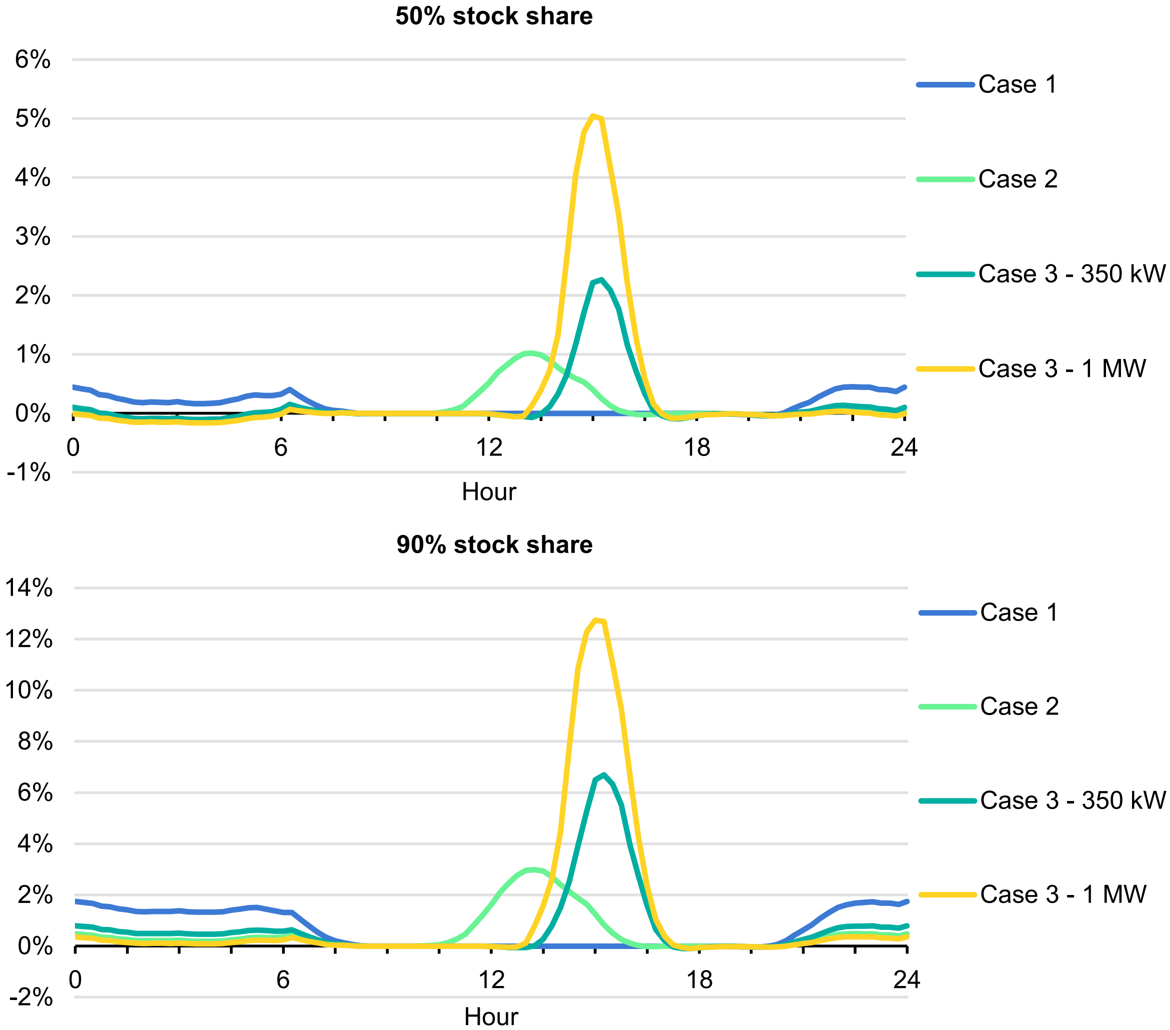
Note: The early evening is considered to be a three-hour period starting at 17:00.

MW-scale truck charging could lead to notable hikes in the utilisation rates of local grids

Drawing from these case studies of HDV charging patterns, grid simulation techniques can be used to examine the possible impacts on the grid, considering the time and location of various loads and generation units. The impacts on local grids will vary greatly depending on the particularities of each system. However, our analysis, based on a simulated local high-voltage grid, suggests that greater use of daytime fast charging for heavy trucks can result in significantly higher utilisation rates of power lines. This highlights the need for anticipatory grid investment planning, and for consideration of available grid-hosting capacities to deploy and operate HDV charging stations without putting security and affordability at risk.

In our analysis, fast daytime charging, particularly MW-scale charging, would be the main driver of investments in the grid (although overnight charging may also necessitate grid upgrades). With higher shares of EVs in the fleet, fast daytime charging can induce much higher average system-utilisation rates of power lines, which suggests that targeted improvements may be needed. Our analysis shows that, at electric truck stock shares of 50%, average line utilisation can increase by up to 5 percentage points in the mid- to late-afternoon (13% with 90% electric truck stock), compared to a case without any electric truck charging. At lower EV stock shares, impacts seen in the networks could be more local. However, higher average system-utilisation rates point to a growing, systemic need for anticipatory investments in either grid expansion or upgrade, non-wire alternatives such as demand management or stationary batteries, or a combination of measures. Moreover, high utilisation rates could threaten electricity security if there is not enough spare capacity in the grid in the case of an unexpected failure.

Percentage point difference in average power line utilisation by heavy-duty vehicle charging case at 50% and 90% electric truck share, compared with no electric truck charging



Notes: The average line utilisation rates are calculated considering each line's capacity utilisation rate and its length (in kilometres) relative to the total grid length. The values shown in the chart represent percentage point differences of each HDV charging case compared with a case without any electric truck charging in the simulated grid. Slightly lower network utilisation rates at times can be explained due to electric truck charging absorbing some of the generation of local power plants, which reduces the power flows through lines.

Source: Analysis by RWTH Aachen University.

Smart charging will be an essential tool for managing the impacts of charging on the electricity grid. Not only can it help with co-ordinating supply and demand at the system level, but it can also help send adequate locational signals that ensure that local constraints are respected, and that charging takes place during the best moments for the system. In the specific case of HDVs, smart charging schemes at overnight depots can help ensure that the flexibility opportunity provided by the long charging window can be exploited as much as possible. Similarly, smart charging can incentivise drivers at loading docks or en-route chargers to either maximise or minimise their use of the charger, leaving space to complete the charge later at the depot if needed.

Several other measures can reduce the impacts of fast charging, and even provide additional grid services. While grid upgrades will be necessary in many cases, other solutions such as electric road systems can be of great help. Measures such as battery swapping can also reduce strain on grids by charging replacement batteries over longer timeframes, reducing the peak power needs. Alternatively, co-located stationary batteries and/or renewable generators can enable the CPO to meet some of their own charging needs. This can combine the advantages of intra-day charging using solar energy, which can be used to charge the stationary batteries, and night discharge to reduce power grid load, where trucks can be charged using the stationary batteries. Additionally, these assets could be used to provide grid services such as energy arbitrage or frequency regulation (provided that the regulatory framework supports it), which can enhance the profitability of such projects. The business cases of each of these measures must be carefully assessed to decide which solution (or set of solutions) could be cheapest for each charging station and for the system.

Co-ordinated, anticipatory measures will be essential to balance the bulk power system benefits of fast charging with local grid impacts

This analysis highlights the need to consider multiple aspects for the smooth roll-out of HDV charging infrastructure, in particular, but also all charging infrastructure in general, including:

- **Co-ordinated charging infrastructure development**: collaborative planning between stakeholders such as policy makers, utilities, system fleet managers and CPOs can optimise system development and reduce costs, particularly as fast charging could create a need for network upgrades in different segments of the grid.
- **Data-gathering**: A careful study of the driving patterns of heavy-duty trucks will be essential to inform the best possible roll-out and operation of HDV charging infrastructure. For example, a recent study used real-world truck stop data to assess the attributes of potential charging locations in Germany, highlighting the

attractiveness of industrial areas along the TEN-T. This can help build understanding not only of charging needs, but also the opportunities for flexibility in charging behaviour.

- **Strategic and integrated power grid planning**: as grid upgrades and expansion can have long lead times, anticipatory planning using authoritative scenarios that also consider the needs of other sectors will be crucial to avoid power grids becoming a bottleneck for the adequate deployment and operation of charging infrastructure. Grid capacities must be considered when choosing a location and designing the installed capacity of chargers. In cases where network congestion is an issue, non-firm connections could possibly serve as a complementary solution to grid reinforcement.
- **Co-ordinated and smart charging across vehicle types**: given that there are trade-offs between daytime and overnight charging, implementing smart charging can help balance benefits, such as renewable integration and reduced system flexibility needs, with the mitigation of stress on the power grids. This can also help avoid unintended events like 'herd' behaviour – such as when all vehicles are charged at night, causing significant grid impacts. Market design (such as time-varying tariffs) to signal where and when it is best to charge to minimise system impacts, the readiness of smart charging infrastructure, and data-sharing between stakeholders, will be vital enablers.
- **Local solutions for managing local challenges**: deploying technologies such as stationary batteries in charging stations, battery swapping, or on-site renewable power plants can reduce stress on the grids and help integrate fast charging, thereby benefiting users. Some of these options can also provide additional services to the power system beyond demand management. In many cases, these solutions have the additional advantage of shorter deployment lead times than grid expansions, and may also be cheaper overall.

9. Outlook for battery and energy demand

Battery demand

Battery demand for electric vehicles jumps tenfold in ten years in a net zero pathway

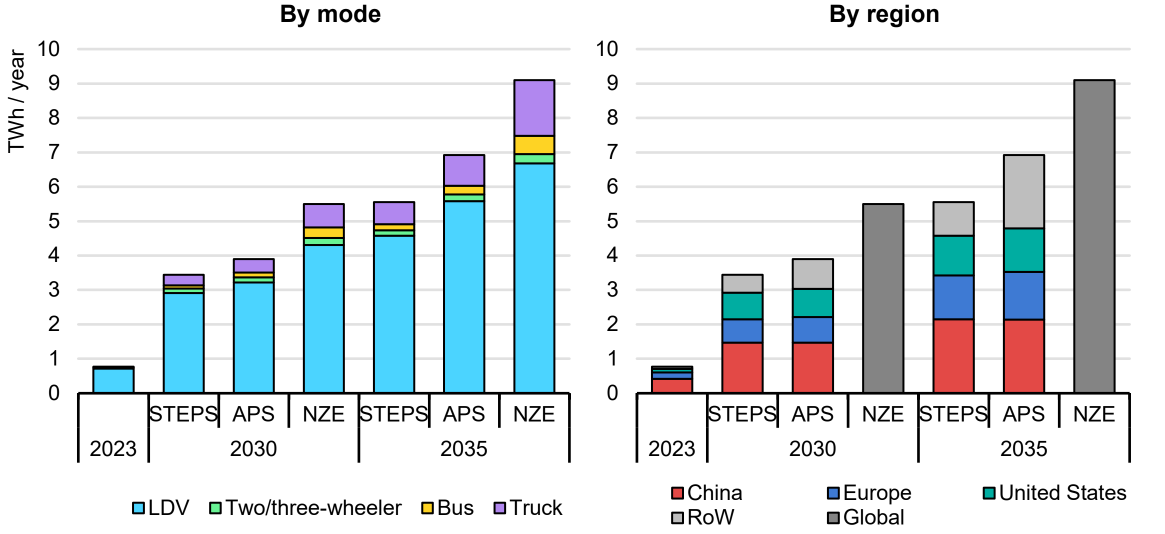
As EV sales continue to increase in today's major markets in China, Europe and the United States, as well as expanding across more countries, demand for EV batteries is also set to grow quickly. In the STEPS, EV battery demand grows four-and-a-half times by 2030, and almost seven times by 2035 compared to 2023. In the APS and the NZE Scenario, demand is significantly higher, multiplied by five and seven times in 2030 and nine and twelve times in 2035, respectively. To put this in context, in the APS in 2035, there could be as much EV battery demand per week as there was in the entire year of 2019.

Cars remain the primary driver of EV battery demand, accounting for about 75% in the APS in 2035, albeit down from 90% in 2023, as battery demand from other EVs grows very quickly. In the STEPS, battery demand for EVs other than cars jumps eightfold by 2030 and fifteen-fold by 2035. In the APS, these numbers reach tenfold by 2030 and more than twenty-fold by 2035. Battery requirements differ across modes, with a 2/3W requiring a battery about 20 times smaller than a BEV, while buses and trucks require batteries that are between 2 and 5 times bigger than for a BEV. This also affects trends in different regions, given that 2/3Ws are significantly more important in emerging economies than in developed economies.

As EVs increasingly reach new markets, battery demand outside of today's major markets is set to increase. In the STEPS, China, Europe and the United States account for just under 85% of the market in 2030 and just over 80% in 2035, down from 90% today. In the APS, nearly 25% of battery demand is outside today's major markets in 2030, particularly as a result of greater demand in India, Southeast Asia, South America, Mexico and Japan. In the APS in 2035, this share increases to 30%.

Stationary storage will also increase battery demand, accounting for about 400 GWh in STEPS and 500 GWh in APS in 2030, which is about 12% of EV battery demand in the same year in both the STEPS and the APS.

Battery demand for electric vehicles by mode and region, 2023-2035



Notes: STEPS = Stated Policy Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; LDV = light-duty vehicle, including cars and vans; RoW = Rest of the world.

Road transport electrification is opening significant opportunities for battery supply chains, including in emerging markets

Battery production has been ramping up quickly in the past few years to keep pace with increasing demand. In 2023, battery manufacturing reached 2.5 TWh, adding 780 GWh of capacity relative to 2022. The capacity added in 2023 was over 25% higher than in 2022.

Looking forward, investors and carmakers have been fleshing out ambitious plans for manufacturing expansion, confident that demand for EV and stationary batteries will continue to grow as a result of increasing electrification and power grid decarbonisation. Global battery manufacturing capacity by 2030, if announcements are completed in full and on time, could exceed 9 TWh by 2030, of which about 70% is already operational or otherwise committed. When assuming a maximum utilisation rate of 85%, this translates to the potential for almost 8 TWh of batteries to be produced in 2030, of which over 5.5 TWh is from plants already operational today and those with committed announcements. This level of production would be sufficient to meet global deployment needs in the APS and over 90% of the deployment needs in the NZE Scenario by 2030.

Most of the announced manufacturing capacity remains concentrated geographically in today's major EV markets. Of course, as EVs and stationary storage reach global markets and battery demand diversifies, new opportunities will be created around the world to produce batteries near demand centres.

However, today's front-runners, which have thus far dominated the supply of batteries to EV makers in China, the European Union and the United States, are still expected to play a critical role in the coming decade.

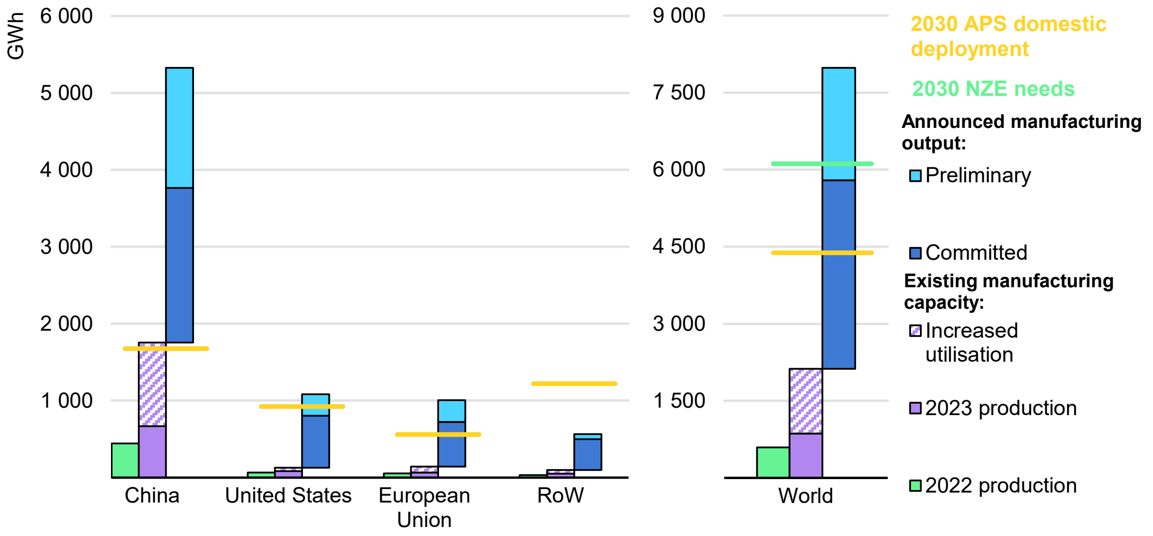
In China, the total committed battery manufacturing capacity is over two times greater than domestic demand in the APS by 2030, opening opportunities for export of both batteries and EVs with batteries made in China, but also increasing financial risks and reducing margins of battery producers. Notably, in both the United States and European Union, battery manufacturing capacity that is already operational or otherwise committed is almost or already sufficient to meet projected battery demand in the APS by 2030. Companies operating in these regions will, however, need to scale up production rapidly and demonstrate that they are cost-competitive in order to satisfy all or a large share of their domestic demand.

About 70% of the 2030 projected battery manufacturing capacity worldwide is already operational or committed, that is, projects have reached a final investment decision and are starting or begun construction, though announcements vary across regions. This encouraging signal from the battery industry indicates that it is ready to produce the batteries needed to achieve road transport electrification and stationary storage targets in full. Over 40% of announced manufacturing capacity in China relies on the expansion of current plants, indicating the strengthening of industrial actors that are already part of the Chinese market. Elsewhere, 80% of announced US and EU manufacturing capacity is expected to come from new plants, with a significant number of new actors entering those markets in the coming years.

The announced manufacturing capacity outside of China, the European Union and the United States, of which 85% is already committed, together with today's capacity, can meet almost half of APS needs in 2030 in these other regions. Almost all the committed manufacturing capacity is divided among other European countries and Canada (about 35% each), India (12%), other Southeast Asian countries (8%), particularly Viet Nam, Malaysia and Singapore, and Japan and Korea (5%). Korea and Japan, however, also account for over 80% of today's capacity in these regions.

There is significant space for growth in South American countries, which today have no significant announced battery manufacturing capacity by 2030, and in countries with manufacturing capacity that falls short of their pledges, such as India, whose announced capacity would cover only a quarter of its demand in the APS. These gaps have important implications for future battery trade and could increase the risk of these regions failing to meet long-term decarbonisation targets without relying significantly on imports.

Announced expansion of battery manufacturing maximum output by region and deployment in the Announced Pledges and Net Zero Emissions by 2050 Scenarios, 2023 and 2030



Notes: APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; RoW = Rest of world. 2022 and 2023 production values reflect estimates of actual utilisation rates. Increased utilisation refers to the gap between 2023 production levels and existing capacity being utilised at 85%. A utilisation rate of 85% is used for both existing and announced manufacturing capacity in 2030. Battery demand refers to EVs and stationary storage batteries. Manufacturing capacity refers to companies that are already certified to serve both the EV and stationary storage markets and companies not yet certified to serve the EV market. Committed refers to plants that have reached a final investment decision and are starting or have already started construction works, and preliminary to plants that have been announced but are not yet being built.

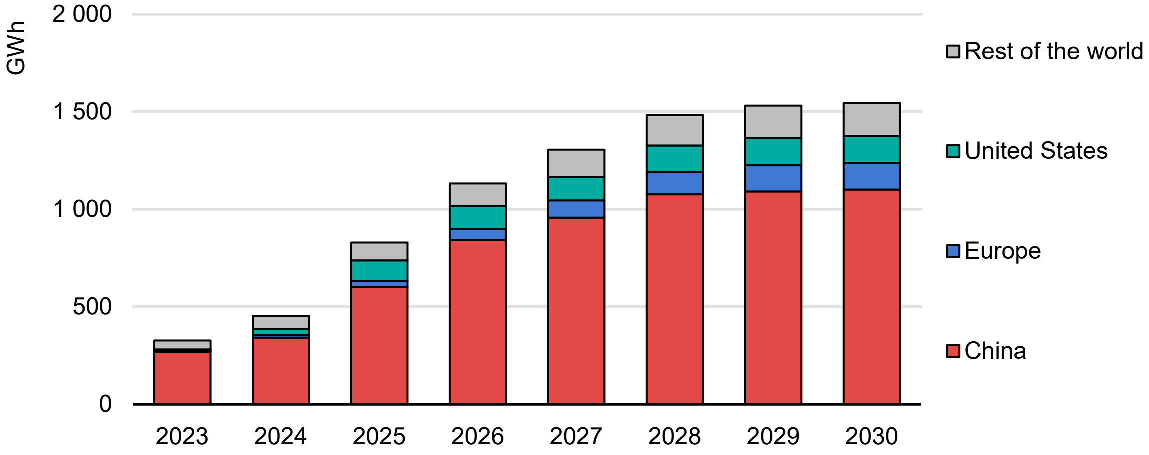
Sources: IEA analysis based on data from Benchmark Mineral Intelligence, Bloomberg New Energy Finance and EV Volumes.

Battery recycling technology and industry players are already getting ready for the 2030s

As the EV stock ages, effective end-of-life strategies that encompass recycling and reuse must be put in place to make supply chains circular and to help mitigate critical mineral demand. The battery recycling sector, still nascent in 2023, will be core to the future of EV supply chains, and to maximising the environmental benefits of batteries.

Global recycling capacity reached over 300 GWh/year in 2023, of which more than 80% was located in China, far ahead of Europe and the United States with under 2% each. Confident in the transition to electromobility, many technology developers and industry actors are seeking to position themselves in the future market for EV end-of-life management and have announced considerable capacity expansions. If all announced projects are developed in full and on time, global recycling capacity could exceed 1 500 GWh in 2030, of which 70% is in China, and about 10% each in Europe and the United States.

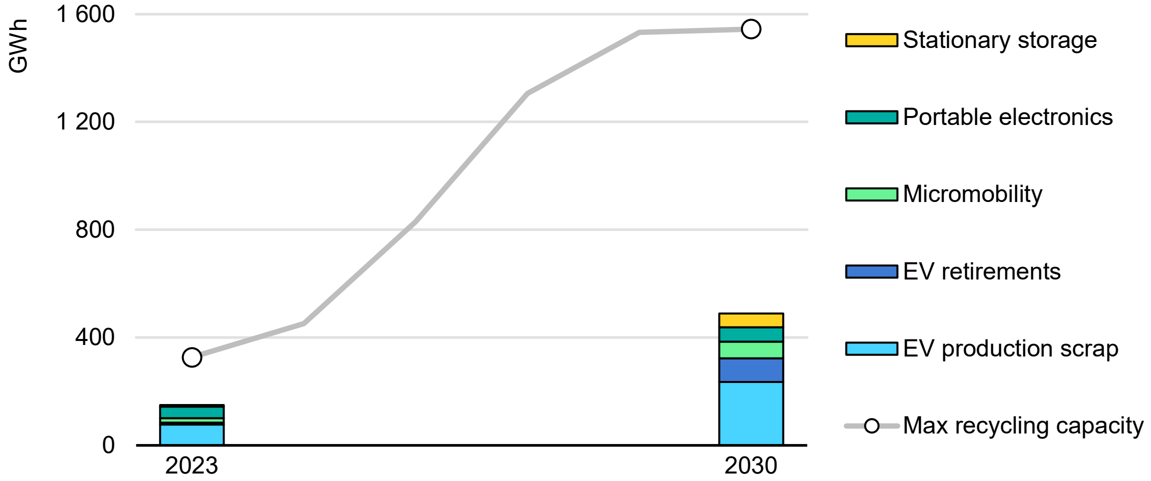
Expected battery recycling capacity by region based on current announcements, 2023-2030



Notes: Recycling capacity refers to material recovery. A maximum utilisation factor of 85% and an average cell energy density of 180 Wh/kg are assumed.
Sources: IEA analysis based on data from Circular Energy Storage.

The main sources of supply for battery recycling plants in 2030 will be EV battery production scrap, accounting for half of supply, and retired EV batteries, accounting for about 20%. Of course, scrap materials remain in an almost pristine state, and therefore are much easier and cheaper to recycle and feed back into the manufacturing plant. While the supply of both battery scrap and retired EVs will increase, current expansion plans and outlooks suggest that battery recycling capacity could be in significant overcapacity in 2030: total supply in 2030 could account for only one-third of the announced recycling capacity in the STEPS and APS. In the short term, overcapacity could also have important financial implications for the business models of recycling companies unable to secure stable sources of end-of-life batteries, resulting in significant consolidation of the market. However, the outlook could still change depending on whether announcements translate into final investment decisions (FIDs), and it is important to note that a rapid growth in retired EV batteries is expected starting from the second half of the 2030s. In Europe and the United States, in particular, EV markets are large, but battery recycling businesses are only just emerging and in need of further investment.

Current and announced global battery recycling capacity and potential supply of end-of-life batteries according to existing and announced policies, 2023-2030



Notes: EV = electric vehicle. “Micromobility” refers to batteries contained in electric bikes or small electric scooters. “Stationary storage” includes uninterruptible power supply batteries, which are assumed to have a shorter life than EV batteries due to more frequent utilisation. Recycling capacity refers to material recovery. Battery recycling capacity in 2023 refers to existing capacity, while future capacity refers to existing and announced capacity. A maximum utilisation factor of 85%, an average cell energy density of 180 Wh/kg, and a battery manufacturing scrappage rate ranging from 10% (2023) to 6% (2030) are assumed. Supply of retired batteries for stationary storage, portable electronics, and micromobility refers to data provided by Circular Energy Storage. Battery production and EV retirements are based on the Announced Policy Scenario (APS).
Sources: IEA analysis based on data from Circular Energy Storage.

Policy also has an important role to play, such as for traceability, quality, safety, and sustainability of recycling practices. In China, for example, a new regulation announced in December 2023 will assign responsibility for EV battery traceability and recycling to EV manufacturers and to battery manufacturers for battery-as-a-service applications, with the view to bring the suppliers and consumers of end-of-life EV batteries closer together. This policy move comes as supply for recyclers in China grows rapidly, and as the number of small, unofficial and unregulated recycling companies increases accordingly. This has raised concerns that they are operating without extensive battery technology expertise, environmental and safety standards, nor reliable traceability systems.

Strong regulation for battery recycling already exists in some regions outside of China, especially in Europe. However, these regulations could still be made more comprehensive to solve existing challenges, notably the transport of end-of-life batteries and black mass,[36] and to improve tracking systems and safety and environmental standards. This is even more important given that the future

[36] Lithium-ion battery recycling is typically composed of two main steps: pre-processing and material recovery. Pre-processing refers to batteries being discharged, dismantled, and mechanically or thermally treated to condition them to ease material and metal recovery, typically in the form of black mass. Material recovery refers to the recovery of battery materials and metals after the pre-treatment step.

geographical distribution of retired batteries is uncertain, and might differ from their first purchase location as a result of the EV second-hand market or other second-life applications.

The evolution of battery chemistries and technology innovation will also have an impact on the recycling landscape of 2030. Of the two principal battery chemistries of today, nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP), the former is particularly well suited for recycling because it contains greater quantities of valuable metals. In contrast, LFP batteries have a lower residual value after recycling, which could put pressure on recycling business models. Nonetheless, regulations can fill this gap by either incentivising or mandating the recycling of end-of-life batteries regardless of their residual value. This is already the case for lead-acid batteries used in ICEVs, which have significantly lower residual values compared to any type of lithium-ion battery but whose recycling rate can be up to almost 100% thanks to regulation.

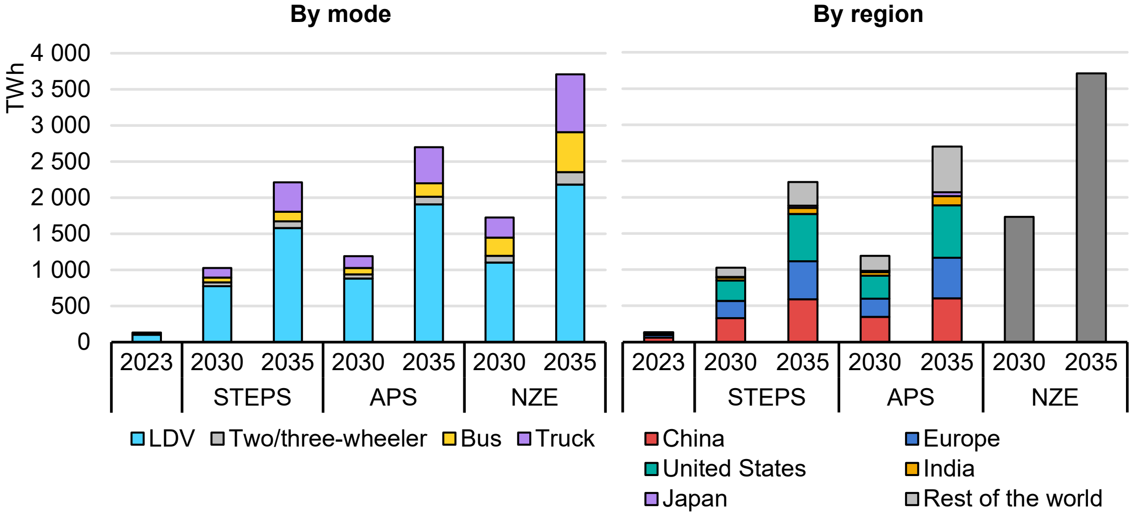
The lower residual value of LFP makes recycling uneconomical in Europe and the United States today, but LFP recycling is already economical in China, even though this is strongly affected by the market price for lithium. In this regard, the Chinese recycling industry is preparing to build sufficient LFP recycling capacity to meet future demand. If all announced plants are built in full and on time, capacity suited to recycle LFP is expected to be two times greater than potential supply by 2030.

Electricity demand

Electric vehicles could account for 6-8% of total electricity demand by 2035, up from 0.5% today

Charging an increasing number of EVs globally will require more electricity, and the share of EVs in total electricity consumption is expected to increase significantly as a result. In 2023, the global EV fleet consumed about 130 TWh of electricity – roughly the same as Norway's total electricity demand in the same year. Zooming out to the global scale, EVs accounted for about 0.5% of the world's total final electricity consumption in 2023, and around 1% in China and Europe. The contribution of different EV segments to electricity demand varies by region. For example, in 2023 in China, electric 2/3Ws and buses combined accounted for almost 30% of EV electricity demand, while in the United States, electric cars represented over 95% of EV electricity demand.

Electricity demand by mode and by region, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; LDV = light-duty vehicle. The analysis is carried out for each region in the transport model within the IEA's Global Energy and Climate Model (GEC-Model) separately and then aggregated for global results. For the NZE Scenario, only global values are reported. Regional data can be interactively explored via the Global EV Data Explorer.

Looking forward to 2035, EV electricity demand could reach nearly 2 200 TWh in the STEPS. In the APS, demand could be higher, standing at about 2 700 TWh in 2035, or over 20% more than in the STEPS, although the stock of EVs would be only around 15% higher. Several factors contribute to the disproportionate increase in EV electricity demand between the STEPS and APS. In the APS, rates of electrification are higher in markets where the average vehicle mileage is high, such as the United States. The APS also sees greater electrification for trucks and buses, which contribute incrementally to vehicle stock while pushing up electricity consumption and mileage, resulting in greater electricity demand per vehicle. In countries with net zero pledges, the APS assumes that a greater share of the distance covered by PHEVs will be driven in full electric mode, thereby requiring more electricity and less gasoline or diesel. This is particularly relevant for cars and vans, which account for more than two-thirds of demand in both the STEPS and the APS.

By 2035, EV electricity demand accounts for less than 10% of global final electricity consumption in both the STEPS and APS. As shown in the World Energy Outlook 2023, the share of electricity for EVs in 2035 remains small in comparison to demand for industrial applications, appliances, or heating and cooling. Further, the electrification of road transport results in overall reductions in energy consumption, given that electric powertrains are more efficient than internal combustion engines. Total road energy demand in the APS decreases by 10% in 2035 compared to 2023, despite road activity (vehicle kilometres travelled) increasing 20%.

Share of electricity consumption from electric vehicles relative to final electricity consumption by region and scenario, 2023 and 2035

Country/region	2023	Stated Policies Scenario 2035	Announced Pledges Scenario 2035
China	0.7%	6.8%	6.9%
Europe	1.1%	13.7%	14.5%
United States	0.6%	14.2%	15.6%
Japan	0.1%	3.1%	5.5%
India	0.2%	6.0%	8.7%
Global	0.5%	8.1%	9.8%

Note: Non-road electricity consumption is taken from the World Energy Outlook 2023.

China remains the largest consumer of electricity for EVs in the STEPS, despite its share of global EV electricity demand decreasing significantly from about 45% in 2023 to less than 30% in 2035. In the APS, this share falls further, to just over 20% in 2035, as a result of strong EV growth in Europe, the United States and other countries. In 2035, the United States ranks first, ahead of China and Europe in terms of EV electricity demand in the APS.

The size of the EV fleet becomes an important factor for power systems in both the STEPS and APS, with implications for peak power demand, transmission, and distribution capacity. As the fleet grows, careful planning of electricity infrastructure, peak load management and smart charging should be priorities for near-term decision-making. Effective management of fast charging, in particular, will be needed to allow for optimal planning and resilience of power systems and to mitigate peak power demand. In both the STEPS and APS, over 80% of the electricity demand for electric LDVs in 2035 is met with slow chargers.

To support policy-making and help countries prioritise charging strategies according to the size of their EV fleet and power system configuration, the IEA has developed a guiding framework and online tool for EV grid integration.

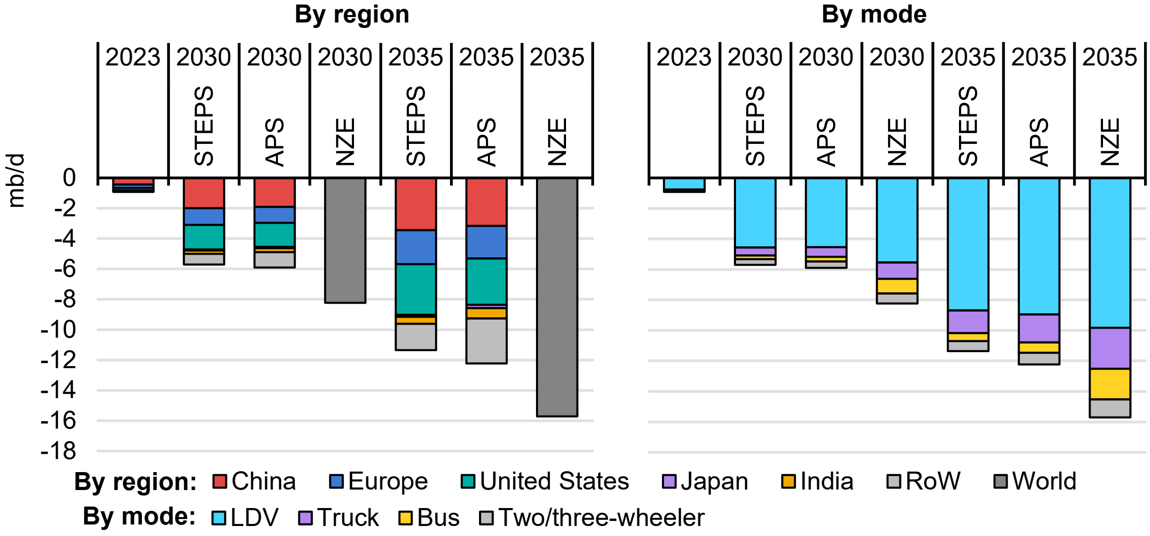
Oil displacement

Electric vehicle uptake means oil demand for road transport is set to peak around 2025 and displace 12 mb/d by 2035

Growing EV stocks reduce the need for oil. Globally, the projected EV fleet displaces 6 million barrels per day (mb/d) of diesel and gasoline in 2030, a sixfold increase on displacement in 2023. By 2035, even less oil is needed for road transport, with displacement reaching 11 mb/d in the STEPS and 12 mb/d in the APS. In fact, we expect global demand for oil-based road transport fuels to peak around 2025.

Displacement is largely attributed to electric LDVs, followed by trucks, buses and 2/3Ws.[37] In particular, it will be important to closely track the uptake of electric 2/3Ws and their role in oil displacement: electric 2/3Ws may displace active modes of travel such as walking or cycling, rather than just fossil-powered transport, which is the assumption underpinning the STEPS and APS. This highlights that while EVs are an important component of transport decarbonisation, they are far from being the only one.

Oil displacement by region and mode in the Stated Policies, Announced Pledges and Net Zero Emissions by 2050 Scenarios, 2023-2035



Notes: STEPS = Stated Policy Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; RoW = Rest of the world; LDV = light-duty vehicle. Oil displacement is based on internal combustion engine (ICE) vehicle fuel consumption to cover the same mileage as the EV fleet. Oil displacement is calculated by assuming that the distance (total kilometres) travelled by EVs by segment each year would have been otherwise travelled by ICE vehicles or hybrid electric vehicles (HEVs). In the case of PHEVs – where the powertrain uses both oil-based fuel and electricity, only the distance covered by electricity is included. This method of estimation assumes that EVs replace ICE or hybrid vehicles of the same segment, and that these vehicles follow the same driving behaviour. The accuracy of this assumption is uncertain. There is some evidence to suggest that EVs are driven further than their ICE counterparts, for example.

Tax reforms will be needed to ensure government revenues can be sustained as EV adoption grows

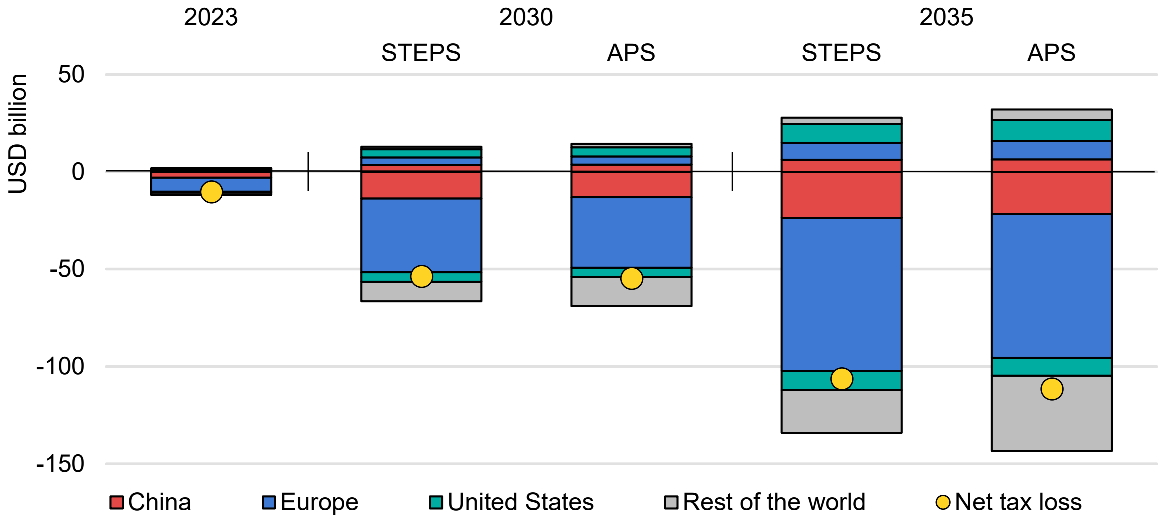
Fossil fuel excise taxes can represent a major source of income for governments, and they are often used to fund road infrastructure. The shift to EVs may

[37] As reported in the Global EV Outlook 2023, assumptions about which mode(s) of transport are displaced by electric 2/3W trips can greatly impact the resulting oil displacement. In IEA analysis, they are assumed to replace trips otherwise made with internal combustion engine 2/3Ws.

significantly reduce revenues under current schemes, as additional revenue from electricity taxes tends to be insufficient to cover the loss. Indeed, the rates of taxation per kilometre driven by EVs are lower than for their fossil fuel equivalents.

In 2023, EVs displaced almost USD 12 billion in gasoline and diesel tax revenues globally. Meanwhile, the use of EVs generated close to USD 2 billion in electricity tax revenue, resulting in a net loss of USD 10 billion. As the stock of EVs (including 2/3Ws) is projected to grow globally to 460 million by 2030 in the STEPS and nearly 500 million in the APS, net tax revenue losses are set to increase by more than 5 times in the STEPS and APS. By 2035, net tax loss reaches USD 105 billion in the STEPS and USD 110 billion in the APS, doubling from 2030 levels as road transport electrification accelerates.

Net tax implications of electric vehicle adoption by region in the Stated Policies and Announced Pledges Scenarios, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Fuel tax rates are assumed to remain constant. Only federal tax rates are included.
Source: Analysis based on tax rates from IEA Energy Prices.

Although China leads global EV stock uptake, 60% of current revenue losses are in Europe, because the taxes for gasoline and diesel are far greater. For example, the gasoline tax rate in France, Germany, and Italy is more than six times that in China. In Europe, fuel tax revenue drops by nearly USD 70 billion by 2035 in the STEPS. In China, tax revenue losses reach USD 17 billion, and they remain under USD 300 million in the United States due to low federal taxation of gasoline and diesel (though greater impacts could be seen at the state level).

However, for oil-importing countries, lost tax revenues could be balanced by reduced fuel import costs. For example, a 2020 study estimated that a total shift from ICE to electric 2Ws in Rwanda could reduce government revenue from fuel taxes by RWF 6.1 billion (Rwandan francs), but would save around RWF 23 billion (around USD 25 million) on fuel imports.

Longer-term measures to stabilise tax revenues will be needed in the transition to electromobility. Policy strategies could involve more wide-ranging tax reforms, such as coupling high taxes on carbon-intensive fuels with distance-based charges. For example, Israel recently approved a new usage tax on kilometres travelled, which will apply to EVs as a way to compensate for lost revenues from excise duty on gasoline and diesel. Road tolls could charge users of road infrastructure. When used in city areas, tolls could also reduce traffic congestion, noise pollution and road infrastructure damage, while encouraging the uptake of alternative modes such as public transport, walking and cycling.

Further, the EV transition can also bring monetary benefits due to health improvements associated with reductions in air pollution, for example by reducing health expenditures, preventing premature deaths and avoiding workdays lost due to illness. A study of the benefits of electric cars in Shanghai estimated that benefits exceed USD 6 000 per EV when replacing an average Chinese ICEV. About 40% of this monetary benefit is attributed to health benefits, and the remainder to climate benefits.

10. Outlook for emissions reductions

Well-to-wheel greenhouse gas emissions

Government electrification ambitions would avoid 2 Gt CO_2 in 2035 on a well-to-wheels basis

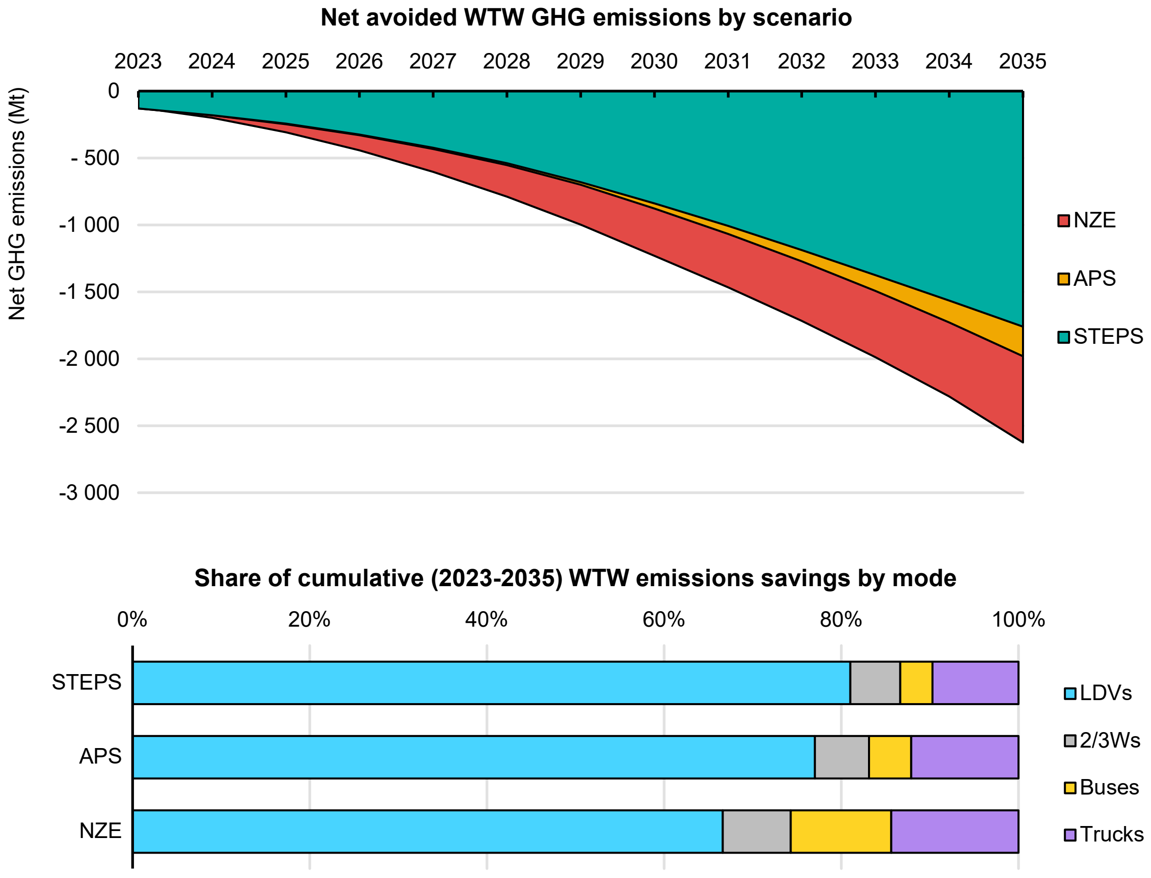
Road transport electrification at the global scale is expected to unlock substantial emission reductions in the coming decades. While it will be important to keep in check any additional emissions coming from electricity generation for EVs, these emissions will be more than outweighed by the emissions reductions resulting from a switch to electric. In the STEPS, the emissions avoided by using EVs rather than ICE equivalents (alongside continued improvements to ICE fuel economy) reach over 2 Gt of CO_2 equivalent (CO_2-eq) in 2035. Additional emissions from electricity generation for EVs are far smaller, at over 380 Mt CO_2-eq, meaning there is a net saving of 1.8 Gt CO_2-eq in 2035 in the STEPS. Sustained decarbonisation of power generation helps deliver even more emission reductions in the APS, in which net emissions avoided by switching to electric reach around 2 Gt CO_2-eq in 2035.

However, there remains a substantial ambition gap between announced pledges and what would be required to put the world on a path consistent with the NZE Scenario. This is especially true in the near term: in 2030, 40% more emissions are avoided in the NZE Scenario compared to the APS, in which only around 5% more emissions are avoided than in the STEPS. By 2035, the gap between the NZE Scenario and APS emissions savings narrows to less than a 35% difference. At the same time, the APS net emissions reductions increase to over 10% relative to the STEPS. Current policies are not aligned with a net zero by 2050 pathway, and nor are announced pledges, calling for greater ambition in policy and corporate decision-making.

Chinese passenger LDVs alone accounted for about 35% of global road transport avoided emissions in 2023, an important reminder of the benefits of switching to electric sooner rather than later to unlock greater cumulative CO_2 benefits. As other segments and regions catch up, this share falls to 25% in 2035 in the STEPS. By 2035, trucks account for almost 15% of avoided emissions globally, and buses nearly 5%. Early adoption of electric 2/3Ws meant that they accounted for almost 10% of avoided emissions in 2023. While this share falls to 5% by 2035, electric 2/3Ws are providing substantial cumulative emissions savings in the interim.

The prospect of retail price parity between electric and ICE cars in some regions and segments by 2030 (see section on Electric car availability and affordability), combined with stronger policy support for electrification of cars than for other vehicle segments, means that the LDV segment is more closely aligned with the NZE Scenario than other segments. In the STEPS and APS, the LDV segment achieves more than 80% of the net avoided emissions by 2035 seen in the NZE Scenario. In contrast, buses are the least aligned with the NZE Scenario, with the STEPS accounting for 20% and the APS only 30% of the emission reductions in the NZE Scenario. For trucks, the STEPS achieves almost half of the net avoided emissions seen in the NZE Scenario in 2035, while the APS delivers almost 70% – a reflection of strong policies in the United States and European Union and pledges across a wider variety of countries.

Net avoided well-to-wheel greenhouse gas emissions from EV deployment, and share of avoided emissions by mode, 2023-2035



Notes: STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; LDVs = light-duty vehicles; 2/3Ws = two/three-wheelers; WTW = well-to-wheel. Net avoided GHG emissions are calculated as the total emissions from electricity generation, transmission and distribution and the negative emissions (i.e. avoided) that the equivalent internal combustion engine (ICE) fleet would have emitted (both upstream and at the tailpipe) if running on fossil fuels. Projections include fuel economy improvements of ICE and electric vehicles, as well as the growing share of renewable electricity generation, as described in the World Energy Outlook 2023.

Lifecycle impacts of electric cars

A battery electric car sold in 2023 will emit half as much as conventional equivalents over its lifetime

Today, there are already substantial emissions benefits to switching to EVs when emissions are considered on a lifecycle basis, which includes the emissions associated with the production of the vehicle as well as the well-to-wheel emissions (i.e. well-to-tank and tank-to-wheel emissions). In both the STEPS and APS these benefits increase over time as the electricity mix is decarbonised further.

Globally, in the STEPS, the lifecycle emissions of a medium-size battery electric car are about half of those of an equivalent ICEV that is running on oil-based fuels, more than 40% lower than for an equivalent HEV, and about 30% lower than for a PHEV over 15 years of operation, or around 200 000 km. These emissions savings increase by around 5 percentage points in the APS, as the grid decarbonises more quickly than in the STEPS. When comparing vehicles purchased in 2035, an ICE car produces almost two-and-a-half times the emissions of a battery electric car in the STEPS, and over three times as many in the APS, over the vehicle lifetime. For a medium-sized car, this equates to 38 t CO_2-eq over the ICE car lifetime compared to 15 t CO_2-eq for a BEV.[38]

Power grid decarbonisation around the world is crucial for maximising the environmental benefit of BEVs. In terms of global averages for medium-size vehicles sold in 2023, well-to-tank emissions decrease by 25% to 35% thanks to electricity emissions intensity improvements foreseen in the STEPS and APS. For vehicles purchased in 2035, well-to-tank emissions decrease by 55% (in the STEPS) and 75% (APS) thanks to grid decarbonisation, as the emissions intensity of electricity generation drops 50-65% between 2023 and 2035. However, even without these improvements, BEV emissions would still be about 30% lower than those from ICEVs. Grid decarbonisation in the APS also causes emissions from battery production to fall by about 10% by 2035.

Vehicle size also plays an important role in determining lifecycle emissions. Many consumers are choosing larger vehicles than previously, prompted in part by model availability. Though smaller vehicles are clearly preferable in terms of both production and operation emissions across powertrains, the greater efficiency of an electric powertrain means electrification mitigates much of the negative impact of larger vehicles. While some large ICE SUVs can emit up to 50% more emissions than a medium-sized ICE car, a large battery electric SUV emits only around 20% more than a medium-sized battery electric car over its lifetime. Choosing a battery electric SUV over an ICE vehicle represents a lifecycle emission saving of about

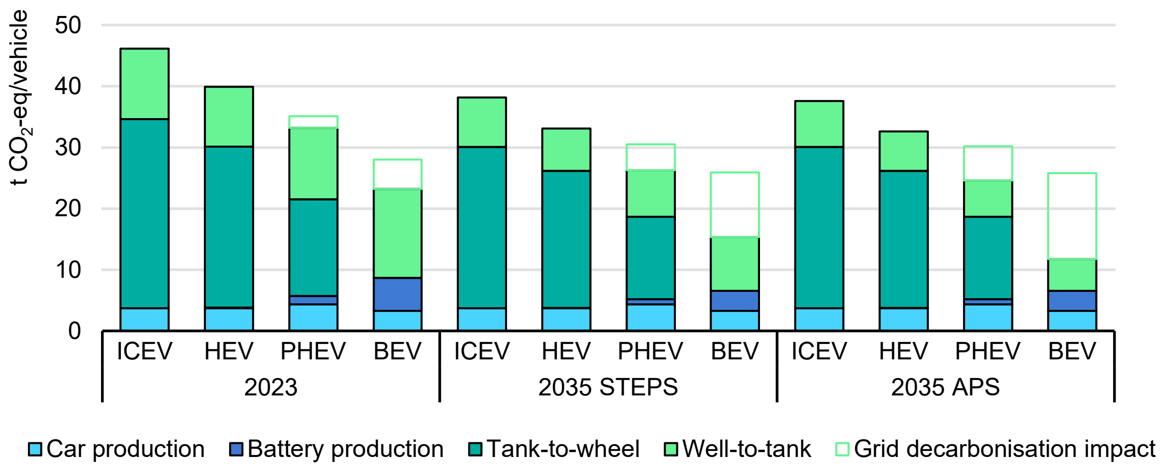
[38] See Annex B for further details on the assumptions behind this lifecycle analysis.

60%. Even compared to a medium-size ICEV, a battery electric SUV results in 40% lower lifecycle emissions. See the earlier section on model availability for more information.

PHEVs purchased in 2023 produce around 30% less emissions than ICEVs over the course of their lifetime in the STEPS, while this gap reaches 35% for vehicles purchased in 2035 in the APS, thanks to further decarbonisation of electricity generation. This analysis assumes that the utility factor (share of kilometres travelled on electricity) of PHEVs is 40%.[39] Greater lifecycle emissions savings can be achieved if the utility factor is higher. In fact, the rated utility factor for PHEVs with range of 60 km is around 65%.

However, analysis from the past few years has shown that the real-world utility factor is significantly lower than the official values from vehicle type approvals (such as the World Harmonised Light Vehicle Test Procedure). The European Commission published a report finding that the real-world CO_2 emissions from PHEVs were on average 3.5 times higher than the laboratory values. A main factor behind this discrepancy is that PHEVs are not charged and driven in full electric mode as frequently as assumed. A separate study has suggested that the real-world utility factor is lower for company cars compared to privately owned cars, because those vehicles tend to be charged less frequently. Increasing PHEV charging and the use of the battery mode would result in greater reductions in emissions, but such measures are difficult to enforce.

Comparison of global average medium-car lifecycle emissions by powertrain in the Stated Policies and Announced Pledges Scenarios, 2023-2035



Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. "Grid decarbonisation impact" refers to the effect of electricity emissions intensity improvements over the lifetime of the vehicle. The years 2023 and 2035 refer to the first year of use of the vehicle. For further details on the assumptions behind this lifecycle analysis, please see annex B. The impact of varying assumptions will be available to explore, with illustrative regional insights, through an upcoming online lifecycle analysis (LCA) tool to be made available on the IEA website.

Sources: IEA analysis based on the Global Energy and Climate Model, IFP, GREET, EV Volumes, Dai et al., Degen et al., Frith et al..

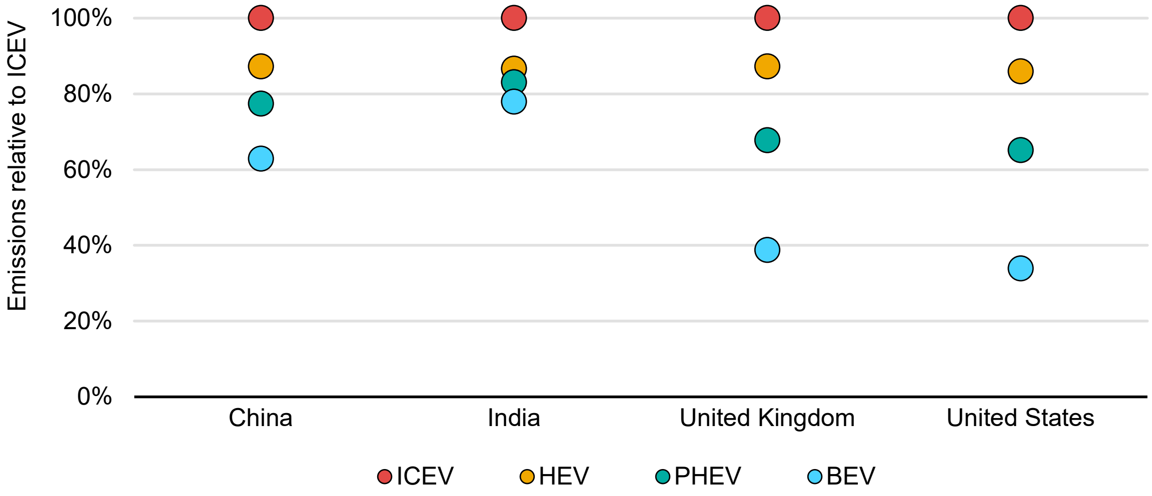
[39] In this analysis the utility factor is held constant over time and across scenarios.

Regionally, the lifecycle emissions benefits of BEVs vary, depending in particular on the local grid emissions intensity, average annual driving distance, and fuel economy of ICEVs. The potential for emissions savings from BEVs is relatively high in the United States, thanks to the high annual mileage of cars and projected rapid power grid decarbonisation. The emissions intensity of the US average grid mix falls by 70% by 2035 in the STEPS. As a result, the lifecycle emissions of a BEV purchased in the United States today are around 45%, 60%, and 65% lower than those of a PHEV, HEV and ICEV. Compared to the ICEV, this amounts to a net lifetime savings almost 50 t CO_2-eq for a medium-sized BEV.

In the United Kingdom, annual mileage is lower than in the United States – and closer to the global average – and, as a result, the lifetime emissions savings for a battery electric car compared to an ICE car amount to less than 20 t CO_2-eq per vehicle. The average annual mileage in India is broadly similar to the United Kingdom, but the emissions intensity of power generation is higher, given a high use of coal. As result, BEV lifecycle emissions are similar to PHEV and HEV (<10% difference), and just 20% lower than ICEV. Thus, a battery electric car in India saves less than 10 tonnes of CO_2-eq over its lifetime compared to an ICE medium-sized car. However, it is worth noting that there are significant efforts to decarbonise electricity generation in the country: the emissions intensity of the grid falls to 60% of today's level by 2035 in the STEPS. The environmental benefit of road electrification in India will therefore increase rapidly in the next years. Even today, electrification can already offer important public health advantages by decreasing air pollution in India's mega cities, like Mumbai.

In China, BEV emissions are about 20%, 30%, and 40% lower compared to PHEV, HEV and ICEV, respectively, equivalent to almost 5 tonnes of CO_2-eq (compared to a PHEV) and up to 10 (compared to an ICEV) for a medium-sized vehicle. Despite the emissions benefits of BEVs being lower in China than in Europe and the United States, its larger battery electric car fleet – over 16 million vehicles compared to over 6.5 million in Europe and around 3.5 million in the United States – makes China the leading country for GHG emissions saved through road electrification.

Lifecycle emissions of a medium-sized car by powertrain relative to a gasoline internal combustion engine car by region in the Stated Policies Scenario, 2023



Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. The year 2023 refers to the first year of use of the vehicle. See annex B for full technical assumptions. Additional regional results and the impact of varying assumptions will be available to explore through an upcoming online lifecycle analysis (LCA) tool to be made available on the IEA website.

Sources: IEA analysis based on the Global Energy and Climate Model, IFP, GREET, EV Volumes, Dai et al., Degen et al., Frith et al..

The importance of vehicle lifecycle emissions is being increasingly recognised in the policy sphere. The EU battery regulation requires a battery passport that includes the battery carbon emissions and, in 2023, France announced new eligibility rules for EV subsidies. These set a cap on the carbon intensity of vehicle production to promote vehicles with lower emissions across their full lifecycle, and include the calculation methodology. Elsewhere, the Brazilian government has issued a provisional measure to establish a programme that would set minimum recycling requirements in vehicle manufacturing and reduce taxes for companies with lower pollution and emissions levels. The EU HDV CO_2 standards include a review clause to evaluate the possibility of developing a common methodology for the assessment and reporting of the full lifecycle CO_2 emissions of new HDVs.

Further efforts are needed to decarbonise battery manufacturing and the processing of critical minerals

Battery chemistry plays an important role in defining the lifecycle emissions of EV batteries. In order to decarbonise battery manufacturing, policy ambition and concerted action to define common LCA methodologies and improve transparency will be required across the entire battery supply chain. Initiatives like the battery passport are particularly important towards this aim.

Of the two main chemistries currently used, high-nickel NMC and LFP, the emissions per kWh of LFP batteries are about one-third lower than NMC batteries at the pack level. In the context of carbon tariffs, or eligibility rules for EV subsidies based on lifecycle emissions, EV and battery producers might therefore be incentivised to rely more on LFP batteries, which today are almost exclusively produced in China, rather than the more emissions-intensive NMC batteries.

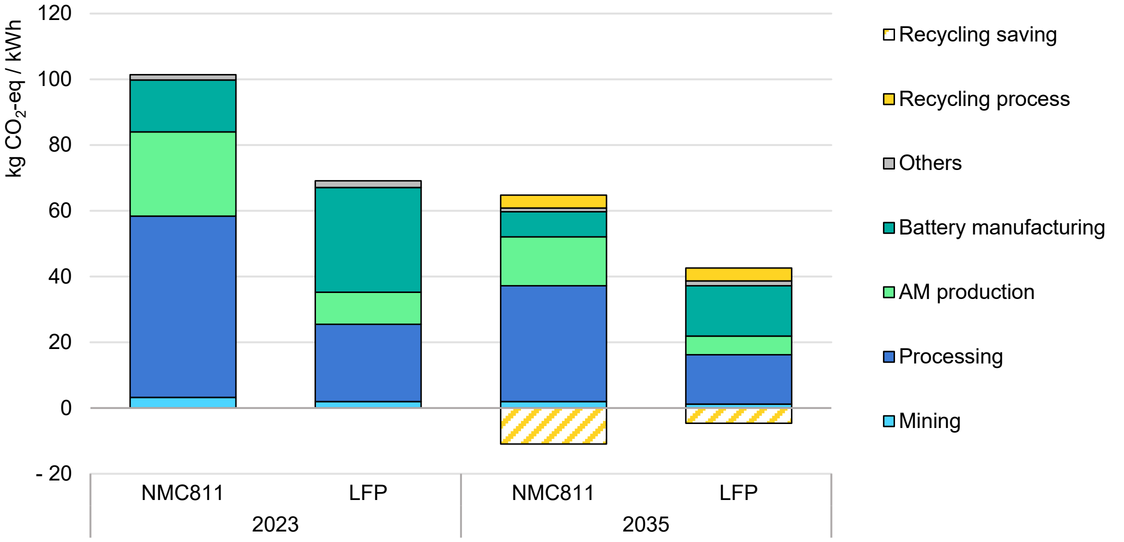
The main source of emissions across the battery lifecycle depends on the chemistry. Critical minerals processing accounts for 55% of total emissions for NMC, compared to 35% for LFP. Battery manufacturing accounts for almost 50% of LFP total emissions, against 15% for NMC. The production of active material for both cathode (NMC or LFP) and anode (graphite) materials is also important, and currently accounts for about 25% of NMC and 15% of LFP emissions.

Strategies to reduce emissions from high-nickel chemistries should focus on critical minerals processing, such as for nickel ores. Improving energy and process efficiency for critical minerals processing, active material production and battery manufacturing can also help, as can electrification along different steps in the supply chain, whenever possible. At the same time, as more retired EV batteries become available, replacing increasing shares of material inputs with recycled content will not only reduce emissions but also improve overall battery supply chain sustainability. In the case of LFP batteries, in particular, decarbonisation strategies should focus on reducing battery manufacturing emissions through higher efficiency and electrification, while reducing emissions associated with lithium ore processing.

Using low-carbon electricity can also support the decarbonisation of battery production. Electricity-related emissions today account for about 20% and 25% of NMC and LFP total lifecycle emissions, respectively. Sourcing this electricity from lower-carbon sources[40] is therefore important, but it is not sufficient for deep battery decarbonisation, which would require higher levels of electrification compared to today's 20-25% electrification rates over the entire battery cell supply chain. Other important strategies to reduce battery-related emissions are increasing the energy density, which decreases the battery material intensity, and recycling. In the APS, battery lifecycle emissions decrease by about 35% for both NMC and LFP through 2035, thanks to 30% higher energy density at the battery pack level, decarbonisation of power grids, and 20% of the cathode active material sourced through recycling.

[40] Electricity carbon emission in this analysis ranges between 400 and 420 g/kWh for the different battery supply chain steps.

Battery pack lifecycle emissions by chemistry in the Announced Pledges Scenario, 2023-2035



Notes: LFP = lithium iron phosphate; NMC811 = lithium nickel manganese cobalt oxide. AM = active material, including both cathode and anode (graphite). Battery manufacturing refers to cell and pack manufacturing. End-of-life options other than recycling are excluded from the analysis, and emissions associated with the transport of materials (which are expected to be low) are not considered. 'Others' refers to emissions associated with other battery pack components like electronics and coolant. See annex B for full assumptions.

Sources: IEA analysis based on data from GREET, EV Volumes, Dai et al., Degen et al., Frith et al., and IEA emissions factors.

General annex

Annex A: Total cost of ownership

Cost of ownership assumptions for cars

Cost of ownership parameters			China	Germany	United States
OPEX	Gasoline ICEV fuel economy (2022)	Small	6.9 l/100 km	5.7 l/100 km	5.9 l/100 km
		Medium	8.1 l/100 km	7.1 l/100 km	7.5 l/100 km
		SUV	9.5 l/100 km	7.3 l/100 km	10.1 l/100 km
	BEV fuel economy (2022)	Small	13.9 kWh/100 km	16.6 kWh/100 km	17.0 kWh/100 km
		Medium	18.7 kWh/100 km	16.5 kWh/100 km	16.0 kWh/100 km
		SUV	19.8 kWh/100 km	18.3 kWh/100 km	23.3 kWh/100 km
	Annual mileage		10 130 km/yr	14 700 km/yr	26 950 km/yr
	Gasoline price (2022)		USD 1.00/litre	USD 2.13/litre	USD 1.00/litre
	Electricity price (2022)	Private	USD 0.08/kWh	USD 0.32/kWh	USD 0.15/kWh
		Public	USD 0.16/kWh	USD 0.63/kWh	USD 0.30/kWh
	Share of public charging		20%		
	Maintenance	BEV	0.5% of retail price per year		
		ICEV	1.5% of retail price per year		
	Insurance	BEV	0.9% of retail price per year		
		ICEV	0.9% of retail price per year		

Cost of ownership parameters			China	Germany	United States
CAPEX	ICEV purchase price (2022)	Small	USD 15 765	USD 22 722	USD 20 406
		Medium	USD 22 314	USD 42 243	USD 29 547
		SUV	USD 31 617	USD 40 876	USD 40 121
	BEV purchase price (2022)	Small	USD 9 937	USD 34 891	USD 33 417
		Medium	USD 28 706	USD 48 361	USD 52 131
		SUV	USD 34 759	USD 54 972	USD 63 026
	Incentive (subsidy)		USD 1 351	USD 5 270	None
	Incentive (purchase tax exemption)		10% of retail price	None	None
	Incentive (tax credit)		None	None	USD 7 500
	Vehicle depreciation		18% annual rate (relative to previous year)		
	Loan term		5 years		
	Loan downpayment		10% of retail price		
	Loan interest rate		5%		

Notes: OPEX = operating expenditure; CAPEX = capital expenditure; ICEV = internal combustion engine vehicle; BEV = battery electric vehicle; SUV = sports utility vehicle.

Cost of ownership assumptions for two- and three-wheelers

Cost of ownership parameters				India	China
OPEX	ICEV fuel economy (2023)	Gasoline	2W	1.6 l/100 km	1.7 l/100 km
		Gasoline	3W	3.1 l/100 km	--
		Diesel		2.7 lge/100 km	--
		Natural gas		4.1 lge/100 km	--
	BEV fuel economy (2023)		2W	0.4 lge/100 km	0.3 lge/100 km
			3W	0.6 lge/100 km	--
	Annual mileage		2W	8 800 km/year	
			3W	29 500 km/year	--
	Gasoline price (in 2022)			USD 1.32/litre	USD 1.00/litre
	Diesel price (in 2022)			USD 1.18/lge	USD 1.14/lge
	Natural gas price (in 2022)			USD 0.68/lge	USD 0.60/lge
	Electricity price (2022)			USD 0.06/kWh	USD 0.08/kWh
	Maintenance		ICEV	3.6% of retail price per year	
			BEV	1.2% of retail price per year	
	Insurance		ICEV	0.9% of retail price per year	
			BEV	0.9% of retail price per year	
CAPEX	ICEV purchase price (2023)	Gasoline	2W	USD 1 094	USD 875
		Gasoline	3W	USD 3 840	--
		Diesel		USD 4 420	--
		Natural gas		USD 4 635	--
	BEV purchase price (2023)		2W	USD 1 442	USD 1 044
			3W	USD 11 966	--
	Subsidy		2W	EMPS: INR 10 000	None
			3W	EMPS: INR 50 000	None
	Tax rebates			RTO: 10% of retail price GST: 23% of retail price	None
	Vehicle depreciation			No resale value considered	
	Loan term			3 years	
	Loan downpayment			10% of retail price	20% of retail price
	Loan interest rate			11.0%	10.3%

Notes: OPEX = operating expenditure; CAPEX = capital expenditure; 2W = two-wheeler; 3W = three-wheeler; lge = litre of gasoline equivalent (= 9.31 kWh); ICEV = internal combustion engine vehicle; BEV = battery electric vehicle; EMPS = Electric Mobility Promotion Scheme; INR = Indian rupee; RTO = Regional Transport Office; GST = Goods and Service Tax; INR = Indian rupee.

Annex B: Lifecycle analysis assessment

"Tank-to-wheel" emissions are emissions from fuel combustion.

"Well-to-tank" emissions are associated with fuel production over the vehicle lifetime. In the case of EVs, well-to-tank emissions are those associated with electricity generation, distribution and charging losses; for ICEVs they are the upstream emissions associated with the production, refining and transport of the gasoline.

"Grid decarbonisation impact" refers to the effect of electricity emissions intensity improvements over the lifetime of the vehicle.

Assumptions behind emission values used in this report

Emission values for car production are for a medium-sized passenger light-duty vehicle and based on weighted global averages by production of the materials.

The battery electric vehicle (BEV) is considered to have a real-world range of 350 km with a battery capacity of 60 kWh. The plug-in hybrid electric vehicle (PHEV) is considered to have a gasoline engine, a battery capacity of 15 kWh to enable a 60 km electric range, and a utility factor of 40%, meaning 40% of the kilometres are electrically driven. Fuel economy improvements over time vary by scenario and by region.

For the world average, a lifetime activity of about 200 000 km over 15 years is assumed. For the regional analysis, lifetime activity of about 330 000 km, 170 000 km, 120 000 km, and 260 000 km is assumed for the United States, United Kingdom, China, and India, respectively. Calculations of lifecycle emissions account for mileage decay, assuming that highest annual mileage occurs in the first year of operation, with mileage in each subsequent year being equal to around 95% of the previous year. This means that by year 15, the car is driven for around half of the annual mileage of year 1. By taking into account mileage decay, our LCA results place more emphasis on the near term, as opposed to assuming constant mileage over the car's lifetime.

Biofuel blending is not considered. Improvements in the emissions intensity of gasoline production are included, in line with those of IEA modelling in the respective scenario.

For car production, world averages related to energy inputs and emissions intensity of mining and material production are assumed. Actual vehicle production emissions would vary based on regional energy mixes associated with each supply chain step.

Battery emissions are calculated using the 2023 chemistry sales-weighted average. NMC811 (lithium nickel manganese cobalt oxide ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$)) is used as a representative chemistry of the high-nickel class, given its larger market share today and considering that lifecycle emissions for individual battery designs within that class are similar. The battery pack energy densities used refer to the 2023 sales-weighted average and are around 135 Wh/kg for LFP and 165 Wh/kg for NMC811. 2035 emissions assume 30% increased energy density at the battery pack level, and 20% of the cathode active material sourced through recycling.

Annex C: Regional and country groupings

Unless otherwise specified, regional groupings used in the Global EV Outlook and EV data explorers are as follows:

Africa

Algeria, Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Kingdom of Eswatini, Libya, Madagascar, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo (Congo), Rwanda, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Tunisia, Uganda, Zambia, Zimbabwe and other African countries and territories.[41]

Asia Pacific

Australia, Bangladesh, Democratic People's Republic of Korea (North Korea), India, Japan, Korea, Mongolia, Nepal, New Zealand, Pakistan, The People's Republic of China (China), Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[42]

Central and South America

Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica,

[41] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone and Somalia.

[42] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.

Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay and other Central and South American countries and territories.[43]

Eurasia

Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, the Russian Federation (Russia), Tajikistan, Turkmenistan and Uzbekistan.

Europe

European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel,[44] Kosovo, Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

European Union

Austria, Belgium, Bulgaria, Croatia, Cyprus,[45, 46] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

Latin America and the Caribbean (LAC)

Central and South America regional grouping and Mexico.

Middle East

Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

[43] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten (Dutch part), Turks and Caicos Islands.

[44] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[45] Note by Republic of Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

[46] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

North America

Canada, Mexico and United States.

Southeast Asia

Brunei Darussalam, Cambodia, Indonesia, Lao People’s Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Abbreviations and acronyms

ACEA	European Automobile Manufacturers Association
ACWI	All Country World Index
AFIR	Alternative Fuels Infrastructure Regulation
AM	active material
APS	Announced Pledges Scenario
ARPA-E	Advanced Research Projects Agency–Energy
ASEAN	Association of Southeast Asian Nations
AUD	Australian dollar
BEV	battery electric vehicle
BMW	Bavarian Motor Works
BNEF	Bloomberg New Energy Finance
BRA	Brazilian reals
BRT	Bus rapid transit
BYD	Build Your Dreams
CADA	Chinese Automobile Dealers Association
CAPEX	capital expenditure
CATL	Contemporary Amperex Technology Co. Limited
CCVDA	China Commercial Vehicles Dealers Association
CNY	Yuan renminbi
COP	Conference of the Parties
CO_2	carbon dioxide
CPO	charging point operator
DC	direct current
DoE	Department of Energy
EAFO	European Alternative Fuels Observatory
EFTA	European Free Trade Association
EMDE	emerging market and developing economy
EMPS	Electric Mobility Promotion Scheme
ENTSO-E	European Network of Transmission System Operators
EPA	Environmental Protection Agency
EREV	extended range electric vehicle
ERS	electric road systems
EU	European Union
EUR	euro
EV	electric vehicle
EV100	The Climate Group's EV100 Initiative
EVI	Electric Vehicle Initiative
EVSE	electric vehicle supply equipment
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FCEV	fuel cell electric vehicle
FID	final investment decision
GBP	British pound sterling

GDP	Gross Domestic Product
GEC	Global Energy and Climate Model
GEVO	Global EV Outlook
GHG	greenhouse gases
GM	General Motors
Gr	graphite
GST	Goods and Service Tax
GVW	gross vehicle weight
HD	heavy duty
HDV	heavy-duty vehicle
HEV	hybrid electric vehicle
HGV	heavy goods vehicle
HRS	hydrogen refuelling station
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
IDR	Indonesian rupiah
INR	Indian rupee
IRA	Inflation Reduction Act
ISO	International Organization for Standardization
JPY	Japanese yen
LCA	lifecycle analysis
LCV	light commercial vehicle
LDV	light-duty vehicle
LFP	lithium iron phosphate
Li	lithium
Li-ion	lithium-ion
Li-metal	lithium metal
MCS	Megawatt Charging System
MD	micro duty
Mg	magnesium
MOU	memorandum of understanding
NACS	North American Charging Standard
Na-ion	sodium-ion
NCA	lithium nickel cobalt aluminium oxide
NEV	new energy vehicle
NMC	nickel manganese cobalt oxide
NMCA	lithium nickel manganese cobalt aluminium oxide
NOx	nitrogen oxide
NZE	Net Zero Emissions by 2050 Scenario
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
PLDV	passenger light-duty vehicle
PLI	Production Linked Incentive
PLN	Polish zloty
PV	photovoltaic

PW	Prussian white
RoW	rest of the world
RTO	Regional Transport Office
RV	resale value
RWF	Rwandan francs
R&D	research & development
SAIC	Shanghai Automotive Industry Corporation
Si-Gr	silicon-graphite
SMMT	The Society of Motor Manufacturers and Traders
STEPS	Stated Policies Scenario
SUV	sports utility vehicle
TCO	total cost of ownership
TEN-T	Trans-European Transport Network
THB	Thai baht
Ti	titanium
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
USD	United States dollar
USGS	United States Geological Survey
VC	venture capital
VW	Volkswagen
WLTP	Worldwide Harmonised Light Vehicle Test Procedure
WTW	well-to-wheel
ZEBRA	Zero Emission Bus Regional Areas
ZETI	Zero-Emission Technology Inventory
ZEV	zero-emission vehicle
2/3W	two/three-wheeler

Units of measure

°C	degree Celsius
g CO_2	grammes of carbon dioxide
Gt CO_2	gigatonnes of carbon dioxide
GW	gigawatt
GWh	gigawatt-hour
km	kilometre
kW	kilowatt
kWh	kilowatt-hours
kt	kilotonnes
mb/d	million barrels per day
Mt	million tonnes
Mt CO_2-eq	million tonnes of carbon dioxide equivalent
MW	megawatt

t	tonne
t CO_2	tonne of carbon dioxide
t CO_2-eq	tonne of carbon dioxide equivalent
TW	terawatt
TWh	terawatt-hour
Wh	watt-hour
Wh/kg	watt-hour per kilogramme

Currency conversions

Market exchange rates (2023)	1 US dollar (USD) equals:
Australian dollar	1.50
Brazilian reals	4.99
British pound	0.80
Chinese yuan renminbi	7.08
Euro	0.92
Indian rupee	82.80
Indonesian rupiah	15236.89
Japanese yen	140.49
Polish zloty	4.20
Rwandan francs	1160.17
Thai baht	34.80

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