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International Energy Agency

Global EV Outlook 2020

Entering the decade of electric drive?

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

ELECTRIC VEHICLES INITIATIVE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

Abstract

The Global EV Outlook is an annual publication that identifies and discusses recent developments in electric mobility across the globe. It is developed with the support of the members of the Electric Vehicles Initiative (EVI). Combining historical analysis with projections to 2030, the report examines key areas of interest such as electric vehicle and charging infrastructure deployment, ownership cost, energy use, carbon dioxide emissions and battery material demand. This edition features case studies on transit bus electrification in Kolkata (India), Shenzhen (China), Santiago (Chile) and Helsinki (Finland). The report includes policy recommendations that incorporate learning from frontrunner markets to inform policy makers and stakeholders that consider policy frameworks and market systems for electric vehicle adoption. This edition also features an update on the performance and costs of batteries. It further extends the life cycle analysis conducted in *Global EV Outlook 2019*, assessing the technologies and policies that will be needed to ensure that EV battery end-of-life treatment contributes to the fullest extent to sustainability and CO_2 emissions reductions objectives. Finally, it analyses how off-peak electricity demand charging, dynamic controlled charging (V1G) and vehicle-to-grid (V2G) could mitigate the impact of EVs on peak demand, facilitate the integration of variable renewables and reduce electricity generation capacity needs.

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Executive summary

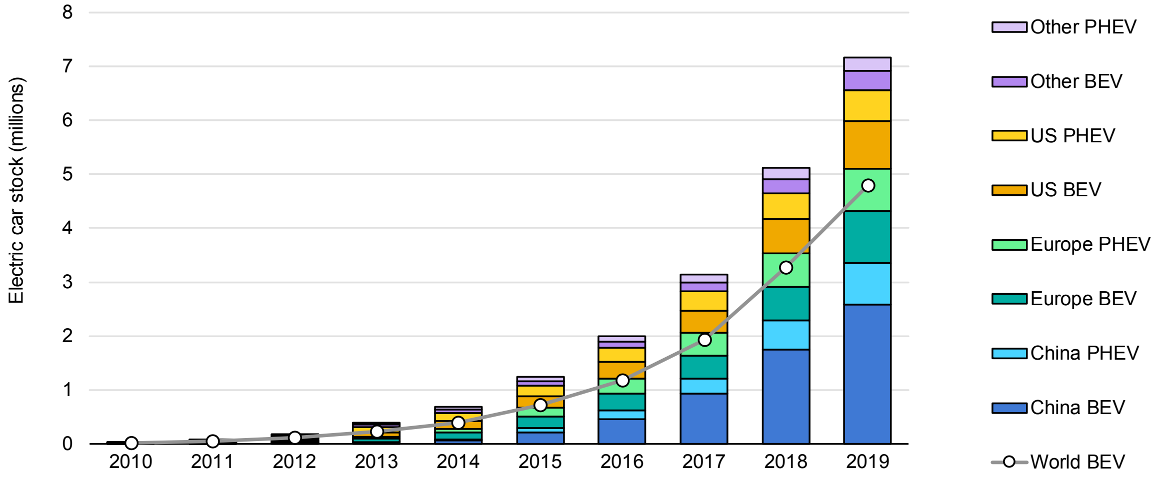
The global electric vehicle fleet expanded significantly over the last decade, underpinned by supportive policies and technology advances

Global sales of passenger cars were sluggish in 2019, but electric cars had another banner year.

Sales of electric cars topped 2.1 million globally in 2019, surpassing 2018 – already a record year – to boost the stock to 7.2 million electric cars.[1] Electric cars, which accounted for 2.6% of global car sales and about 1% of global car stock in 2019, registered a 40% year-on-year increase. As technological progress in the electrification of two/three-wheelers, buses, and trucks advances and the market for them grows, electric vehicles are expanding significantly. Ambitious policy announcements have been critical in stimulating the electric-vehicle rollout in major vehicle markets in recent years. In 2019, indications of a continuing shift from direct subsidies to policy approaches that rely more on regulatory and other structural measures – including zero-emission vehicles mandates and fuel economy standards – have set clear, long-term signals to the auto industry and consumers that support the transition in an economically sustainable manner for governments.

[1] In this report, "electric car" or "passenger electric car" refers to either a battery electric vehicle or a plug-in hybrid electric vehicle in the passenger light-duty vehicle segment. It does not include hybrid electric vehicles that cannot be plugged-in.

Global electric car stock, 2010-19



Sources: IEA analysis based on country submissions, complemented by other sources. For more details, see figure 1.1 in the main report.

Electric cars, which expanded by an annual average of 60% in the 2014-19 period, totalled 7.2 million in 2019.

After entering commercial markets in the first half of the decade, electric car sales have soared. Only about 17 000 electric cars were on the world's roads in 2010. By 2019, that number had swelled to 7.2 million, 47% of which were in The People's Republic of China ("China"). Nine countries had more than 100 000 electric cars on the road. At least 20 countries reached market shares above 1%.[2]

The 2.1 million electric car sales in 2019 represent a 6% growth from the previous year, down from year-on-year sales growth at least above 30% since 2016. Three underlying reasons explain this trend:

- **Car markets contracted**. Total passenger car sales volumes were depressed in 2019 in many key countries. In the 2010s, fast-growing markets such as China and India for all types of vehicles had lower sales in 2019 than in 2018. Against this backdrop of sluggish sales in 2019, the 2.6% market share of electric cars in worldwide car sales constitutes a record. In particular, China (at 4.9%) and Europe (at 3.5%) achieved new records in electric vehicle market share in 2019.

[2] Market share is defined in this report as the share of new EV registrations as a percentage of total new vehicle registrations, whereas stock share refers to the share of electric vehicle stock as a percentage of total passenger vehicle stock.

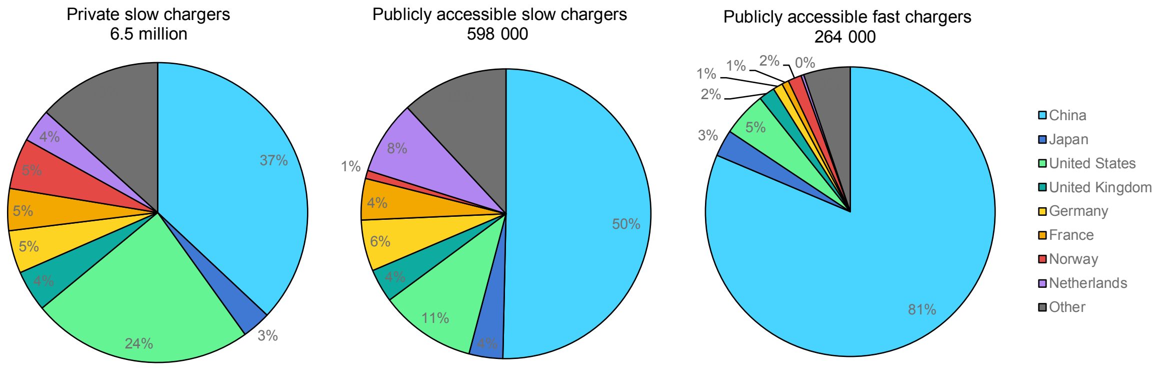
- **Purchase subsidies were reduced in key markets**. China cut electric car purchase subsidies by about half in 2019 (as part of a gradual phase out of direct incentives set out in 2016). The US federal tax credit programme ran out for key electric vehicle automakers such as General Motors and Tesla (the tax credit is applicable up to a 200 000 sales cap per automaker). These actions contributed to a significant drop in electric car sales in China in the second half of 2019, and a 10% drop in the United States over the year. With 90% of global electric car sales concentrated in China, Europe and the United States, this affected global sales and overshadowed the notable 50% sales increase in Europe in 2019, thus slowing the growth trend.
- **Consumer expectations of further technology improvements and new models**. Today's consumer profile in the electric car market is evolving from early adopters and technophile purchasers to mass adoption. Significant improvements in technology and a wider variety of electric car models on offer have stimulated consumer purchase decisions. The 2018-19 versions of some common electric car models display a battery energy density that is 20-100% higher than were their counterparts in 2012. Further, battery costs have decreased by more than 85% since 2010. The delivery of new mass-market models such as the Tesla Model 3 caused a spike in sales in 2018 in key markets such as the United States. Automakers have announced a diversified menu of electric cars, many of which are expected in 2020 or 2021. For the next five years, automakers have announced plans to release another 200 new electric car models, many of which are in the popular sport utility vehicle market segment. As improvements in technical performance and cost reductions continue, consumers are placed in the position of being attracted to a product but wondering if it would be wise to wait for the "latest and greatest model".

The Covid-19 pandemic will affect global electric vehicle markets, although to a lesser extent than it will the overall passenger car market. Based on car sales data during January to April 2020, our current estimate is that the passenger car market will contract by 15% over the year relative to 2019, while electric sales for passenger and commercial light-duty vehicles will remain broadly at 2019 levels. Second waves of the pandemic and slower-than-expected economic recovery could lead to different outcomes, as well as to strategies for automakers to cope with regulatory standards. Overall, we estimate that electric car sales will account for about 3% of global car sales in 2020. This outlook is underpinned by supporting policies, particularly in China and Europe. Both markets have national and local subsidy schemes in place – China recently extended its subsidy scheme until 2022. China and Europe also recently strengthened and extended their New Energy Vehicle mandate and CO_2 emissions standards, respectively. Finally, there are signals that recovery measures to tackle the Covid-19 crisis will continue to focus on vehicle efficiency in general and electrification in particular.

Most charging is done at home and work, yet deploying publicly accessible charging points is outpacing electric vehicle sales

The infrastructure for electric-vehicle charging continues to expand. In 2019, there were about 7.3 million chargers worldwide, of which about 6.5 million were private, light-duty vehicle slow chargers in homes, multi-dwelling buildings and workplaces. Convenience, cost-effectiveness and a variety of support policies (such as preferential rates, equipment purchase incentives, and rebates) are the main drivers for the prevalence of private charging.

Private and publicly accessible chargers by country, 2019



Sources: IEA analysis based on country submissions, complemented by other sources. For more details, see figure 1.8 in the main report.

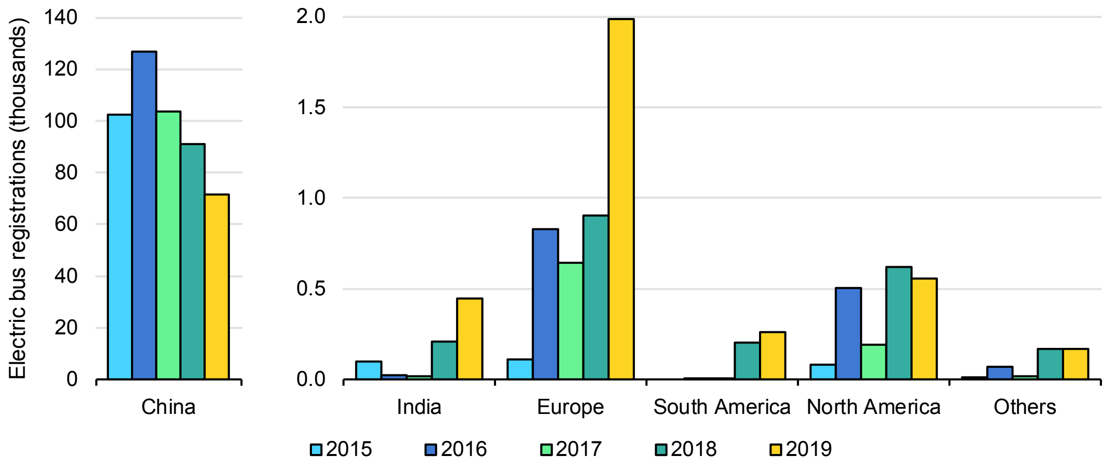
The vast majority of electric light-duty vehicle chargers are private chargers. China accounts for 80% of publicly accessible fast chargers compared to 47% of the world's electric light-duty vehicle stock.

Publicly accessible chargers accounted for 12% of global light-duty vehicle chargers in 2019, most of which are slow chargers. Globally, the number of publicly accessible chargers (slow and fast) increased by 60% in 2019 compared with the previous year, higher than the electric light-duty vehicle stock growth. China continues to lead in the rollout of publicly accessible chargers, particularly fast chargers, which are suited to its dense urban areas with less opportunity for private charging at home.

China continues to lead in electrifying two/three-wheelers and urban buses

Transport modes other than cars are also electrifying. Electric micromobility options have expanded rapidly since their emergence in 2017, with shared electric scooters (e-scooters), electric-assist bicycles (e-bikes) and electric mopeds now available in over 600 cities across more than 50 countries worldwide. An estimated stock of 350 million electric two/three-wheelers, the majority of which are in China, make up 25% of all two/three-wheelers in circulation worldwide, driven by bans in many Chinese cities on two-wheelers with internal combustion engines. About 380 000 light commercial electric vehicles are in circulation, often as part of a company or public authority vehicle fleet.

New electric bus registrations by country/region, 2015-19



Sources: IEA analysis based on country submissions, complemented by other sources. For more details, see figure 1.4 in the main report.

Fewer new registrations of electric buses in China led to a 20% drop in registrations worldwide in 2019, despite strong growth in other regions.

About half a million electric buses are in circulation, most of which are in China. Although the number of new registrations in 2019 was lower than in previous years due to a gradual subsidy phase-out from 2016 and a decline in the overall bus market, the bus fleets in a number of city centres in China are near-fully or fully electrified and contribute to improve the air quality. Driven by similar air quality concerns, bus electrification is also gaining ground in many other regions: the City of Santiago de Chile is home to the largest electric urban bus fleet outside of China. Case studies of electric bus deployment in Helsinki (Finland), Shenzhen (China), Kolkata (India) and Santiago de Chile (Chile) highlight the unique nature of each public transit system, the roll-out of electric buses facing context-specific challenges related to network size, ridership, degree of sector privatisation and the availability of funding streams other than fare revenues.

With Covid-19, urban public transit, including buses, will face challenges of providing high-capacity and affordable services while ensuring health security. There is a risk that commuters may opt temporarily or definitively for personal vehicle options. However, in dense cities of the developing and developed world alike, urban buses provide a key means of transport that is not easily substitutable by cars without exacerbating already severe congestion. Hence, the future of public transit in general and electric buses in particular will be balanced between the impacts of the pandemic, the overall capacity of the urban transport system, and continued government support.

Electrifying heavy-duty trucks and air- and seaport operations offer opportunities for cost and emission savings

Opportunities for electrification can be seized over the coming decade even in modes where emissions are hard to abate such as heavy-duty trucks, aviation and shipping. Global sales of electric trucks hit a record in 2019 with over 6 000 units, while the number of models continue to expand. High-power chargers are being developed and standardised globally. Research on dynamic charging concepts, as well as demonstrations of catenary line solutions, may enable expansion of the range of operations for heavy-duty and long-distance operations for regional buses and long-haul trucking. Electrification of shipping operations at ports is increasingly common and is gradually being mandated by legislation in Europe, China, and, in the United States, California. In aviation, electric taxiing (i.e. the electrification of ground operations in aircraft) offers immediate potential for pollutant and CO_2 emissions reductions and operational cost savings for airlines.

Policies continue to support electric vehicle deployment and are evolving to a more holistic policy portfolio

Environmental and sustainability objectives drive electric vehicle policy support at all governance levels

Electric vehicles are a key technology to reduce air pollution in densely populated areas and a promising option to contribute to energy diversification and greenhouse gas emissions reduction objectives. Electric vehicle benefits include zero tailpipe emissions, better efficiency than internal combustion engine vehicles and large potential for greenhouse gas emissions reductions when coupled with a low-carbon electricity sector. These objectives are major drivers behind countries' policy support in the development and deployment of electric powertrains for transport. To date, 17 countries have announced 100% zero-emission vehicle targets or the phase-out of internal combustion engine vehicles through 2050. France, in December 2019, was the first country to put this intention into law, with a 2040 timeframe.

Policy actions for electric vehicles depend on the status of the electric vehicle market or technology. Setting vehicle and charger standards are prerequisites for wide electric vehicle adoption. In the early stages of deployment, public procurement schemes (e.g. for buses and municipal vehicles) have the double benefit of demonstrating the technology to the public and providing the opportunity for public authorities to lead by example. Importantly, they also allow the industry to produce and deliver bulk orders to foster economies of scale. Emerging economies can scale up their policy efforts for both new vehicles and second-hand imports.

Tax rates that reflect tailpipe CO_2 emissions can be conducive to increased electric vehicle uptake. Fiscal incentives at the vehicle purchase, as well as complementary measures (e.g. road toll rebates and low-emission zones) are pivotal to attract consumers and businesses to choose the electric option. Local governments are key in proposing and implementing measures to enhance the value proposition of electric vehicles. The use of local low- and zero-emission zones can steer car purchase decisions far beyond just those zones and may influence the relative resale value of internal combustion engines and electric powertrains.

The vast majority of car markets offer some form of subsidy or tax reduction for the purchase of an individual or company electric car as well as support schemes for deploying charging infrastructure. Provisions in building codes to encourage charging facilities and the "EV-readiness" of buildings are becoming more common. So too are mandates to build charging infrastructure along road corridors and fuel stations.

Policies are being tailored to support market transition

There is common understanding that government support for electric vehicle purchases can only be transitional, as sale volumes increase. In the near term, a point will be reached when technology learning and economies of scale will have driven down the purchase cost of electric vehicles and mass-market adoption is triggered. For the first time a decrease in government spending for electric car purchase incentives was observed in 2019, while both consumer spending and total expenditure on electric cars continued to increase. At the national level, both China and the United States witnessed substantial purchase subsidies reductions or partial phase out in 2019, but there are cases where these reductions were met by increases in local government support. In China the central government was planning in 2019 to culminate a phase-out that dates to 2016, though, in the face of bleak electric car sales in the second half of 2019, the subsidy scheme was extended through 2022. Yet some other countries extended or implemented new purchase incentives schemes in 2019 or early 2020, for example, Germany and Italy.

Shifts to a variety of regulatory and fiscal measures are likely to gradually become a main driver of electric vehicle deployment, setting clear goals and a long-term vision for the industry. Many of the regulatory policies impel vehicle makers to sell a greater number or share of electric or otherwise more efficient vehicles. For example, today 60% of global car sales are covered by China's New Energy Vehicle mandate, the European Union CO2 emissions standard (which is applicable to all EU member states) or a zero-emission vehicle mandate (in selected US states and Canadian provinces). The European Union approved a new fuel economy standard for cars and vans for 2021 30 and a CO2 emissions standard for heavy-duty vehicles (2020 30), with specific requirements or bonuses for electric vehicles. In the European Union, 2020 is the target year for compliance with the CO2 emissions standards for light-duty vehicles of 95 grammes of CO2 per kilometre, which has contributed to the successful uptake of electric light-duty vehicles in Europe in recent years. In 2019, China announced a tightening of its New Energy Vehicle mandate scheme with both setting new credit targets for 2021-23 and a more stringent calculation method for the credits beyond 2021. These actions are in step with its planned gradual transition from direct to more indirect forms of subsidies and incentives (including increasing support for charging infrastructure and other support services). In the United States, regulatory developments were different from other markets; the Safer Affordable Fuel-Efficient (SAFE) vehicles final rule, put in place in March 2020, replaced the 2012 rule, lowering the annual improvement in fuel economy standards from 4.7% in the 2012 rulemaking to 1.5% in SAFE for model years 2021 through 2026.

Range of credits per vehicle type in China's New Energy Vehicle programme

Year	Range of credits per vehicle			NEV credit targets
	BEV	PHEV	FCEV	
Until 2020	1-5	2	1-5	2019: 10% 2020: 12%
From 2021	1-3.4	1.6	1-6	2021: 14% 2022: 16% 2023: 18%

Notes: For details, see table 2.3 in the main report.

Other countries with increasing policy activity to support electric vehicles are Canada, Chile, Costa Rica, India and New Zealand. For example, Chile seeks to establish energy efficiency standards for new vehicles sold by car manufacturers or importers, including multipliers for electric and hybrid vehicles in the calculation of the sales average car efficiency.

In addition to new regulations, in order to transition from internal combustion engines to electrified vehicles in the transport sector governments need a long-term vision and a diversified and adaptive portfolio of policy measures, including new fiscal schemes. For instance, governments will need to anticipate and adapt taxation approaches early to replace lost fuel tax revenues, such as taxation based on vehicle activity (e.g. distance- or congestion-based pricing).

Government responses to Covid-19 will influence the pace of the transition to electric vehicles

Many uncertainties characterise the Covid-19 crisis, from the capacity of governments and companies to double-down on transport electrification efforts to what behavioural changes could potentially be expected from the current crisis, including from low oil prices and confinement measures. As cities gradually emerge from lockdowns, some of them are placing temporary restrictions on the frequency and occupancy of public transport, raising the risk of a spike in car traffic. Many cities, particularly in Europe, are therefore rapidly putting together policies to rethink the use of urban space and to promote walking and cycling. As part of economic recovery efforts, a focus on promoting clean transport is being called for at national and local levels.

Auto manufacturing, a critical sector of economic activity in many of the world's largest economies, employs millions of people across the entire supply chain. It has been severely affected during the Covid-19 crisis; practically all major car manufacturers halted production lines for some period. Governments need to carefully consider appropriate policy responses. It is reasonable to expect that stimulus packages will seek to bolster the economy in countries with important vehicle manufacturing capacity by including measures to support the automotive industry, not least given their relevance for the labour market. While such measures will inevitably help boost electric vehicle sales as well, targeted measures to support electric vehicle sales in particular will be required to ensure that the electrification of road transport remains on track towards the postulated goals.

In China, policy makers were quick to identify the auto market as a primary target for economic stimulus. Among other measures, the central government encouraged cities to relax car permit quotas, at least temporarily, complemented by strengthening targeted New Energy Vehicle measures. In the European Union, at the time of writing, existing policies and regulations were being maintained and countries like France and Germany announced increased support measures towards electric vehicles for the remainder of 2020.

Experience of automotive industry stimulus measures has been mixed. Cash-for-clunkers programmes can be an effective approach if they are designed to support the uptake of more efficient (e.g. hybrid) and electric cars. In past stimulus packages, however, such considerations were not always adequately addressed and sales of sport utility vehicles and diesel cars were boosted, which pushed up global oil demand and air pollution. Support for the auto industry can also be tied to ambitious fuel economy regulations, which in the past triggered innovation and helped jump-start key parts of today's electric car industry. Other targeted and direct support measures, such as for charging infrastructure, or via favourable loans with low interest rates and/or public co-funding, towards corporate fleets for bulk procurement of electric cars, buses and trucks, could support continued growth in electric vehicle sales. In countries where fossil fuel subsidies prevail, the low oil price environment is an important opportunity to phase out price supports, which are detrimental for pursuing energy efficiency efforts in general and for creating a context that supports road vehicle electrification in particular.

Prospects for electrification in transport in the coming decade

Adoption of electric drivetrains accelerates

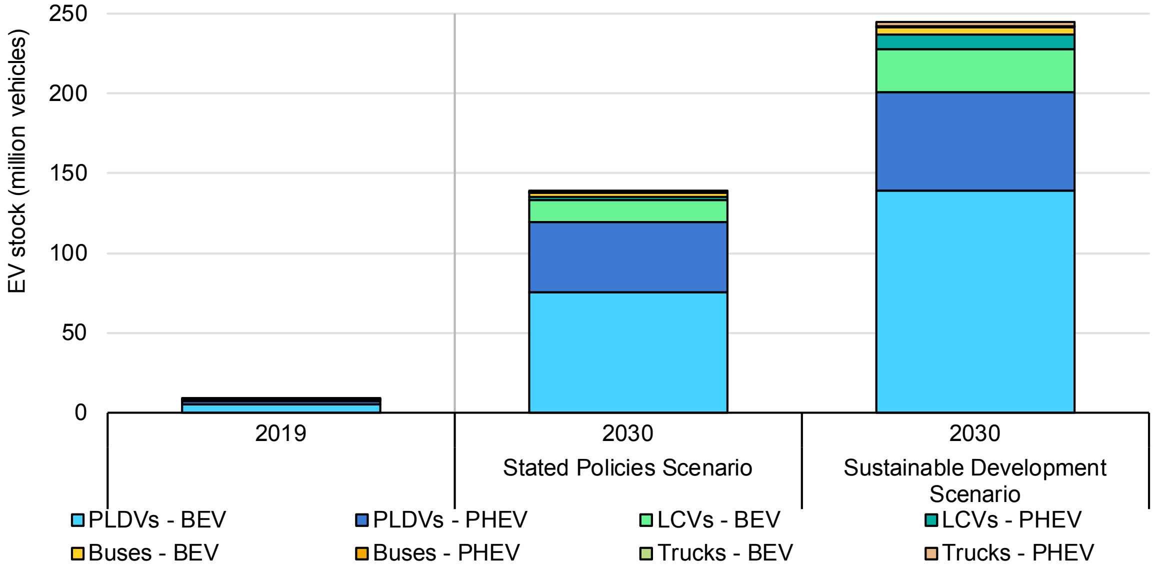
This report explores the outlook for electric mobility to 2030 through two IEA scenarios: the Stated Policies Scenario, which incorporates existing government policies, and the Sustainable Development Scenario, which is fully compatible with the climate goals of the Paris Agreement. The Sustainable Development Scenario incorporates the targets of the EV30@30 Campaign[3] to collectively reach a 30% market share for electric vehicles in all modes except two-wheelers by 2030.

Electric vehicles play a critical role in meeting the environmental goals of the Sustainable Development Scenario to reduce local air pollution and to address climate change. In this scenario, the global electric vehicle stock (excluding

[3] The EV30@30 Campaign was launched at the Eighth Clean Energy Ministerial in 2017. The participating countries are Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden and United Kingdom.

two/three-wheelers) grows by 36% annually, reaching 245 million vehicles in 2030 – more than 30 times above today's level. Other than two/three-wheelers, growth is strongest for the light-duty vehicle segment where electric powertrain technologies are most readily available. In the Stated Policies Scenario, under the assumptions taken, the global electric vehicle stock (excluding two/three-wheelers) reaches nearly 140 million vehicles and accounts for 7% of the global vehicle fleet.

Global electric vehicle stock by scenario, 2019 and 2030



Notes: PLDVs = passenger light-duty vehicles; LCVs = light commercial vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle.
Source: IEA analysis developed with the IEA Mobility Model.

By 2030, the global electric vehicle stock (excluding two/three-wheelers) is about 140 million in the Stated Policies Scenario, while the more ambitious Sustainable Development Scenario projects about 245 million electric vehicles.

Electric car sales drive cost reductions in batteries, which boosts deployment across all road vehicle categories

With the projected size of the global electric vehicle market, expansion of battery manufacturing capacity will largely be driven by electrification in the car market. Indeed the electrification of cars is a crucial driver in cutting unit costs of automotive battery packs that can be used in a variety of road modes. By 2030, the light-duty vehicle fleet (cars and light commercial vehicles) represents the largest part of the fleet of electric four-wheelers, regardless the scenario. China and Europe lead this deployment, as policies promote electrification.

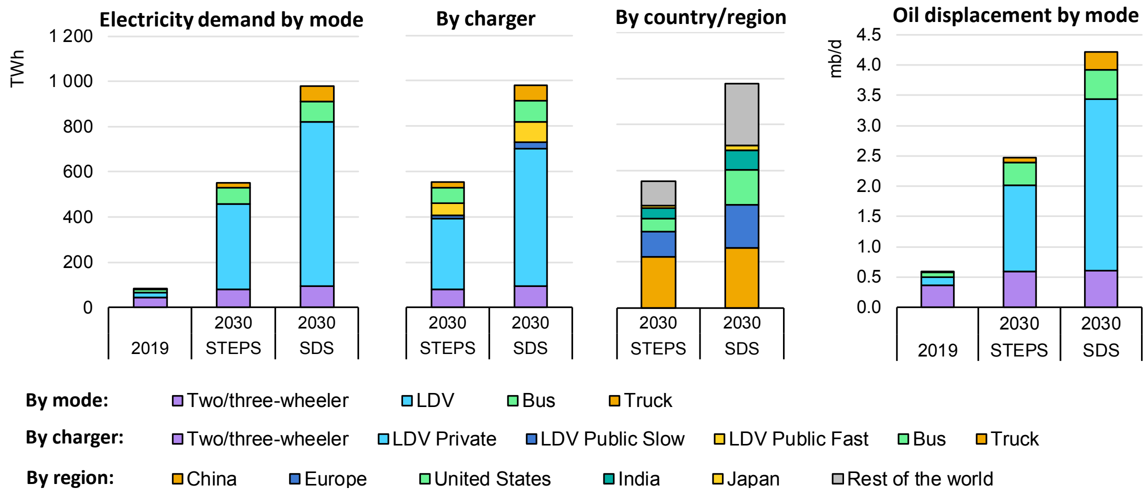
Electric two/three-wheelers will continue to represent the lion's share of the total electric vehicle fleet, as this category is most suited to rapid transition to electric drive. The future electric two/three-wheeler fleet is concentrated in China, India and the ten countries of ASEAN. Electrification of buses is mostly in urban areas due to their shorter ranges and driving cycles suitable for electrification. Due to the characteristics of their operations, intercity buses are not projected to make significant inroads in the period to 2030, thus the overall stock shares of buses lag slightly behind those of light-duty vehicles in both scenarios. Similarly, electrification of medium- and heavy-duty trucks is mostly in urban environments. Trucks that operate on regional and long-haul basis show the lowest sales and stock shares among all vehicle categories in the scenarios.

Electric vehicles increase electricity demand but reduce oil demand and well-to-wheel greenhouse gas emissions

In 2030, in the Stated Policies Scenario, global electricity demand from electric vehicles (including two/three-wheelers) reaches 550 TWh, about a six-fold rise from 2019 levels. The share of demand due to electric vehicles in total electricity consumption at a national/regional level grows to as high as 4% in Europe. In the Sustainable Development Scenario, with demand rising nearly eleven-fold relative to 2019, to almost 1 000 TWh, the share of total demand ranges from 2% in Japan to 6% in Europe.

In both scenarios, electricity demand on slow chargers represent the majority of electric vehicle electricity demand (mainly due to a continuing dominance of private charging). Fast-charging infrastructure is gradually deployed to respond to the growth in relative shares of electric vehicles with higher battery capacity and power requirements, e.g. buses and trucks.

Electricity demand from the electric vehicle fleet by mode, charger type, country/region and oil displacement, 2019 and 2030



Notes: Mb/d = million barrels of oil per day; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; LDV = light-duty vehicle. For more details, see figure 3.5 in the main report.
Source: IEA analysis developed with the IEA Mobility Model.

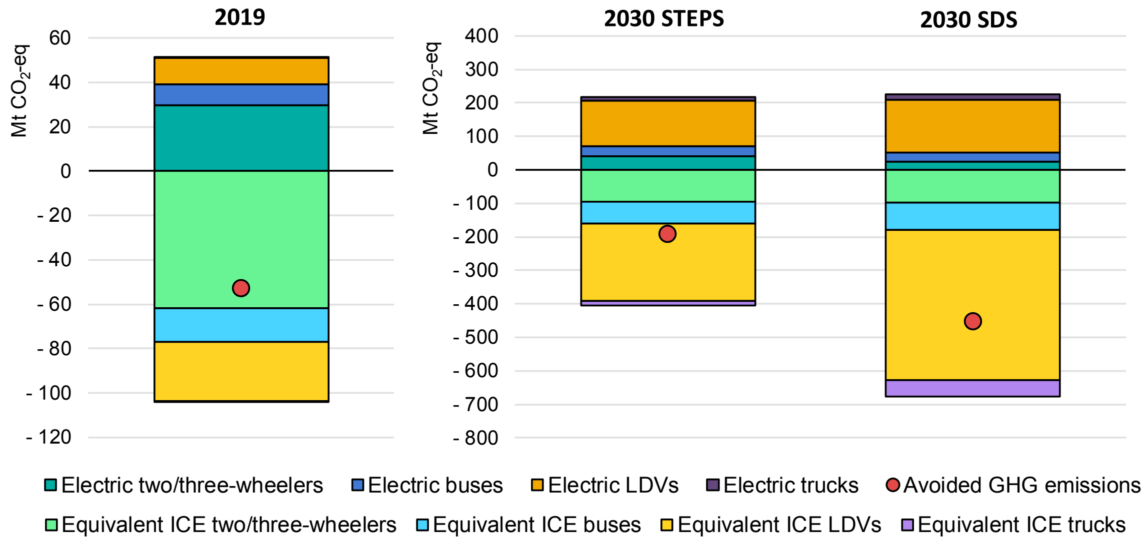
Global electricity demand from electric vehicles grows from 80 TWh in 2019 to 550 TWh in 2030 in the Stated Policies Scenario, when oil displacement reaches 2.5 mb/d.

In 2019, electric vehicles in operation globally avoided the consumption of almost 0.6 million barrels of oil products per day. In 2030, in the Stated Policies Scenario, the electric vehicle fleet displaces around 2.5 mb/d of oil products. In the Sustainable Development Scenario, it displaces 4.2 mb/d of gasoline and diesel.

In 2019, the electricity generation to supply the global electric vehicle fleet emitted 51 Mt CO_2-eq, about half the amount that would have been emitted from an equivalent fleet of internal combustion engine vehicles, corresponding to 53 Mt CO_2-eq of avoided emissions.

To ensure that electric vehicles can unleash their full potential to mitigate climate change, it is crucial to reduce the CO_2 intensity of power generation. Indeed, the well-to-wheel emissions of the future electric vehicle fleet are projected to be significantly lower than are those of internal combustion engines in 2030 in both scenarios. The net emission reductions are more significant in the Sustainable Development Scenario, in which higher electric vehicle deployment is coupled with more rapid decarbonisation of electricity generation, in line with the Paris Agreement goals.

Net and avoided well-to-wheel GHG emissions from the global electric vehicle fleet, 2019 and 2030



Notes: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; LDVs = light-duty vehicles; ICE = internal combustion engine. Positive emissions are from the global EV fleet. Negative emissions are those that would have been emitted by an equivalent ICE fleet. The red dot denotes net CO_2 emissions savings from EVs in comparison with an equivalent ICE fleet.

Sources: IEA analysis developed with the IEA Mobility Model; carbon intensities from *Energy Technology Perspectives 2020* (IEA, forthcoming).

In 2030, electric vehicles reduce GHG emissions by almost half compared to an equivalent fleet of internal combustion engine vehicles in the Stated Policies Scenario and by two-thirds in the Sustainable Development Scenario.

Batteries: An essential technology to electrify road transport

Battery capacity increases, pushing up demand for materials

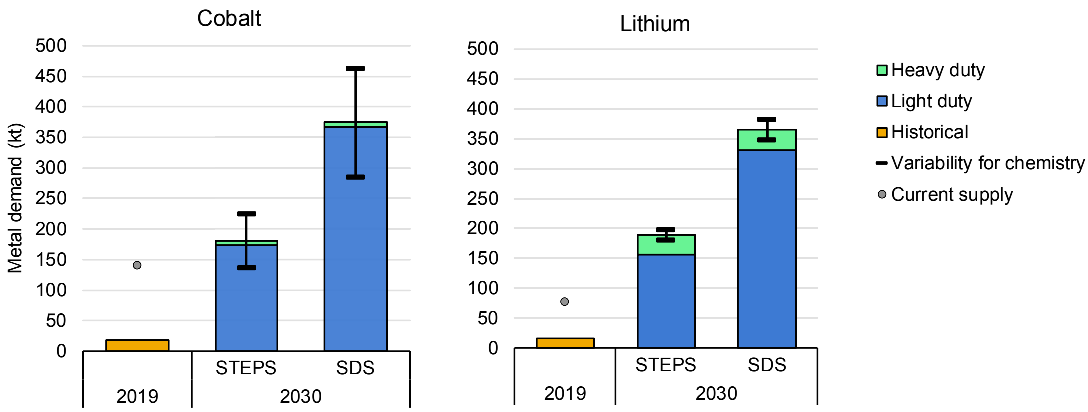
The ongoing trend of increasing battery capacity is projected to continue. By 2030, battery electric vehicles are assumed to reach an average driving range of 350-400 km corresponding to battery sizes of 70-80 kWh. In addition to battery size, another important variable in projecting total battery capacity is the proportion of battery electric vehicles and plug-in hybrid electric vehicles in overall electric vehicle sales.

In the Stated Policies Scenario, global electric vehicle battery capacity increases from around 170 GWh per year today to 1.5 TWh per year in 2030. In the Sustainable Development Scenario, demand of 3 TWh is projected. Despite ambitious electrification in the Sustainable Development Scenario, modes other than cars account for only 11% of overall battery demand in 2030, highlighting the centrality of electric cars in the battery market over the next decade.

The demand for the materials used in electric vehicle batteries will depend on changing battery chemistries, nickel cobalt aluminium oxide (NCA), nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) cathodes for lithium-ion (Li-ion) batteries being the most widely used today.

The estimated material demand for the batteries of the electric vehicles sold in 2019 was about 19 kt for cobalt, 17 kt for lithium, 22 kt for manganese and 65 kt for nickel. For battery needs in the Stated Policies Scenario, cobalt demand expands to about 180 kt/year in 2030, lithium to around 185 kt/year, manganese to 177 kt/year and class I nickel to 925 kt/year. In the Sustainable Development Scenario, higher electric vehicle uptake leads to 2030 material demand values more than twice as high as the Stated Policies Scenario.

Annual lithium and cobalt demand for electric vehicle batteries, 2019-30



Notes: kt = kilotonnes; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario. Error bars show the variability arising from varying assumptions related to the development of future battery chemistries.

Demand for materials to make batteries for electric vehicles will increase exponentially in the period to 2030; cobalt is the most uncertain reflecting various battery chemistries.

Battery technologies improve and costs drop

The cost of batteries for electric vehicles is falling markedly. Industry reports show that sales-weighted battery pack prices in 2019 were an average of USD 156 per kilowatt-hour, down from more than USD 1 100/kWh in 2010. The average battery pack size across electric light-duty vehicles sold (including battery electric vehicles and plug-in hybrid electric vehicles) continues an upwards trend; it is now 44 kWh, up from 37 kWh in 2018, and battery electric cars in most countries are in the 50-70 kWh range. This increase is driven by two trends: battery electric vehicle models with longer ranges are becoming available and are increasingly in demand, and the share of battery electric vehicles relative to plug-in hybrid electric vehicles is rising.

The most common cathode chemistry used in electric vehicle Li-ion batteries is NMC. The energy density of cells with NMC cathodes increases with increasing nickel content. On these grounds, there are reasons to believe that density is also continuing on an upward trend. While Li-ion technology has made tremendous progress over the past decade in terms of energy density, costs and cycle life, room for improvement remains. Research is being conducted to improve all three key components of Li-ion battery cells: cathodes, anodes and electrolytes. In addition, recent developments in battery design and thermal management aim primarily to cut the costs of the pack and module components.

Promising avenues for advanced battery technologies arise, but not without trade-offs

The next generation of Li-ion battery technology, set to enter the market in the coming five to ten years, is likely to have low nickel content and use either NCA (with less than 10% nickel) or NMC 811 cathodes. Near-term developments should enable cell-level energy densities of up to 325 Wh/kg and pack-level energy densities could reach 275 Wh/kg. These values approach the upper performance bounds of Li-ion technology.

However, some electric vehicles might not necessarily be designed for the highest possible energy density. This might be the case for urban buses or delivery vehicles where volumetric constraints are less stringent, or for low-end electric vehicles where affordability is more important than long driving ranges. For these applications, the LFP cathode could be well suited.

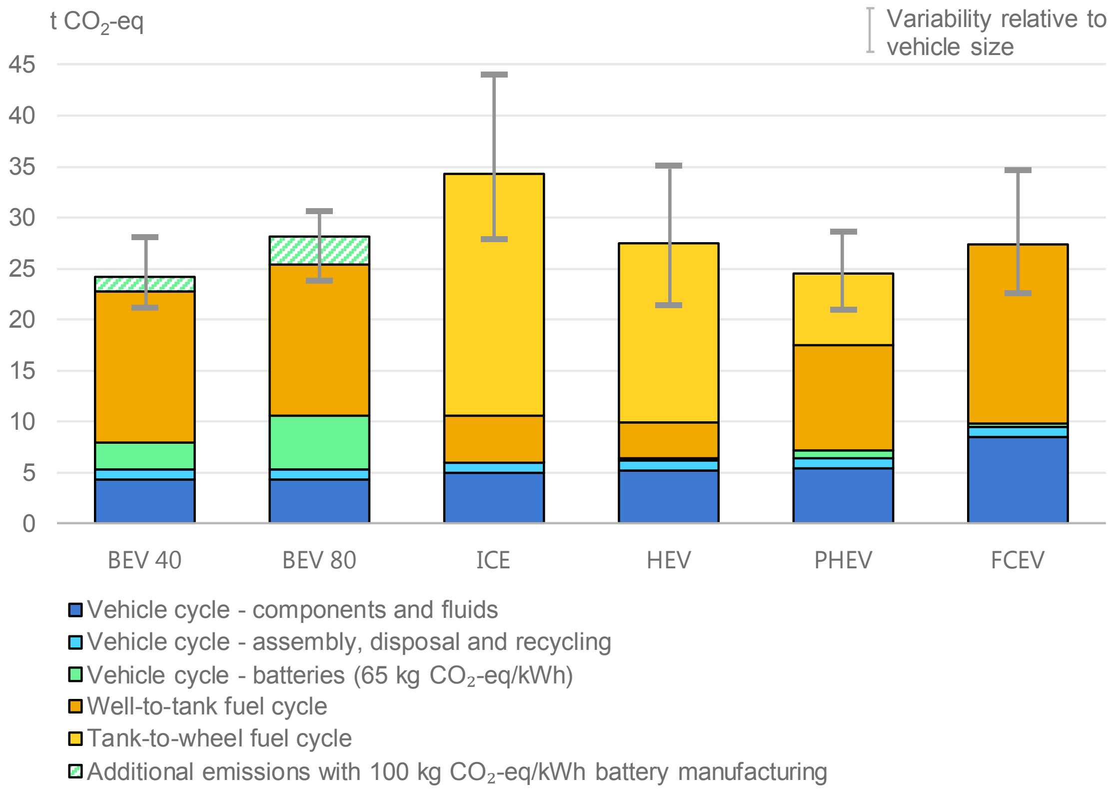
For the next decade, the Li-ion battery is likely to dominate the electric vehicle market. For the period after 2030, a number of potential technologies might be able to push the boundaries beyond the performance limits imposed by Li-ion battery technology. These include the lithium-metal solid state battery, lithium-sulphur, sodium-ion or even lithium-air, which could represent an improvement from Li-ion on indicators such as cost, density, cycle life, and benefits from more widely available materials than Li-ion technologies. However, not a single technology reaps all these benefits at the same time. In addition, even once performance is proven in the lab, deployment and scale-up of these new technologies will take time and compete with the well-established Li-ion technology, which by now benefits from considerable experience in its large-scale manufacture and solid understanding of its long-term durability characteristics, and of substantial investments already made.

As volumes and ranges increase, an appropriate battery value chain is important for ensuring that electric vehicles continue to contribute to sustainability goals

Considering the life-cycle greenhouse gas emissions of available powertrains, analysis suggests that:

- Today the use phase is the largest contributor to life-cycle greenhouse gas emissions of all powertrains.
- With a greenhouse gas intensity of electricity generation equal to the current global average, battery electric vehicles, hybrid electric vehicles and fuel cell electric vehicles have similar lifetime greenhouse emissions, and lower than those of an average internal combustion engine vehicle.
- Increasing the range of a battery electric vehicle reduces its relative benefits compared to internal combustion engine vehicles or fuel cell electric vehicles.
- As the electricity supply decarbonises and serves both battery manufacturing facilities and charging, the benefits of lower life-cycle greenhouse gas emissions of electric cars amplify relative to other powertrains.

Comparative life-cycle greenhouse gas emissions over ten year lifetime of an average mid-size car by powertrain, 2018



Notes: The powertrains considered are globally representative: mid-size versions of an ICE car, a hybrid car, a plug-in hybrid electric car with 60% of its lifetime mileage driven on electricity and 40% on gasoline, a BEV with a 40 kWh or a 80 kWh battery, and a fuel cell electric vehicle with a hydrogen supply primarily sourced from steam methane reforming of natural gas. The CO_2 intensity of the electricity used to power the electric powertrains is based on the global average in 2018. For more details, see figure 4.2 in the main report.

Sources: IEA analysis based on ANL (2018); Kelly et al. (2019); IEA (2019a); IEA (2019b).

On a global average, battery electric vehicles provide life-cycle greenhouse gas emissions benefits relative to internal combustion engine vehicles. Decarbonising fuel used in a vehicle is the biggest potential area for life-cycle emission reductions for all powertrains.

In the global average example in the figure, in a current battery electric vehicle with a large battery (80 kWh) manufactured in China (representative of high greenhouse gas intensity of battery manufacturing), the battery can be responsible for up to a third of the vehicle's life-cycle emissions. The main areas of action to reduce battery manufacturing emissions and life-cycle impacts are:

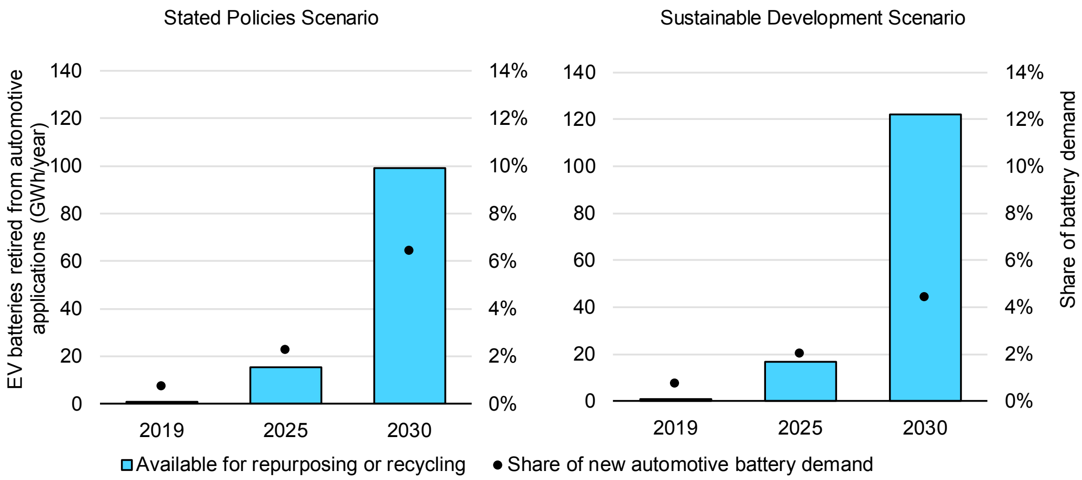
- Increase the energy density of batteries.
- Scale up manufacturing facilities and increase throughput.
- Increase energy efficiency and use low-carbon energy sources in mining and refining processes for raw materials, especially for aluminium, and in synthesis of active materials such as nickel, cobalt and graphite.

- Increase energy efficiency and use low-carbon energy sources in cell manufacturing and pack assembly.
- Ensure appropriate end-of-life battery management.

How batteries are used, recycled, or disposed of after their electric vehicle application affects their life-cycle impacts

Based on the two scenarios, it is estimated that 100-120 GWh of electric vehicle batteries will be retired by 2030, a volume roughly equivalent to current annual battery production. Without effective measures to address such volumes, this can become a significant environmental liability. Spent batteries can be channelled to second-use or recycling with the aid of policies that help to steer these markets towards sustainable end-of-life practices.

Automotive battery capacity available for repurposing or recycling, 2019-30



Notes: For details, see table 4.3 in the main report.

Spent battery availability in 2030 is projected to be comparable to current production volumes.

Battery reuse in second-life, stationary storage applications for services to electricity network operators, electric utilities, and commercial or residential customers can extend the lifetime of batteries that are no longer suited for automotive applications. Extending the useful life of automotive batteries can contribute to displacing the environmental impacts, emissions and costs of manufacturing new batteries for the provision of the same services. However, there is little experience to date from this nascent market. Challenges in implementing second-life applications for automotive batteries reside primarily in competition with the decreasing cost of new battery manufacturing and a potentially long and technical refurbishing process that requires efficient technical information transfer between the stakeholders along the value chain. An industry is starting to emerge, made up of stakeholders from original equipment manufacturers, utilities and specialised start-ups.

As volumes of spent electric vehicle batteries increase, the development of an effective recycling industry will be key to the sustainability of Li-ion batteries. By recovering critical materials, a robust recycling system would reduce demand for raw materials, greenhouse gas emissions and negative local impacts from mining and refining. Furthermore, domestic recycling enables countries to reduce their reliance on imports of critical materials. So far, economic viability and market incentives for recycling have been limited because of generally low raw material prices and small volumes of spent electric vehicle batteries to date. However, as the growing market for electric vehicles puts further pressure on primary resources, raw material prices could increase and/or prices may become more volatile. Thus, materials recovered through recycling would become more competitive. The economic and strategic value of essential inputs, such as lithium and cobalt, may incentivise recycling in the long term and steer recycling policies.

It is estimated that current recycling facilities using mainstream recycling technologies such as pyrometallurgy and hydrometallurgy, may add a limited greenhouse gas footprint to an electric vehicle battery (about 10%), compared to a battery manufactured from primary raw materials. Research points towards a net benefit when considering non-greenhouse gas indicators such as ecotoxicity. The scale-up of Li-ion battery recycling facilities, driven by electric vehicle deployment, as well other energy efficiency measures and renewable energy input into recycling processes will be necessary to significantly reduce greenhouse gas emissions from battery recycling. New, innovative recycling processes using less energy, and adequate sorting and separation of battery pieces that need recycling or that can directly be repurposed or repackaged into new batteries are also under research.

The policy landscape for battery end-of-life is evolving in key regions

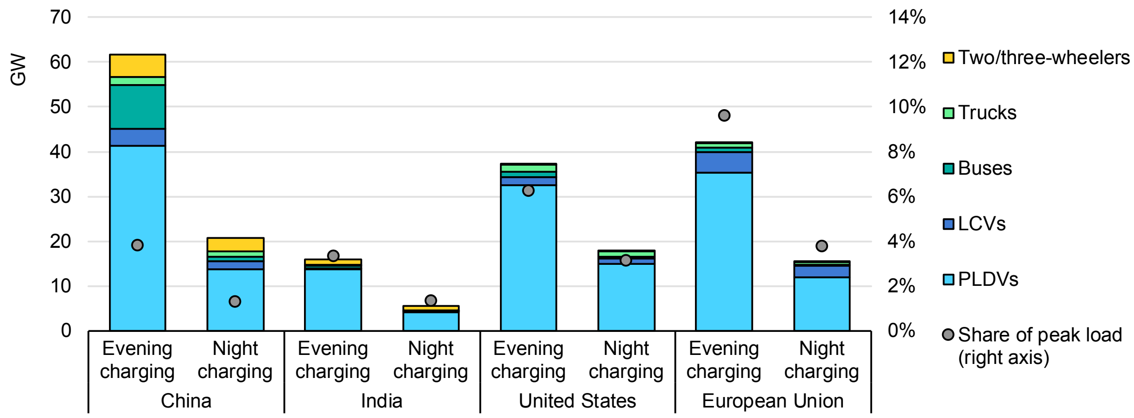
Recent policy developments highlight an increased focus on the projected large-scale deployment of batteries for automotive applications and their life-cycle impacts. Battery collection and recycling policies have usually focused on other industries and battery technologies than the Li-ion batteries used in electric vehicles, such as consumer electronics or lead-acid batteries. Hence, they are not designed for electric vehicle battery end-of-life. In 2019, China mandated producer responsibility, holding them responsible for the recycling, as well as the reverse logistics involved in taking back the Li-ion batteries. The European Union is currently reviewing its Battery Directive to adapt to transport electrification through identifying improvements and assessing the relevance, effectiveness, efficiency, coherence, and added value of the policy; it has set up a Battery Alliance to discuss further measures with key stakeholders. In the United States, the California Assembly Bill 2832 requires the formation of a Lithium-Ion Car Battery Recycling Advisory Group to advise the legislature on electric vehicle Li-ion battery recycling policy. These developments, along with private sector innovation, are expected to push forward battery end-of-life solutions.

Integrating electric vehicles with power systems can benefit both

Balancing electricity demand and supply will become an increasing challenge to ensure the smooth integration of variable renewables-based energy generation and the electrification of multiple end-use sectors. The uptake of electric vehicles in the Sustainable Development Scenario, in which electric vehicles account for around 4% of global annual electricity demand by 2030 (up from 0.3% today), brings implications and opportunities for power systems.

Over the coming decade, managing electric vehicle charging patterns will be key to encourage charging at periods of low electricity demand or high renewables-based electricity generation. With 250 million electric vehicles on the road by 2030 in the Sustainable Development Scenario, the share of electric vehicle charging in the average evening peak demand could rise to as high as 4-10% in the main electric vehicle markets (China, European Union and United States), assuming unmanaged charging. A range of ready options with various degrees of complexity can be tapped to reduce electric vehicle charging at peak system demand, thereby diluting the need for upgrades to generation, transmission and distribution assets. While off-peak charging at night through simple end-user programming and/or nighttime tariffs would more than halve the contribution of electric vehicles to peak demand, controlled charging in response to real-time price signals from utilities (V1G) could further exploit synergies with variable renewable electricity generation and expand the range of services electric vehicles offer to the grid.

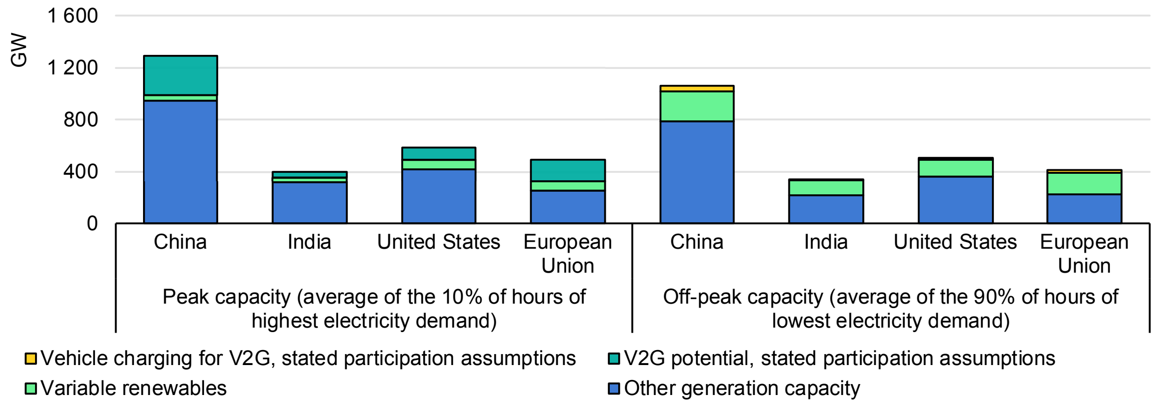
Contribution of electric vehicles to hourly peak demand by country/region in the evening and night charging cases in the Sustainable Development Scenario, 2030



Shifting electric vehicle charging practices to avoid peak hours could reduce the contribution of electric vehicles to peak demand to less than 4% in 2030 in the Sustainable Development Scenario.

Not only are there means to alleviate the potentially negative impact of electric vehicle charging on power systems, but the 16 000 GWh of energy that can be stored in electric vehicle batteries globally in the Sustainable Development Scenario in 2030 could actively provide energy to the grid at suitable times via vehicle-to-grid solutions (V2G). The V2G potential depends on availability of vehicles or vehicle fleets to participate in such services at suitable times, consumer acceptance, and the ability for participants to generate revenues, as well as other technical constraints related to battery discharge rates or impacts on battery lifetime. All being accounted for, an estimated 5% of the total electric vehicle battery capacity could be made available for vehicle-to-grid applications during peak times. This could provide about 600 GW of flexible capacity globally by 2030 across China, the United States, the European Union and India, contributing to offset lower renewable electricity generation during peaks as well as the increase of capacity needs to meet peak demand.

Vehicle-to-grid potential and variable renewable capacity relative to total capacity generation requirements in the Sustainable Development Scenario, 2030



Notes: Analysis represented in this figure is based on the EV deployment rates in the Sustainable Development Scenario and assumptions of V2G capacity potential. For more details, see figure 5.5 in the main report.

Vehicle-to-grid services could unlock up to 600 GW of flexible capacity distributed across the main electric vehicle markets in 2030 and moderate intermittency of variable renewables during peak demand.

As a result, simple solutions can be implemented via relatively straightforward forms of policy support to largely alleviate peak time charging, such as the promotion of workplace charging or the use of off-peak tariffs. However, unlocking the full flexibility potential of electric vehicles through dynamic controlled charging (V1G) and vehicle-to-grid services (V2G) to reap synergies with variable renewable generation and reduce electricity generation capacity needs would require the adaptation of regulatory and market frameworks. Currently, flexible electric vehicle integration is not on track for power systems to accommodate the distributed loads that electric vehicle batteries represent in a co-ordinated way and on a large scale. Specific stakeholders such as aggregators, along with business models that make use of new regulatory frameworks to reward electric vehicle owners for providing flexibility services are also needed for electric vehicle batteries to contribute to the power system stability on a significant scale.

Introduction

Electric vehicles (EVs), including full battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) have been gaining traction thanks to their ability to deliver multiple environmental, societal and health benefits. These include:

- Energy efficiency: EVs are three-to-five times more energy efficient than conventional internal combustion engine (ICE) vehicles. This provides unmatched energy efficiency improvement potential for vehicle road transport.
- Energy security: Electric mobility boosts energy security as it transitions the road transport sector from its strong reliance on oil-based fuels. It reduces dependence on oil imports for many countries. Furthermore, electricity can be produced with a variety of resources and fuels, and is often generated domestically.
- Air pollution: Thanks to zero tailpipe emissions, EVs are well suited to address air pollution issues, especially in urban areas and along road networks, where a large number of people are exposed to harmful pollutants from road transport vehicles.
- GHG emissions: Increasing electric mobility in association with a progressive increase in low-carbon electricity generation can deliver significant reductions in GHG emissions from road transport relative to ICE vehicles. In addition, EVs can play an expanded role through their use to provide flexibility services to power systems and act in concert with the integration of variable renewable energy sources for electricity generation.
- Noise reduction: EVs are quieter than ICE vehicles and hence contribute to less noise pollution, especially in the two/three-wheeler category.
- Industrial development: EVs are crucially positioned as a potential enabler of major cost reductions in battery technology, one of the key value chains of strategic importance for industrial competitiveness, given its relevance for the clean energy transition.

These and other advantages of electric vehicles have led to growing global deployment and increased understanding of the challenges and opportunities of electric mobility over the last decade. While in some countries the transition to electric mobility is still at an early phase, in several of the world's largest car markets the EV fleet is expanding at a fast pace. The cost of batteries and EVs is dropping and EV infrastructure is being installed in many places, which supports the case for EVs across transport modes (buses, taxis and shared vehicles, light-duty vehicles (LDVs), two/three-wheelers and heavy-duty vehicles with short range requirements such as urban deliveries). The range of models from which consumers can choose has also continued to expand as manufacturers have launched new vehicles and announced the roll out of several new models in the near future. Nevertheless, effective policies are important to decrease the upfront investment cost gap, to promote charging infrastructure and to ensure a smooth integration of EV charging demands into power systems. The foundations for enabling the transition to electric mobility across several large economies having been laid, there are strong prospects for the 2020 decade to become the decade for electric mobility.

This report provides an update of the status of the transition to electric mobility worldwide. It considers the factors that have influenced recent developments in electric mobility, the dynamics behind the rapid evolution, the impacts on future prospects to 2030 for electrification and the implications for policy developments.

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 electric vehicles, the EVI is dedicated to accelerating the deployment of electric vehicles worldwide. To do so, it strives to improve the understanding of the policy challenges that come with electric mobility, helping governments to address them and serving as a platform for knowledge-sharing, taking into account important transformations that are occurring in the transport sector.

The EVI facilitates exchanges between policy makers working in governments that are committed to supporting EV development and a variety of partners, bringing them together twice a year. Its multilateral nature, its openness to various stakeholders and the development of activities looking at different levels of governance (country and city-level in particular) offer interesting opportunities to exchange information and learn from experiences developed by a range of actors in the transition to electric mobility.

Governments that have been active in the EVI in the 2019-20 period include Canada, Chile, the People's Republic of China (hereafter "China"), Finland, France, Germany, India, Japan, Netherlands, New Zealand, Norway, Sweden and United Kingdom. Canada and China are the co-leads of the initiative. The International Energy Agency serves as the EVI co-ordinator.

EV30@30 Campaign

The EV30@30 Campaign was launched at the 8th Clean Energy Ministerial meeting in 2017 with the goal of accelerating the deployment of electric vehicles. It sets a collective aspirational goal for all Electric Vehicle Initiative members of a 30% market share for electric vehicles in the total of all vehicles sales (except two-wheelers) by 2030. This will be the benchmark against which progress achieved in all members of the EVI will be measured.

Eleven countries endorsed the campaign: Canada; China; Finland; France; India; Japan; Mexico; Netherlands; Norway; Sweden and United Kingdom. In addition, 29 companies and organisations support the campaign: C40; FIA Foundation; Global Fuel Economy Initiative; Hewlett Foundation; Natural Resource Defence Council; REN21; SLoCaT; The Climate Group; UN Environment; UN Habitat; World Resources Institute; ZEV Alliance; ChargePoint; Energias de Portugal (EDP); Enel X; E.ON; Fortum; Iberdrola; Renault-Nissan-Mitsubishi Alliance; Schneider Electric; TEPCO and Vattenfall.

Global EV Pilot City Programme

The Global EV Pilot City Programme, launched in May 2018, at the 9th Clean Energy Ministerial, is one of the implementing actions of the EV30@30 Campaign. It aims to build a network of at least 100 cities over an initial period of five years, to work together on the promotion of electric mobility. Its central pillars are to facilitate information exchange among cities and to encourage the replication of best practices, for example through webinars and workshops. Another important element is to use the network to build on experience gained by creating analytical outputs and reports to help cities and other stakeholders learn from previous experiences of member cities.

The IEA and the Shanghai International Automobile City (SIAC) serve as the joint secretariat of the EVI Global EV Pilot City Programme.

A key activity under the Pilot City Programme in 2020 is the delivery of the EV City Casebook and Policy Guide (the Casebook). The Casebook is a joint project under the EVI and the Hybrid Electric Vehicles Technology Collaboration Programme (HEV TCP) and will include policy recommendations for local governments interested in supporting the deployment of electric vehicles as well as showcasing large-scale electrification projects from across the world.

To date, 41 cities are participating in the Global EV Pilot City Programme:

Global EV Pilot City Programme members

Country	Cities
Canada	Calgary, Halifax Regional Municipality, Montréal, Stratford, Surrey, Richmond, Winnipeg, York
Chile	Santiago de Chile
China	Beijing, Rugao, Shanghai, Shenzhen, Yancheng
Colombia	Medellín
Finland	Helsinki, Espoo, Oulu, Tampere, Vantaa
Germany	Offenbach am Main
India	Pune
Japan	Aichi, Kanagawa, Kyoto, Tokyo
Netherlands	Amsterdam, the Hague, Rotterdam, Utrecht and Metropolitan Region Amsterdam
New Zealand	Christchurch, Hauraki
Norway	Oslo
Sweden	Stockholm
Thailand	Betong, Nonthaburi
United Kingdom	Coventry, Dundee, London
United States	New York City

Drive to Zero Campaign

The EVI Advisory board approved in November 2019 to suggest a new CEM Campaign focused on the deployment of zero-emission and near-zero commercial vans (medium and heavy duty), the 'Commercial Vehicle Drive to Zero Campaign' (Drive to Zero Campaign). It aims to bring together governments, and leading stakeholders such as manufacturers and fleet users, to work collaboratively to set in place requirements, policies, and programs that can support electrification of commercial vehicles. The Campaign is to be launched at the next Clean Energy Ministerial in 2020. Its operating agent is CALSTART.

GEF-7 Global Programme on electromobility

In late 2020 or early 2021, the GEF-7 Global Electric Mobility Programme (the Programme) will be launched. The Programme is funded by the Global Environment Facility (GEF) and aims to support low and middle-income countries with a shift to electromobility. Within the Programme, there are currently 1 global project and 27 country projects that will be implemented over a five-year period. The IEA will together with UN Environment (UNEP) lead the global project, which aims to expand and complement the work under EVI. Under the global project, the IEA and UNEP will, through a number of working groups (light-duty vehicles, two/three-wheelers, heavy-duty vehicles and system integration and batteries), produce knowledge products to help transferring experience and knowledge to the country projects. Knowledge transfer will be supported by regional platforms (Africa, Asia, Europe and Latin America/Caribbean). In addition, the data tracking framework used for the *Global EV Outlook* publications will be extended to the countries under the Programme. The Programme will in parts be implemented in collaboration with the EC Solutions Project – a project funded by European Union's Horizon 2020 focused on EV deployment in urban areas.

Clean Energy Ministerial Horizontal Accelerator for power system integration of EV infrastructure

The Clean Energy Ministerial Horizontal Accelerator for Power System Integration of EV Infrastructure (CEM Horizontal Accelerator) was launched in 2019 as a new mechanism for strengthening the collaboration and capitalising on the synergies between four CEM work streams involving the International Smart Grid Action Network (ISGAN), the 21st Century Power Partnership (21CPP), the Electric Vehicle Initiative (EVI) and the Power System Flexibility (PSF) Campaign. The CEM Horizontal Accelerator is a step towards developing a cross-sectoral and holistic approach to power system integration. Project participants consist of a transdisciplinary group of international experts and sector stakeholders from different levels of government, research and industry with complementary knowledge and insights into the EV-power system nexus.

Scope, content and structure of the report

This report analyses the development of the global EV market to May 2020. It includes recent policy developments for the main markets relevant for EV and supply equipment for deployment, technology development and the outlook for EVs to 2030. It focuses on electric vehicles, including full battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) used in road transport applications. Its geographic scope attempts to be as broad as possible, as data availability permits.

The analyses are presented in five chapters:

- Chapter 1 looks at trends in electric mobility, highlighting the electric mobility developments in the 2010s covering EV registrations (vehicle sales) and stocks, including data for the first months of 2020 when available. It discusses the underlying factors that have been driving demand. It summarises the early impacts Covid-19 has had on the auto industry and more particularly on EV markets.
- Chapter 2 looks at existing policies and strategies to deploy electric vehicles and charging infrastructure. It highlights electric vehicle policies in place today as well as updates since *Global EV Outlook 2019*. It includes a special focus on the deployment of electric buses in cities compiling findings from four case studies. It also covers industry announcements.
- Chapter 3 presents the outlook to 2030. It focuses on projections of EVs and chargers, evaluating the impacts that these have on energy use, well-to-wheel greenhouse gas emissions, battery production volumes and material demand. It does so in the context of two scenarios, the Stated Policies Scenario and the Sustainable Development Scenario, plus it explores possible effects of the Covid-19 pandemic on EV deployment to 2030.
- Chapter 4 focuses on current and future EV battery technology developments and life-cycle impacts, including reuse and recycling. It concludes with policy recommendations.
- Chapter 5 focuses on the integration of EVs with power systems with an overview of possible approaches to optimise it and reap benefits from synergies between EVs and variable renewable electricity generation. It concludes with policy recommendations

Chapter 1. Trends in electric mobility

Electric mobility developments in the 2010s

Oil was the predominant energy source in the transport sector, providing 92% of final energy over the past decade, down only two percentage points from 1973. Increased demand for transport for people and goods called for more oil use, which was accompanied by increased carbon dioxide (CO_2) emissions. Today the transport sector is responsible for nearly one-quarter of global energy-related direct CO_2 emissions and is a significant contributor to air pollution. Global and local objectives and commitments to improve climate and air quality underscore that the transport sector has a critical role to play.

Even with the ongoing dominance of oil products in transport, these drivers drove rapid change. Over the last decade momentum accelerated to deploy a range of powertrains and alternative fuels. The 2010s were ground breaking for the introduction of electric vehicles[1] and to shape a promising nascent market. Electrification is a key technological strategy to reduce air pollution in densely populated areas and a promising option to contribute to countries' energy diversification and greenhouse gas (GHG) emissions reduction objectives. Electric vehicle benefits include zero tailpipe emissions, better efficiency than internal combustion engine (ICE) vehicles and large potential for GHG emissions reduction when coupled with a low-carbon electricity sector.

Hitting the commercial market in the first-half of the decade, the sales of electric cars[2] have soared over the last five years. The top sellers were both fast growing emblematic companies such as Tesla as well as established automakers such as Nissan (Leaf model) and Renault (Zoe model). Notably, a rapidly developing industry in the People's Republic of China (hereafter, "China") had the biggest impact on electric car sales.

Only about 17 000 electric cars were on the world's roads in 2010. Just five countries could count more than 1 000 on their roads: China, Japan, Norway,

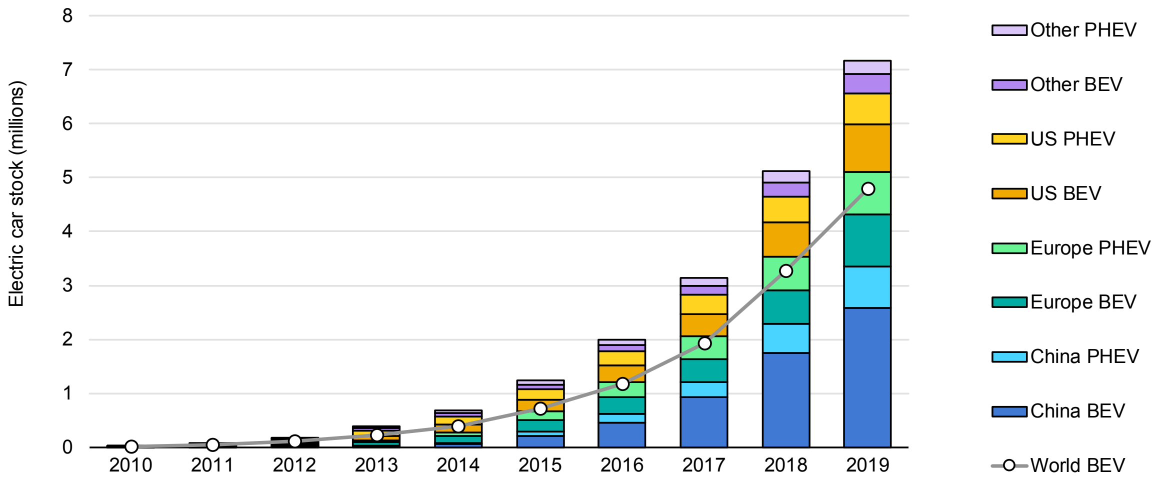
[1] The term electric vehicle includes battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs). This report focuses on BEVs and PHEVs, i.e. electric vehicles that are fuelled with electricity from the grid. All figures and discussion exclude FCEVs unless otherwise stated.

[2] In this report, "electric car" or "passenger electric car" refers to either a battery electric vehicle (BEV) or a plug-in hybrid electric vehicle (PHEV) in the passenger light-duty vehicle (PLDV) segment. It does not include hybrid electric vehicles (HEVs) that cannot be plugged-in.

United Kingdom and United States. The electric vehicle (EV) market was in its infancy and made up of early adopters.

Yet by 2019 there were about 7.2 million electric cars on the world's roads. Nine countries had more than 100 000 electric cars on the road (Figure 1.1). The global stock remains concentrated in China, Europe and United States. At least 20 countries reached market shares[3] above 1% in 2019.[4]

Figure 1.1 Global electric car stock, 2010-19



Notes: PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. Other includes: Australia, Brazil, Canada, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand. Europe includes: Austria, Belgium, Bulgaria, Croatia, Cyprus,[5,6] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

Sources: IEA analysis based on country submissions, complemented by ACEA (2020); EAFO (2020c); EV-Volumes (2020); Marklines (2020); OICA (2020); CAAM (2020).

In 2019, the global electric car stock reached 7.2 million units. Over the five-year period (2014-19), the annual average increase was 60%.

[3] Market share is defined in this report as the share of new EV registrations as a percentage of total new vehicle registrations, whereas stock share refers to the share of EV stock as a percentage of total passenger vehicle stock.

[4] These include: Australia, Belgium, Canada, China, Denmark, Finland, France, Germany, Iceland, Israel, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Thailand, United Kingdom, and United States.

[5] Note by all the European Union Member States of the Organisation for Economic Co-operation and Development and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[6] Note by Turkey: 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. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

EVs are becoming commonplace in many cities across the world. Moreover, electrification of transport is occurring across multiple modes. These include personal cars, taxi, car-sharing, ride-hailing and municipal fleets, urban buses, two/three-wheelers (especially in Asia), and increasingly in commercial and freight vehicle segments.

Governments have introduced a range of ambitious policies to support and structure a nascent EV industry. These include approaches to reduce adoption barriers and to promote deployment of the needed charging infrastructure. Achievements in technology advances and market development coalesce with the objectives of a number of policy makers, industry players and civil society to portend further acceleration of EV deployment in the 2020s which may significantly transform the road transport sector.

The initial policy focus of many governments addressed early adoption barriers, in particular the higher upfront cost of EVs relative to conventional vehicles, the availability of charging infrastructure, range anxiety and limited consumer knowledge about the technology. Incentives for EV purchases and measures to support market development such as installing publicly accessible chargers and procurement programmes for public vehicle fleets were key approaches to tackle barriers during the initial phase. When it comes to supporting EV adoption, differentiated vehicle taxation based on their environmental performance exists in a number of countries, enabling an EV support mechanism that tends towards revenue-neutrality.

In recent years, many policies have started to shift towards regulatory signals to set out a vision for the longer term. These include EV mandates, such as the Zero Emission Vehicle (ZEV) mandate in California and the ZEV States,[7] as well as the New Energy Vehicle (NEV) mandate in China. These initiatives have typical target timeframes of 2015, 2030 and/or 2040.[8] In addition, stringent vehicle fuel-economy regulations and/or CO_2 emissions regulations (e.g. European Union) provide strong impetus for vehicle electrification. In 2019, these three policies (i.e. US states ZEV mandates, China New Energy Vehicle [NEV][9] and EU CO_2 emissions regulation)

[7] States with zero-emission vehicle (ZEV) mandates include California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont and, as of March 2020, Washington in the United States. For further information, see Chapter 2, section on US EV policies. The provinces of Québec and British Columbia in Canada also have ZEV mandates in place.

[8] For further details, see Annex B.1 and Annex B.2.

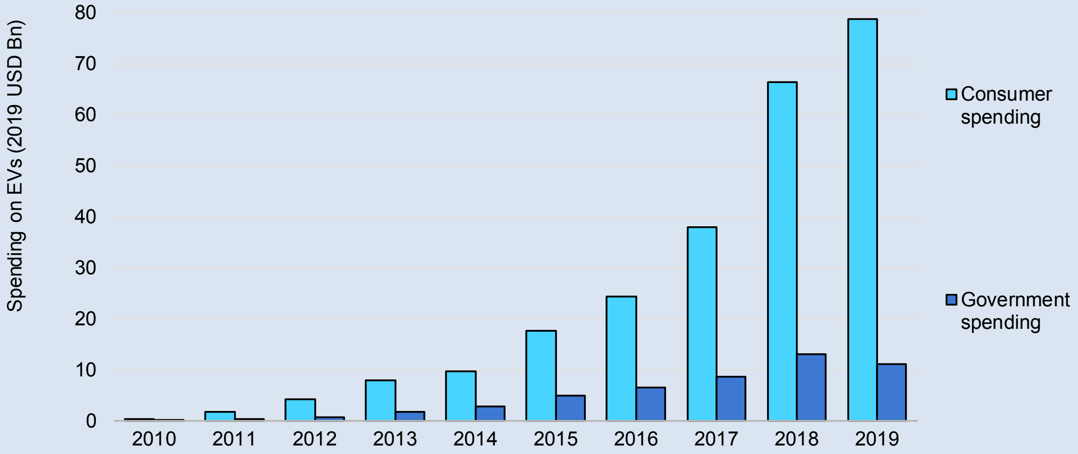
[9] For a discussion of the definition of New Energy Vehicles (NEVs) in China and the regulatory framework that applies to them, see the country policy profile of China in Chapter 2.

covered about 60%[10] of the global car market.[11] In addition, 17 countries have announced 100% ZEV targets or the phase-out of ICE vehicles through 2050 (see Chapter 2, Table 2.1).[12] Many cities around the world have announced or are looking to establish zero-emission zones or bans on ICE vehicles, which have the potential to steer electric car purchase decisions far beyond those urban borders.[13]

Box 1.1 Government and consumer spending on electric cars

Spending on electric cars expanded significantly over the last decade. In 2019 it totalled USD 90 billion, a 13% increase from the previous year.

Spending on electric cars by consumers and national governments, 2010-19



Notes: Government incentives are the sum of direct government spending through purchase incentives and foregone revenue due to taxes waived specifically for electric cars. Consumer spending is the total expenditure based on model price, minus government spending. Only national government purchase support policies for electric cars are taken into account.

Sources: IEA analysis based on Marklines (2020); IEA (2019a); EV-Volumes (2020).

[10] In 2019, China represented about 30% of the global passenger car market, European Union accounted for 23%, the US states with ZEV mandates represented 7% (IEA, 2020a; ICCT, 2019a).

[11] It is worth noting that about 85% of global light-duty vehicle sales are in markets with fuel-economy standards and/or CO_2 emissions (but 25% of these sales are in countries without ZEV mandates).

[12] To date, only a limited number of these announcements have been adopted into law.

[13] For further information on announcements made in local jurisdictions, see table 2.4 in *Global EV Outlook 2018* (IEA, 2018b).

Direct consumer spending

The 2019 increase in consumer spending was driven by an increase in overall sales (up 6% from 2018) and by a higher average electric car price. The increase in price was due to a higher share of electric cars sold in Europe (25% in 2019 versus 18% in 2018), which on average are 50% more expensive than their counterparts In China.

Government spending

Governments represent a substantial part of the spending on EVs through incentive schemes and tax waivers. The recent trends in government spending and direct consumer spending have diverged: while government expenditure contracted by 15% to USD 11 billion in 2019, consumer expenditure increased by 19% to USD 79 billion. Globally, the share of government spending decreased from 17% in 2018 to 12% in 2019. Changes to incentive schemes in the United States and China have driven the drop in government spending, as discussed in the next section.[14]

While government expenditure in Europe increased, decreases were observed in China and the United States because average European incentives are on the lower end of the spectrum, at around USD 4 000 per vehicle (with the exception of Norway, where incentives, in the form of tax exemptions, are much higher).

Despite tremendous sales growth over the last decade, the number of electric passenger cars still represents only a small fraction (under 1%) of all cars in circulation worldwide. Electrification of vehicles is proceeding in parallel with other important trends such as the popularity of large and more fuel consuming cars in many markets (IEA, 2019a).[15] There are strong examples of EVs already being established or emerging in specific contexts; for example the dominance of electric two/three-wheelers in China, the near fully electrified bus and taxi systems in some Chinese cities, and EV sales dominating the car market in Norway.

[14] China's central government subsidy levels decreased by about half between 2018 and 2019. In the United States, the federal tax incentives decreased; vehicles from Tesla and General Motors did not receive the full tax credit of USD 7 500 for BEVs in 2019, as they had reached their quota of 200 000 vehicles sold.

[15] Large EV models, in particular sport utility vehicles (SUVs) are increasing their penetration levels in the range of models that automakers offer (see Chapter 2, Expansion of electric car models).

Electric car market in 2019: Annual growth slows, but market share increases

Electric car market in 2019

The global stock of electric passenger cars continued to expand at a rapid pace in 2019, reaching 7.2 million units, 40% higher than in 2018. While significant, this pace was slower than in previous years as the stock expanded by 63% in 2018 and 58% in 2017. Over the last decade, only in 2019 was the year-on-year growth below 50%. Battery electric vehicles (BEVs) accounted for 67% of the world's electric car fleet in 2019.

Nearly half (47%) of the world's electric car fleet was in China in 2019, up from 45% in 2018. The stock of 3.4 million electric cars in China in 2019 was a 46% increase from the previous year. Europe, with 1.7 million electric cars, accounted for 25% of the global stock in 2019, and 1.5 million units in the United States represented 20%.

By far, Norway was the global leader based on shares of electric cars, at 13% of the total stock in 2019.[16] The second, Iceland, tallied 4.4% of electric cars in total stock. Even with the ongoing expansion of electric car sales, only five countries, including four members of the Electric Vehicle Initiative (EVI),[17] had an electric car stock share higher than 1.5% in 2019: Norway (13%), Iceland (4.4%), Netherlands (2.7%), Sweden (2.0%) and China (1.6%).

Global electric car sales surpassed the 2 million mark in 2019 (2.1 million), just two years after having crossed the 1 million mark in 2017. Worldwide the market share of electric cars reached 2.6% in 2019, an all-time high (up from 2.4% in 2018 and 1.5% in 2017), even though the year-on-year growth in electric car sales saw the lowest value in a decade, dropping to 6%, down from 69% in 2018. China remained the world's largest electric car market at over 50% of global sales; with 1.06 million electric cars sold in 2019, 2% less than the previous year. Europe was the second-largest electric

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[16] In this analysis, EV sales and stock in Norway do not account for second-hand imported electric vehicles (about 10% of passenger car sales in 2019) to avoid double counting with exporting countries. This factor can be explained by the high demand for EVs in Norway, which is a challenge for manufacturers to supply enough vehicles. As a result, there is a trend to import newly registered electric cars from other European countries. A number of second-hand EVs from other countries are also imported in Norway because of their cheaper price relative to new vehicles.
[17] The Electric Vehicles Initiative (EVI) is a multi-government policy forum under the Clean Energy Ministerial dedicated to accelerating the introduction and adoption of electric vehicles. It is co-ordinated by the International Energy Agency. Thirteen countries currently participate in the EVI: Canada, China, Chile, Finland, France, Germany, India, Japan, Netherlands, New Zealand, Norway, Sweden and United Kingdom. For further information, see the introduction to this report.

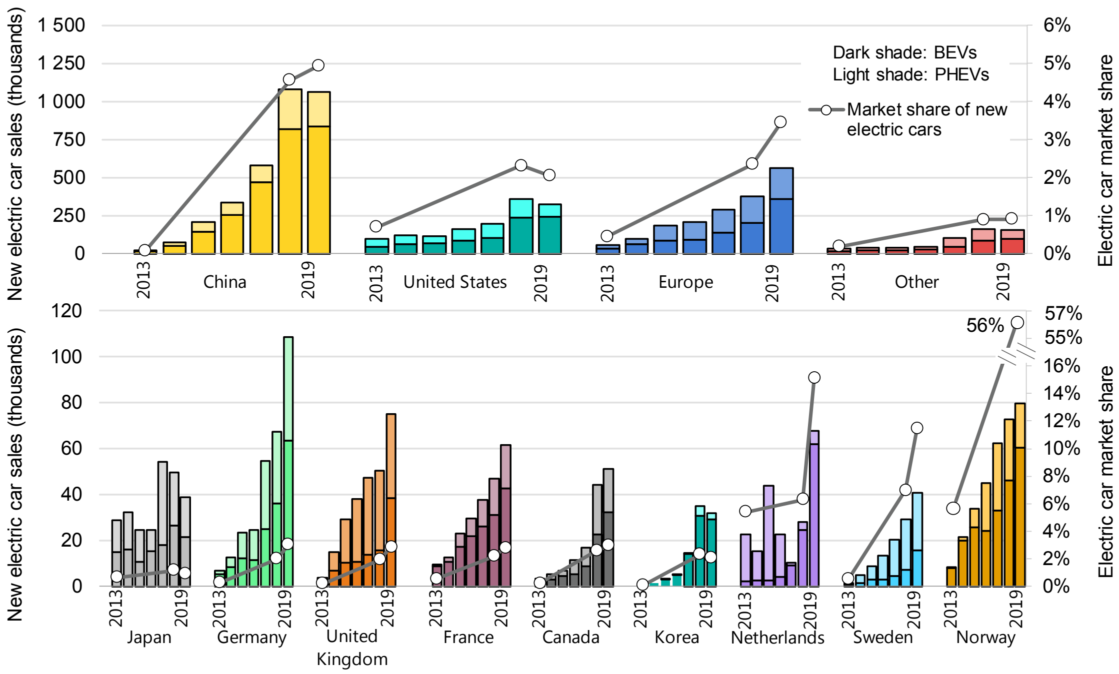
car market in 2019, with sales of 561 000 units. In 2019 in both China and Europe, the market share for electric cars rose to their highest point so far – 4.9% and 3.5% respectively – in the context of declining total car sales. The United States was the third-largest electric car market with sales of 327 000 units.

In Europe, electric car sales in 2019 increased by 50% relative to 2018, a growth rate that is significantly higher than the previous year (32%). Moreover, the countries with the highest shares of electric cars in overall car sales are in Europe. The top two were Norway at 56% and Iceland at 22%. In the Netherlands, the electric car market share increased to 15% in 2019, up from 6% in 2018. Germany surpassed Norway in 2019 for the highest sales volume at 109 000 electric cars (a 61% increase relative to 2018). France, Netherlands and United Kingdom each has sales volumes above 50 000 electric cars in 2019.

Electric car sales in the United States fell by 10% in 2019 versus 2018, when a surge of Tesla Model 3 deliveries made up a very significant portion of new electric car registrations. In Canada, registrations continued to increase (up 15% relative to 2018) to more than 55 000 units in 2019. Japan is the only major electric car market where sales fell for a second year in a row (down 14%); in Korea sales dropped for the first time (down 9%).

Worldwide, BEV sales rose 14% in 2019 relative to 2018, while plug-in hybrid electric vehicles (PHEV) sales declined 10%. BEVs accounted for almost three-quarters of worldwide electric car sales in 2019. The share of BEVs increased steadily from 50% in 2012 to 68% in 2018, closely mirroring the rapid growth in electric car sales in China, which is a market dominated by BEVs (79%). The share of PHEVs in electric car sales dropped in the United States from 34% in 2018 to 26% in 2019, in the context of strong BEV sales. Europe remained a strong market for PHEV sales; they dominated in Finland (76%), Sweden (61%) and constituted nearly half the electric car sales in the United Kingdom (49%). Nonetheless, in 2019, each country represented in Figure 1.2 saw a decreasing share of PHEVs in total electric vehicles sales relative to 2018.

Figure 1.2 Passenger electric car sales and market share in selected countries and regions, 2013-19



Note: Regions and countries in this figure represent the largest electric vehicle markets and are ordered by size of their conventional car market.

Sources: IEA analysis based on country submissions, complemented by ACEA (2020); EAFO (2020c); EV-Volumes (2020); Marklines (2020); OICA (2020); CAAM (2020).

The worldwide market share of electric cars reached a record high of 2.6% in 2019, expanding in all major markets except Japan, Korea and United States.

Forces driving the 2019 trends

Although the sales and market shares of electric cars reached new records in 2019, there was a significant slowdown in the overall growth of electric car sales compared with previous years. There are three underlying reasons: contracting vehicle markets; cuts in electric car purchase subsidies in some key regions; and consumer expectations of further technology improvements and new EV models.

Car markets contract

Total passenger car sales volumes were depressed in 2019 in many key countries. Car markets that were fast growing in the 2010s for all types of vehicles, such as China and India, had lower sales in 2019 than in 2018. In China, total passenger car sales dropped 8% in 2019 on the heels of a 4% decline in 2018 from the previous year. In India, the car market dropped 13% bucking the trend of year-on-year growth rates above 3% since 2014. In the United States, total vehicle sales volumes dipped nearly

2% (Europe differed and saw an uptick of 1% in car sales volumes). Against this backdrop of sluggish sales volumes in 2019, the 2.5% market share of electric cars in worldwide car sales constitutes a record. In particular, China at 4.9% and Europe at 3.5% achieved new records in EV market share in 2019.

Cuts in purchase subsidies

Incentives in the form of purchase subsidies and tax reductions to alleviate purchase costs were key drivers in all expanding electric car markets in the 2010s.[18] There is common understanding that government support for EV purchases can only be transitional, not least because of the potential volume of support needed as sale volumes increase. In the near term, a point will be reached when technology learning and economies of scale will have driven down the purchase costs of EVs and mass market adoption is triggered. Accurately anticipating consumer adoption and technology cost improvements is important to identify financial limits in providing direct support to an increasing number of adopters.[19, 20] In many countries, EV purchases are regularly observed just before subsidy schemes are diminished or eliminated. These can impact monthly and annual sales data, and reflect timely action on the part of EV purchasers to take advantage of subsidies, rather than very short-term consumer interest variations.

China cut subsidies for electric car purchases by about half in 2019 as part of a gradual phase out of direct incentives set out in 2016.[21] The effect on the electric car market was immediate, with a striking fall in sales in July 2019 when the policy change took effect and in subsequent months.[22] In late 2019 a pause in the roll back of the subsidy was proclaimed and in March 2020 it was announced that the subsidiy scheme would be maintained until 2022. The intention is to maintain the EV market, in particular in light of the Covid-19 crisis, although the government retains a near-term plan to phase out subsidies and transition to other policies to support EV market uptake (e.g. NEV mandate, licence plate control, circulation restrictions). The effect

[18] Details on purchase subsidies and tax reductions in selected countries are presented in Chapter 2, Figure 2.2.

[19] There are also revenue-neutral policy mechanisms that aim to balance government support with direct revenue streams from the sale of particularly polluting and/or GHG-emitting cars, for example the Bonus-Malus scheme in France.

[20] These considerations are also relevant when considering a long term, high penetration of alternative powertrain vehicles on the road and their impact on government revenue from fuel taxation. A shift in transport taxation taking into account a diversification of fuels and technologies is an important aspect for governments to take into account. This was extensively discussed in *Global EV Outlook 2019*, Chapter 5, section "Government revenue from taxation" (IEA, 2019b).

[21] After a few years of China gradually reducing EV subsidies, local government subsidies were fully ended and national subsidies were cut by more than half relative to 2018.

[22] The market response to changes (up or down) in direct government support to consumers was discussed extensively in the *Global EV Outlook 2017* (Table 1) (IEA, 2017).

of the 2019 subsidy change on the electric car market therefore may be considered short term, noting that in parallel the government is boosting its 2025 NEV sales target from 15-20% to 25% and tightening the credit allocation to NEVs in its NEV mandate.

Legislation in the United States includes a phase-out schedule for the programme that provides federal tax credits per automaker. The tax credit applies to electric car sales up to 200 000 units, from that point it is phased out over the subsequent year.[23] Electric car manufacturers such as Tesla and General Motors (and some others) reached that cap in 2019 and saw the subsidies applicable to their models decline. Many states are responding to these reductions in federal subsidies by introducing or augmenting EV purchase subsidies (AFDC, 2020a).

Consumer expectations of further technology improvements and new EV models

Significant technology improvements have increased the attractiveness of electric cars for consumers. The 2018-19 versions of some common electric car models such as the Nissan Leaf, Renault Zoe and Tesla display a battery energy density that is 20-100% higher than their equivalents in 2011-12 (BNEF, 2020). Plus, battery costs have decreased by more than 85% since 2010. The range of electric car models on offer has mushroomed; worldwide some 250 models were available in 2019 compared with around 70 in 2014. Another 200 models have been announced and expected to come to market by 2025 (EV-Volumes, 2020).[24] Charging times are also becoming less of a concern, in particular for long distance travel, thanks to technological progress in fast charging (with chargers of 250-500 kilowatts [kW] for cars being deployed or announced, an advance from the 50-120 kW capacity of most current electric car models.)

Today's electric car market profile is evolving from being populated by early adopter and technophile purchasers. Significant potential exists for further technical performance improvements and cost reductions, which places mainstream consumers in the position of being attracted to a product but wondering if it would be wise to wait for the "upcoming and better model" to roll out in the coming years; automakers have announced a diversified menu of coming electric car models, many of which are expected in 2020 or 2021. Examples include the Volkswagen ID.3,

[23] Electric cars receive 100% of the US federal tax credit up to 200 000 sales by car maker, then 50% of the federal tax credit for the following six months, 25% for the following six months after which the tax credit is fully phased out.

[24] See Chapter 2, Expansion of electric car models section.

Toyota RAV4 Prime and Tesla Model Y. With the next expected deliveries of Tesla's Model 3 – its more affordable and mainstream model (in particular in China) – it is possible that consumer interest in EVs will surge.[25]

Box 1.2 Fuel cell electric vehicles

Fuel cell electric vehicles (FCEVs) are a type of electric vehicle in which hydrogen combines with oxygen in a fuel cell to generate the electricity needed to power an electric motor. FCEVs have the potential to be zero-emission vehicles since the utilisation of hydrogen in fuel cells does not generate GHG emissions. However, similar to other EVs that use electricity as an energy carrier, the overall GHG emissions of FCEVs depend on the method used to produce hydrogen. To ensure GHG emission reductions relative to conventional fossil fuels for transport, hydrogen would need to be produced either from fossil fuel technologies coupled with carbon capture and storage or from electrolysis using low-carbon electricity (IEA, 2019c).

FCEV sales have only begun to reach beyond the thousands in the last few years. Policy momentum is accelerating and sales volumes in 2019 were notable. Yet the number of FCEVs currently in use is significantly less than levels of BEVs or PHEVs: for every fuel cell electric car on the road in 2019 there were about 120 PHEVs and nearly 250 BEVs. This reflects diverse factors such as the later introduction of FCEVs to the market, fewer vehicle models on the commercial market and higher investment requirements per refuelling station.

FCEV stock

Total sales of FCEVs in 2019 was 12 350, bringing the global stock to 25 210 units (including passenger cars, buses and trucks) (AFC TCP, 2020). This roughly doubles the figures from 2018, when global sales were 5 800 units and total stock was 12 950 FCEVs.[26]

Passenger cars account for the majority of FCEV sales and stocks. Models from Toyota (Mirai), Hyundai (Nexo) and Honda (Clarity Fuel Cell) dominate the market. BMW plans to start producing a small number of crossovers (Hydrogen NEXT) from 2022. Practically all the FCEVs in Japan, Korea and United States are passenger cars.

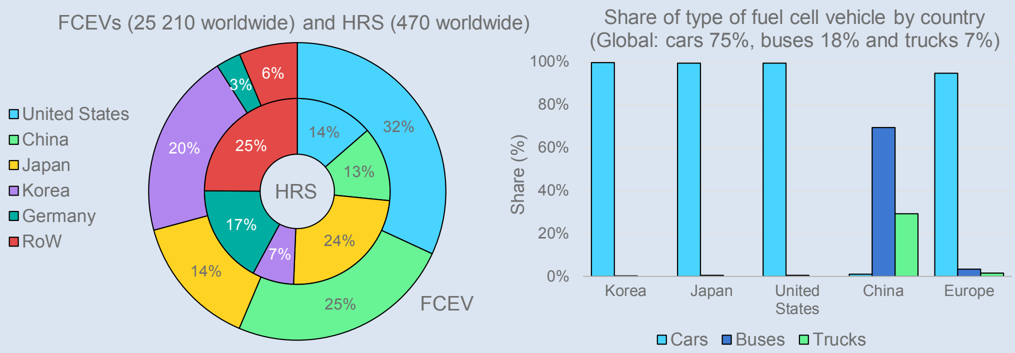
[25] This effect was observed in Japan in 2017. PHEV sales nearly quadrupled relative to 2016 stimulated by the introduction of the next-generation PHEV Prius. This growth rate was unmatched by BEVs in that year or by PHEVs in any other year,

[26] The stock and sales figures include only vehicles already operational at the end of 2019; vehicles ordered but not delivered are not included.

Similarly, the European stock is dominated by cars (almost 95%), although there are also a few buses (80) and trucks (28 light-duty vehicles and eight heavy-duty trucks).[27]

The United States has the highest percentage of the global FCEV stock, mostly cars. But China's stock of FCEVs is escalating reflecting rapid deployment of fuel cell electric buses (from 3 400 in 2018 to 4 300 in 2019) and commercial vehicles (from 1 300 in 2018 to 1 800 in 2019). Fuel cell electric buses account for almost 70% of the current FCEV stock in China and road freight vehicles for most of the remaining 30%, while fuel cell electric cars are only about 1% of the FCEV stock. Thus China dominates the global stock of fuel cell electric buses (97%) and road freight vehicles (98%). By developing refuelling of these commercial vehicles at large and centralised stations that acquire by-product hydrogen from nearby chemical plants, China has effectively implemented the most promising near-term business model to deploy FCEVs at scale in operations with cost competitiveness to other zero-emission technology options (highlighted in *The Future of Hydrogen* (IEA, 2019c)). Few fuel cell electric heavy-duty trucks are in operation, reflecting the limited availability of fuel cell electric trucks models on offer.

Global shares of fuel cell electric vehicles and hydrogen refuelling stations, and shares by vehicle mode and country, 2019



Notes: FCEVs = fuel cell electric vehicles; HRS = hydrogen refuelling stations; RoW = rest of world. Global fleet shares include fuel cell electric passenger cars, buses and trucks.

Source: All fuel cell vehicle data reported in this figure and section are based on the annual data submission of the Advanced Fuel Cell Technology Collaboration Platform (AFC TCP) to the IEA secretariat (AFC TCP, 2020).

[27] Vans with fuel cell range extenders are included within passenger cars figures.

Hydrogen refuelling stations

By the end of 2019, 470 hydrogen refuelling stations (HRS) were in operation worldwide, an increase of more than 20% from the previous year. Japan has the most with 113 HRS stations, followed by Germany (81) and the United States (64). In China, the number of HRS increased threefold in 2019 (from 20 to 61). Currently, deploying HRS require subsidies although some innovative business models are being tested. This is the case in Germany (H2Mobility), where stations are built on a joint venture basis between original equipment manufacturers (OEMs), fuel suppliers and HRS manufacturers.

Favourable total costs of ownership for FCEVs – in particular for long distance and high energy demand heavy-duty vehicle applications where hydrogen fuel cell powertrains are most competitive – depend critically on competitive costs for fuel cell and hydrogen delivery. Cost reductions for fuel cells are expected through mass manufacturing and learning-by-doing. For hydrogen delivery, in addition to the costs of production, transmission and distribution, the size and utilisation rate of a HRS has a critical impact on the final hydrogen delivered price.[28] Achieving high utilisation rates is particularly challenging during the early phase of FCEV deployment, as the HRS siting and scale need to be carefully rolled out to service refuelling demand. Other factors that contribute to the favourable case of FCEVs in long-haul transport are the lower refuelling times and the higher energy intensity of stored hydrogen in FCEVs compared with the other electric vehicle types.

EV markets in 2020: the potential impacts of Covid-19 and government responses

The market developments of the last decade and the shared visions among some policy makers, industry players and civil society suggest a potentially transformative further acceleration of EV adoption during the 2020s. At the outset of this decade, however, the Covid-19 pandemic has disrupted economic activity and markets around the world. How electric vehicles and the road transport sector progress will

[28] The impact of HRS size and utilisation on the delivered price of hydrogen, as well as suggestions for policies and operations that could foster the deployment of FCEVs where they are most competitive in the near term. (Discussed in Chapter 5 of *The Future of Hydrogen* [IEA, 2019c]).

hinge on how consumers and the global EV industry emerge from the crisis and what policy makers do to further bolster EV market uptake.

Many uncertainties surround the pandemic's implications on electric car markets over the next years. The extent and pace of the potential rebound of the auto-industry will depend on a range of factors, including the pace at which confinement measures are eased, potential second waves of the pandemic, the pace of economic recovery and the willingness and ability of consumers and businesses to purchase new cars. Government policy will also be critical (IEA, 2020b).

The impact of Covid-19 on car sales and manufacturing

Overall car sales slumped with the outbreak of Covid-19

To understand market expectations for electric cars, it is important to look at them in the context of overall car market trends. The first four months of 2020 have seen an unprecedented drop in global car sales. Global car sales between January and April this year dropped by about one-third from the same period in 2019, with around 9 million fewer cars sold.

On a monthly basis, the decline in sales was even more pronounced, mirroring the timing and stringency of the lockdowns across many countries. China, the world's largest car market, registered its sharpest year-on-year decline in February. Car sales in China almost always dip in February because of the Lunar New Year holiday. But this year, they plummeted by 80% compared with February 2019.

Other major car markets experienced their heaviest declines in April. In the United States, they roughly halved year on year; in Germany, they dropped about 60%; and in France, they plunged nearly 90%. In the United Kingdom and Italy, sales dropped by 98% in April, signalling a complete breakdown of those markets. For India virtually no car sales were reported.

Initial signs in countries where the lockdown is gradually easing suggest the potential for a quick recovery. In China, policy makers were quick to identify the auto market as a primary target for economic stimulus and encouraged cities to relax car permit quotas, among other measures. Chinese car sales rebounded strongly in April to reach 80% of the level registered in the same month a year earlier. Fears of Covid-19 also were reported to be bolstering sales, with driving generally seen as posing a lower risk of infection than taking public transport. In Korea, where the spread of the virus was contained quickly, car sales actually registered an increase over 2019 levels in both March and April. In the first half of 2020, we currently expect global car sales to be around 30% lower than in the same period last year (IEA, 2020b).

The impact of the crisis on electric car sales in early 2020

The outbreak of the Covid-19 pandemic also brought about a dramatic decline in electric car sales. In China, the drop followed that of overall car sales. The decline was largest in February, with electric car sales falling to 16 000 vehicles, a plunge of around 60% from the same month in 2019. Sales rebounded strongly in April, reaching around 80% of the level they were at a year earlier. In the United States, electric car sales in April more than halved from a year earlier to about 10 000 vehicles.

Electric car sales in European countries bucked the trend of the overall car market for a variety of reasons. 2020 is the target year of the European Union's CO_2 emissions standards, which limit average CO_2 emissions per kilometre driven of new car sales. In addition, Germany increased electric car purchase subsidies in February, and the impacts of the system introduced in Italy in 2019 to encourage electric cars started to affect the market.

The result: in the largest European car markets combined (France, Germany, Italy and the United Kingdom), sales of electric cars in the first four months of 2020 reached more than 145 000 electric cars, about 90% higher than in the same period last year. In Norway, the country with the highest share of electric cars in overall car sales, the number of electric cars sold between January and April 2020 was about the same as in the same period in 2019 (IEA, 2020b).

The impacts of Covid-19 on vehicle manufacturing

Around the world, the reaction to the pandemic shuttered production lines of vehicle manufacturers as well as OEMs along the supply chain. Hubei province is one of China's main hubs for automotive parts production and the area where the coronavirus was first identified, and so the outbreak had an asymmetric impact on manufacturers. Neither the Wuhan-based Dongfeng Group (the largest state-owned automobile manufacturer in terms of NEV sales), nor its joint ventures with Honda and Renault produced any vehicles in February 2020. Production gradually resumed afterwards. According to the Chinese Association of Automobile Manufacturers, 90% of factories had resumed work by 11 March 2020, with 77% of workers having returned. By 9 March, of the 13 automotive parts groups surveyed, six had restored all factories and five had restored over 80% of their factories. Actual production showed slower recovery: by 11 March, the average production rate was less than 40% among the surveyed groups (Caixin, 2020).

In February 2020, battery manufacturers produced 0.9 gigawatt-hours (GWh) of batteries on top of the 0.6 GWh that were installed on cars. Prices of key parts and materials declined in the first-half of March. Longer term, the pace at which EV sales pick up in China will determine the battery supply and demand balance; battery manufacturers in China lost about two months of production. The policy response in China to deal with the impacts of the pandemic on the automotive industry as well as on NEVs has been rapid. On 3 February China's president requested to "stabilize automobile sales and encourage relaxing car permit quotas". Since then, several policies and measures have been adopted at a national, provincial or city level, both to bolster overall car markets as well as NEV sales (see Chapter 2).

What to expect from the global car market in 2020

We currently expect overall car sales in 2020 to be around 15% (or 13 million cars) lower than in 2019, with the largest drops registered in Europe, the United States and China. This represents a historic drop twice the size of the decline that occurred between 2008 and 2009.

Electric cars are likely to have a much better 2020 than the rest of the auto industry. They are gradually becoming competitive in some countries on the basis of the total cost of ownership (which includes fuel expenses as well as purchase costs), even if the recent plunge in oil prices has eroded that somewhat. But the high upfront investment for consumers – electric car prices are still higher than those of conventional cars – mean that the electric car market still relies on government support.

But the Covid-19 crisis has raised concerns that the economic crisis could lead governments to relax fuel efficiency standards to lower the pressure on struggling automakers, or reduce support measures for electric cars to free up funds for use elsewhere. That has not happened so far. China announced it would extend the purchase subsidies that it had originally planned to discontinue this year until 2022 – albeit at a slightly reduced rate. Italy also revised its existing programmes with additional funds available for 2021 and 2022 as well as an extra EUR 1 500 (USD 1 700) per electric vehicle if an old car is scrapped. France announced temprorarily strengthened EV subsidies and cash-for-clunker programme, applicable between June and December 2020. In addition, the typical electric car buyer still tends to be wealthier than the average consumer and might be less affected by the economic downturn. And around 100 new electric car models are expected to become available over the course of 2020, increasing the choice for potential customers.

Against this backdrop, it is quite possible that global electric car sales in 2020 will be more resilient than the overall car market, experiencing a substantially lower impact of the pandemic. Our central estimate today is for global electric car sales to broadly match or even slightly exceed 2019's total to reach more than 2.3 million and achieve a record share of the overall car market of more than 3%. This would bring up the total number of electric cars on the road worldwide to a new record of about 10 million (IEA, 2020b).

However, many uncertainties remain, such as what possible behavioural changes could be expected from the current crisis and confinement measures. As cities are gradually emerging from lockdowns, some of them are placing temporary restrictions on the frequency and occupancy of public transport, raising the risk of a spike in car traffic. Many cities, particularly in Europe, are therefore rapidly putting together policies to rethink the use of urban space and promote walking and cycling. At the same time, however, national governments may look to reduce potential employment losses in the auto industry through measures that stimulate car sales.[29] The greatest uncertainties though are with possible second waves of the pandemic (which are not considered in our estimate) and with the pace of economic recovery along with their impacts on consumer and corporate spending.

Governments' responses to Covid-19 determines the pace of the transition to electric cars

Today, electric cars in many markets are subject to a host of incentives and regulatory efforts. Most global electric car sales involve a financial incentive from governments that often takes the form of direct purchase subsidies or tax reductions. Ultimately, government responses to the Covid-19 crisis will contribute to determining what happens to electric car markets in 2020 and beyond. Sales could go into decline if governments weaken fuel economy standards or electric vehicle mandates – or if they implement an early phase-out of the subsidies for electric vehicle purchases. On the other hand, targeted and direct support measures, including for recharging infrastructure, could help push sales higher.

The car industry is a critical part of economic activity in many of the world's largest economies employing millions of people across the entire supply chain. It has been impacted severely during the Covid-19 crisis, with practically all major car manufacturers halting production lines for varying periods of time. The challenge for governments now is to craft the appropriate policy response. It is reasonable to expect that stimulus packages will seek to bolster the economy in countries with important vehicle manufacturing capacity by including measures to support the automotive industry, not least given their relevance for the labour market. While such

[29] Longer-term policy and behavioural drivers and possible electric car stock outlooks to 2030 resulting from the Covid-19 crisis are explored in Chapter 3, Box 3.1, in addition to the principal Stated Policies and Sustainable Develpoment scenarios.

measures will inevitably help boost EV sales as well, targeted measures to support EV sales in particular will be required to ensure that the electrification of road transport remains on track towards the postulated goals.

There is a need for governments to sustain confidence among manufacturers in their near- and long-term objectives for road vehicle electrification.[30] Clear and targeted measures to boost EV sales in the near term are critical. But there is a risk that the financial liquidity of the auto industry will be reduced in the fall-out from the pandemic; supporting access to targeted and time-limited loans, guarantees and other tools can help the private sector to continue to invest. Favourable loans, with low interest rates and/or public co-funding, could help public or corporate fleets for bulk procurement of electric cars, buses and trucks. Governments can additionally provide signals to consumers and manufacturers by spurring investment in the infrastructure necessary to boost EV deployment such as charging facilities and by aligning complementary policies such as codes requiring charging stations in new construction or refurbishment. Infrastructure investment will bolster confidence in the uptake of EVs and the associated construction activity will support job creation or preservation.

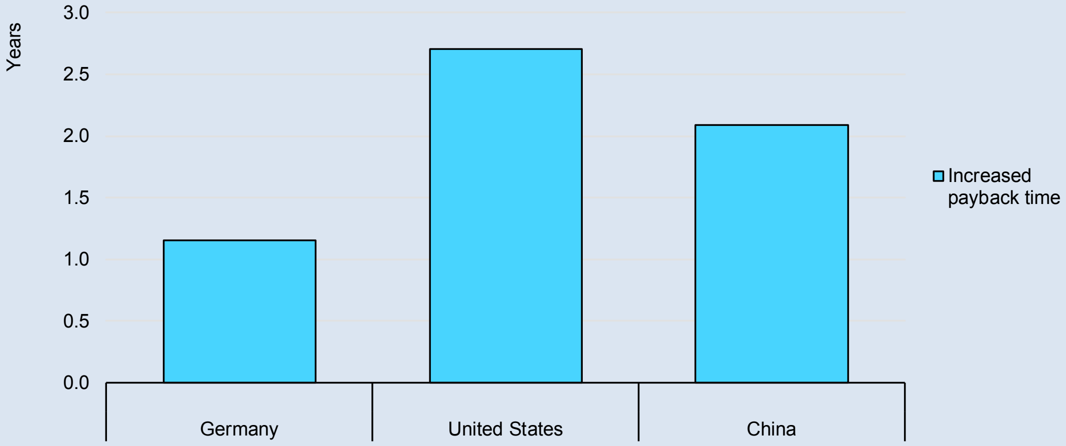
Past experience of automotive industry stimulus measures has been mixed. Cash-for-clunkers programmes can be an effective approach if they are designed to support the uptake of more efficient (e.g. hybrid) and electric cars. In past stimulus packages, however, such considerations were not always adequately addressed and sales of SUVs and diesel cars were boosted, which pushed up global oil demand and air pollution. Support for the auto industry can also be tied to ambitious fuel economy regulations, which in the past triggered innovation and helped jump start key parts of today's electric car industry. In countries where fossil fuel subsidies prevail, the low oil price environment (Box 1.3) is an important opportunity to phase out price supports, which are detrimental for pursuing energy efficiency efforts in general, and for creating a context that supports road vehicle electrification in particular. Examples of early responses from governments are available in Chapter 2.

[30] For further information on Automakers ambitions for EV production and sales, see Chapter 2.

Box 1.3 Cheap gasoline inflates the payback period for electric cars

EVs have an initial higher purchase price than their ICE counterparts. From a consumer perspective, the main economic advantage of owning an electric car is lower running cost; electric powertrains have lower maintenance costs and, depending on fuel and electricity prices, generally lower operating costs (IEA, 2018b; IEA, 2019b). A key determinant of this cost difference is the price of fuel. In countries with high levels of fuel taxation, consumers recover the extra purchase price faster. In a low oil price environment, the costs of fuelling ICEs are reduced. If the price of oil remains low, then the economic case for EVs will be hindered in most countries: assuming oil prices of USD 25 per barrel, it could take 1-2.5 extra years to recover the extra costs associated with an EV compared with an average oil price of USD 60 per barrel. The impact is smaller in countries with higher fuel taxation, since a larger portion of the fuel price at the pump is less directly dependent on oil prices. Increased payback times are likely to have a greater impact on the medium and small car segments, where consumers are more likely to be budget constrained.

Increased payback time for electric cars due to lower oil prices



Notes: The payback period is calculated as the time needed to recover the extra costs associated with the purchase of an electric car. Costs are recovered due to the lower fuel and maintenance costs of an electric car compared to an ICE. The increase in payback period for an oil price of USD 25 per barrel compared with USD 60 USD per barrel is calculated for a typical vehicle in the three countries. The fuel tax rate is about 60% in Germany and just under 20% in China and the United States. No discount rate is included. For more detailed information on cost comparisons between EVs and ICE vehicles, refer to the *Global EV Outlook 2019* (IEA, 2019b).

Source: Analysis based on IEA (2020).

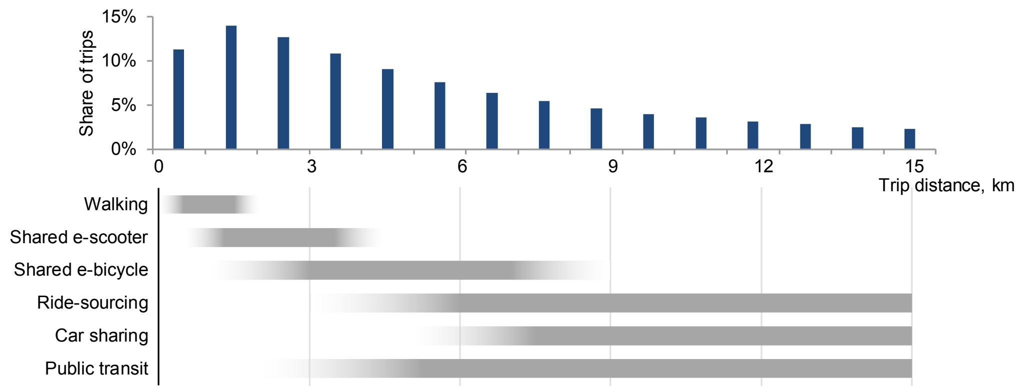
Electric mobility trends in other modes

Micromobility

Electric micromobility services have expanded rapidly since their emergence in 2017.[31] Shared electric scooters (e-scooters), electric-assist bicycles (e-bikes) and electric mopeds are now available in over 600 cities across more than 50 countries worldwide (NUMO, 2020). In most markets, e-scooters account for the largest proportion of shared micromobility vehicles and trips. Nonetheless, micromobility remains a small share of trips and travel distance overall.

In China, European Union and United States, around half of passenger-kilometres (pkm) are trips under 8 kilometres (km), so the potential market for micromobility is immense (McKinsey & Company, 2019). Globally, shared e-scooter trips are expected to quadruple from around 230 million trips in 2019 to 850 million by 2028 (Navigant Research, 2019). Dense cities such as Paris could see cycling and micromobility services account for a fifth of all trips by 2030 (Schuller and Aboukrat, 2019). Micromobility services can help reduce local air pollution, making them particularly attractive mobility options in cities.

Figure 1.3 Share of trips under 15 km in the United States and suitable trip distances of mobility options



Note: Trip frequency shares are for trips shorter than 15 km only.
Source: IEA analysis based on BCG (2019).

The average distance of trips varies across modes. Electric micromobility modes are a viable substitute only for the shorter range of car trips in major cities.

[31] Micromobility is defined by SAE Ground Vehicle Standard J3194 as "vehicles that have a curb weight of less than or equal to 500 pounds (227 kilogrammes) and a top speed of 30 miles per hour (48 kilometres per hour) or less" (SAE, 2019). This section focusses on small micromobility vehicles such as standing electric scooters (e-scooters) and electric bicycles (e-bikes). The next sections discuss two/three-wheelers and four-wheel low speed EVs.

The energy and emissions implications of micromobility depend primarily on two factors: modal shifts (i.e. which modes are displaced and/or complemented) and the life-cycle energy and emissions intensity of micromobility services.[32]

Actual use data of shared micromobility are limited. According to early user surveys, a quarter to half of e-scooter rides replaced a trip that would have been taken by car, and 20% of e-scooter trips in cities provided first/last-mile[33] services to connect to public transit (Bird, 2019; City of Santa Monica, 2019; Lime, 2019). However, other surveys found that nearly half of micromobility trips displaced trips that would have been taken by walking or non-motorised cycling (6-t, 2019; City of Santa Monica, 2019; Grow Mobility, 2019; Hollingsworth, Copeland and Johnson, 2019). While micromobility also displaces some trips on public transit, it is at the same time an important last-mile and public transport connection solution, and is an enabler of increased mobility access.

Studies analysing the energy and emissions performance of micromobility vehicles and services are emerging. Hollingsworth et al. (2019) found that shared e-scooters in Raleigh, North Carolina (United States) had lower life-cycle GHG emissions intensity per passenger (126 grammes of CO_2-equivalent per passenger kilometre [gCO_2-eq/pkm]) than conventional personal cars, but higher emissions than a public bus with high ridership.[34] Moreau et al. (2020) estimated life-cycle GHG emissions of 131 gCO_2-eq/pkm for shared e-scooters in Brussels, nearly 20% higher than the modes they displaced. The same study found that personal e-scooters today have much lower life-cycle emissions (67 gCO_2-eq/pkm), primarily as a result of longer lifetimes compared to shared e-scooters.

These studies highlight both the current sustainability challenges as well as the considerable opportunities to reduce GHG emissions. With over 90% of e-scooter life-cycle GHG emissions associated with materials, manufacturing and transporting scooters overnight, longer lifetimes and zero-emission support fleets can substantially reduce life-cycle emissions.

[32] Life-cycle energy use and emissions from micromobility services include those associated with materials and components, manufacturing, transport (from the location of manufacture to final use), use and operations (collection and distribution, electricity for charging) and end-of-life processing.
[33] Micromobility services offer considerable potential to provide first-mile/last-mile connections to mass transit, which could have considerable indirect benefits by reducing overall energy use, and CO_2 and local pollutant emissions.
[34] Some of the study's base case assumptions are fairly conservative (e.g. daily scooter collection and recharging regardless of state of charge), which work to inflate the emissions intensity. The study includes sensitivity analyses around key uncertainties such as collection travel distance, scooter use and scooter lifetime.

As the industry matures, micromobility companies are building and deploying substantially more durable scooters compared to previous generations, which were designed for private consumer use. The introduction of swappable components and batteries are helping to reduce downtimes and extend lifetime (Lewin, 2019). Several companies are electrifying their support fleets, with some targeting a 100% EV fleet in 2020 (either by electric vans or electric cargo bikes).

Cities will play an increasingly vital role in encouraging broader and safer micromobility use, and in improving its environmental performance. For example, procurement and permitting strategies could select companies and services operating zero-emission fleets (or committing to them). Thoughtful planning decisions around building protected lanes, improving micromobility parking spaces and enforcing speed limits can boost public acceptance, adoption and safety (ITF, 2020). Increasing the number of micromobility users could also help broaden the coalition for support of cycling infrastructure and road space shifting in favour of less space-intensive modes.

Beyond personal mobility, electric micromobility vehicles – notably e-cargo bicycles – can play an increasing role in last-mile delivery in cities. E-cargo bikes are being used across several European cities by postal and courier services, including PostNL, Swiss Post, La Poste, Deutsche Post and DHL.

In the wake of the Covid-19 pandemic, shared micromobility companies have drastically reduced or suspended services due to confinement and social distancing measures, which induced plummeting demand. Some operators are running reduced fleets with strict hygiene maintenance protocols. The financial impacts so far have hit the start-ups in the shared micromobility landscape hardest (many of which were not yet making a profit). This is the case even for the two largest companies with Bird cutting 30% of its workforce in late March 2020, and a report estimated that Lime only had enough cash to survive until mid-June (Bliss, 2020; Lanxon and Cheng, 2020).In the near term, significant market consolidation of operators seems inevitable, given the financial challenges for many operators even before the pandemic. Post-pandemic mobility preferences of users (including their future preference for either shared or private micromobility vehicles) will likely play a very large role in their viability in the long term. Bearing in mind the potential to reduce both car travel and high occupancy on collective public transport, the degree of active local policy support towards micromobility will be key to its viability in urban transport.

Two- and three- wheelers

Two-wheelers

China leads the electric two-wheeler market with the largest fleet and annual sales. In late 2019, the stock of electric two-wheelers in China was close to 300 million units (Xinhua News, 2019a). Recent data suggests that the annual production of electric two-wheelers rose from approximately 33 million in 2018 to 36 million units in 2019 (China Bicycle Association, 2019).[35] Regulations and modest prices have played a major role in the high demand for electric two-wheelers. The growth of electric two-wheelers has been spurred by two notable policies from the central government. First, in 1999, the government designated electric two-wheelers possessing a low speed and weight as bicycles. This exempted them from registration requirements and permitted them to be driven on bicycle lanes. Second, several urban areas have banned gasoline powered two-wheelers from city centres (Cherry, 2010).

The sales of electric two-wheelers in India rose from 54 800 units in 2018 to 126 000 units in 2019 (Wadhwa, 2019). India had an estimated fleet size of 0.6 million electric two-wheelers in fiscal year[36] 2018-19 (IEA, 2019b). About 20% of the CO_2 emissions and 30% of particulate emissions in India are estimated to be caused by motorised two-wheelers (Viswanathan and Sripad, 2019). Recent government policies have taken into consideration the need to electrify the motorised two-wheeler fleet. In 2019, the national government proposed a plan to make all two-wheeler sales electric ones (up to 150 cubic centimetres) as from March 2025 (Vardhini, 2019). Under the first phase of the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME I) scheme, 88 models of electric two-wheelers were eligible for a subsidy. Until September 2018, around 90% of the beneficiaries under FAME I were lead-acid powered electric scooters. From October 2018, subsidies for lead-acid battery vehicles were discontinued, but incentives for lithium-ion battery vehicles remained. As from April 2019, the second phase of the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME II) scheme encompasses strict speed, range and energy efficiency requirements that would exclude 90% of the remaining lithium-ion battery-driven models from the FAME subsidy scheme (CRISIL, 2019).[37]

[35] The scope of this section is motorised two-wheelers, which excludes in principle bicycles with electric assistance. However, there is possible overlap between these two categories in the numbers from the China Bicycle Association and Xinhua.

[36] *Fiscal year* covers the period April to March.

[37] Under this revised scheme, 5 electric two-wheeler manufacturers are eligible, as opposed to 18 two-wheeler manufacturers under FAME I (Susvirkar, 2019).

Fleet operators of shared rental schemes operate electric two-wheelers in a few European cities. Users can rent the electric two-wheelers using the operator's smartphone apps (IEA, 2018b). Recently, Cityscoot, one of the shared electric two-wheeler operators and based in France, along with Uber announced the integration of the Cityscoot option in the Uber application (Uber, 2019).

Three-wheelers

China has the largest electric three-wheeler stock in the world, with more than 50 million electric three-wheelers on its roads (Xinhua News, 2019b). Competitive purchase prices relative to conventional ICE three-wheelers and the presence of numerous domestic electric three-wheeler manufacturers are the prominent factors fuelling the demand for electric three-wheelers in China (VynZ Research, 2019). Electric three-wheelers have been widely adopted throughout for last-mile deliveries, as well as to bring produce and other wares to and from markets. Logistics operators have adopted them for their ability to circumnavigate traffic jams and to deliver goods to the sometimes very narrow streets in urban areas (Sustainable Transport, 2018).

Three-wheelers provide a cheap mode of transportation across South Asia. While a large portion of these are not electric, the three-wheeler fleets in South Asian countries are gradually moving in that direction. With the largest population in the region, India is home to approximately 1.5 million battery-powered electric three-wheelers/e-rickshaws (Bhatia, 2020). The e-rickshaws transport about 60 million people per day (Goel and Singh, 2019). Start-ups are cashing in. For example SmartE, an app-based e-rickshaw ride-hailing service based in Delhi, is massively ramping up its fleet (Varshney, 2019). Pakistan has adopted a new EV policy that aims to bring 500 000 electric two-wheelers and rickshaws into the fleet in the next four to five years (Mukhtar, 2020).

Low-speed electric vehicles in China

Low-speed electric vehicles (LSEVs) are small four-wheeled vehicles having a maximum speed of around 40-70 kilometres per hour. These vehicles have a small driving range (IEA, 2019b). Low-speed electric vehicles are in their vast majority concentrated in China. They are exempted from some registration requirements because of their speed and size (IEA, 2019b). It is difficult to track exact numbers due to a lack of data sources, as these vehicles are not systematically registered. However, their number was estimated to exceed 5 million units in 2018, with about 700 000 new sales in that year (IEA, 2019b). Recent policies aim to tighten regulations to contain further market expansion as these LSEVs pose road safety concerns (Government of China, 2018). In November 2018, the government decided to accelerate the phase-out of LSEVs that could not be brought up to established standards (Government of China, 2018). Future developments of the industry will be managed according to national regulations which aim to provide a stricter framework for their production and use. It is unclear at this point as to the extent these tightened regulations have impacted the LSEV market in China and how sales evolved in 2019.

Light-commercial electric vehicles

In addition to the 7.2 million passenger electric cars, there were almost 377 000 electric light-commercial vehicles (LCVs) on the world's roads in 2019, up from 310 000 in 2018.[38] Electric LCVs often are part of a company or public authority vehicle fleet. In 2019, China had the largest electric LCV fleet (247 500 vehicles), comprising 65% of the global stock. Europe had the second-largest electric LCV fleet, with 31% of the global stock and over 115 000 vehicles, with the largest fleets in France (49 000 vehicles) and Germany (22 000 vehicles).[39]

In 2019, about 70 000 electric LCVs (mostly BEVs) were sold, almost entirely in China (42 500 LCVs) and Europe (25 000 LCVs). This was the first time in the past decade that electric LCV sales dropped (-37%) relative to the previous year, as growth slowed in Europe and sales declined in China.

Electric buses

The global market for electric buses has declined since a spike in sales in 2016. In 2019, new electric bus registrations numbered about 75 000 vehicles, down 20% from 93 000 units in 2018. There were about 513 000 electric buses worldwide in 2019, up 17% from 2018.

About 95% of the electric buses registered in 2019 were made and sold in China. Year-on-year registrations have decreased by about 20%, due to a decrease in purchase subsidies in 2019 (the subsidy decreased by 40% compared to 2016 (MIIT, 2015)), as well as a decline in the bus market in China.

The number of electric buses has strongly increased in Europe and in the United States – although they are about two orders of magnitude lower than in China – slightly reducing that Chinese market concentration. Still, the vast majority (over 0.5 million buses, or 98% of the global fleet) of electric buses operate in China.

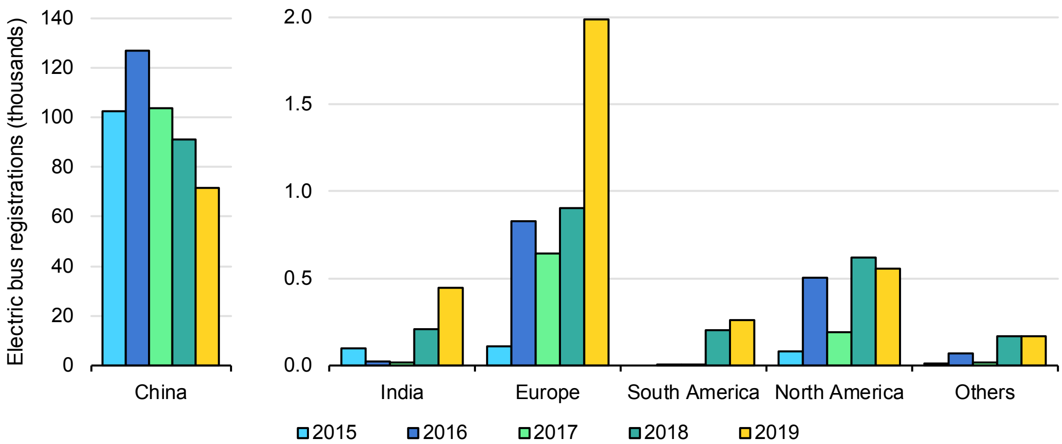
[38] Light-commercial vehicle refers to vehicles used for commercial purposes that have a gross vehicle weight of less than 3 500 kilogrammes.
[39] Data on LCVs is sourced from country submissions, EV-Volumes (2020) and EAFO (2020c).

With the backing of the FAME II programme,[40] deployment of electric buses in India increased rapidly in 2019. Electric bus fleets now operate in cities such as Kolkata, Mumbai, Pune and Bengaluru. New registrations have doubled over a year, reaching 450 units bringing India's electric bus fleet to more than 800 vehicles in 2019.

In 2019, Europe registered 1 900 electric buses, more than double from the previous year. Most of Europe's 4 500 electric buses operate in the Netherlands (800), United Kingdom (800), France (600) and Germany (450). For the second year in a row, the 2019 registrations for electric buses in Europe surpassed those of natural gas buses, another popular alternative fuel for public buses (EAFO, 2020a). The European electric bus fleet is larger than North America's, which had 2 255 electric buses, including more than 500 new registrations in 2019 (EV-Volumes, 2020). The introduction of 63 electric buses in Mexico City marked the beginning of their roll out in Mexico (Yutong, 2019).

South America is one of the major growth markets for electric buses. Registrations in 2019 were 3.5 times as high as in 2018, at more than 450. Santiago de Chile maintains the largest fleet in the region with almost 400 electric buses. Other cities operating electric buses are located in Argentina, Brazil, Colombia and Ecuador.

Figure 1.4 New electric bus registrations by country/region, 2015-19



Sources: IEA analysis based on country submissions, complemented by ACEA (2020); CAAM (2020); EAFO (2020a); EV-Volumes (2020); Marklines (2020); OICA (2020).

Fewer new registrations of electric buses in China led to a 20% drop of worldwide registrations in 2019, despite strong growth in other regions.

[40] More details on India's FAME II programme can be found in Chapter 2.

Today battery electric is almost the exclusive technology choice for electric buses with a 95% market share globally, by far exceeding new registrations of plug-in hybrid and fuel cell electric buses. However, the fuel cell electric buses have garnered increasing interest and some 4 000 were registered in 2019, more than 80% in China (Box 1.2).

Electric trucks

Sales and stocks

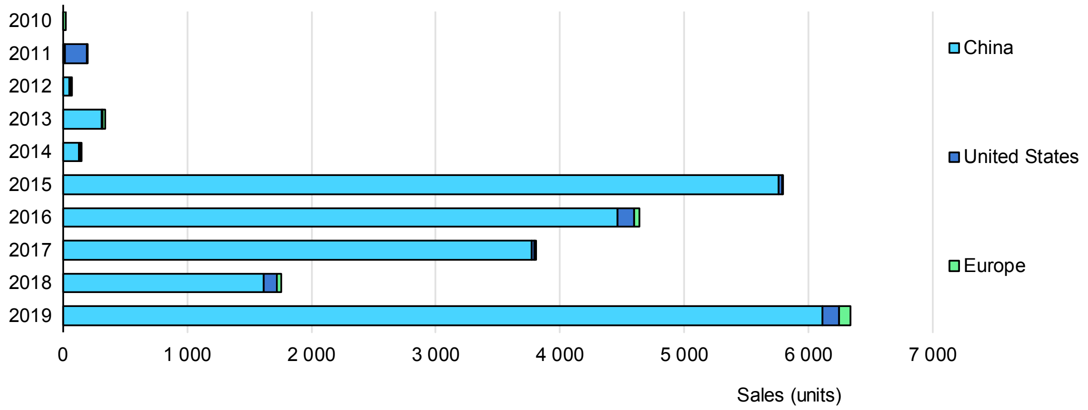
Various data sources report broadly consistent, but slightly different sales and cumulative fleet numbers for medium- and heavy-duty electric trucks. Most are in China where official sales data for medium- and heavy-duty[41] electric trucks report 6 112 vehicles in 2019, 60% more than the previous sales spike in 2017 (Figure 1.5). These trucks are nearly all battery electric. The turning point for EV truck sales in China was 2015, when the central government extended subsidies and eliminated upper weight limits on subsidies for electric LCVs and trucks. The qualification requirements for the New Electric Vehicle programme subsidy scheme were progressively tightened on electric cars, BEV trucks and LCVs (ICCT, 2019b).

Together with steady improvements in battery performance and cost reductions, as well as an expanding model range, the volume of electric truck sales has been increasing in China. Electric truck sales have been increasing to a more limited extent in Europe and the United States where most heavy-duty electric truck activity is in demonstration and customer trials. The commercial adoption of electric trucks lags other vehicle categories mainly due to challenges stemming from the lower energy density of batteries and the resulting weight and volume limitations, but also due to limitations related to long charging times and availability of charging points.

To date, most electric trucks operate in urban environments, for instance in delivery fleets or for garbage collection and other municipal operations. Trucks operating in cities are able to recharge overnight at fast charging depots. In theory, in cities where delivery is restricted or incentivised during the night or off-peak congestion periods, electric trucks could also take advantage of bus depot charging stations during the day, thereby maximising the utilisation of the infrastructure.

[41] Heavy-duty trucks are more than 3.5 tonnes gross vehicle weight.

Figure 1.5 Global sales of medium- and heavy-duty electric trucks, 2010-19



Sources: IEA analysis based on country submissions, complemented by ACEA (2020); CAAM (2020); EAFO (2020a); EV-Volumes (2020); Marklines (2020); OICA (2020).

More than 6 000 heavy-duty electric trucks were sold in China in 2019 as it pioneers electrification in this vehicle segment.

China is poised to emerge as the pioneer country in the electrification of heavy-duty road freight. Though only accounting for 0.1% of the heavy-duty trucks on its roads, cumulative sales of heavy-duty electric trucks are more than 12 000 over the last decade. A major boost in commercial fleet adoption in Europe or the United States could challenge that lead.

Charging infrastructure for heavy-duty electric trucks

Heavy-duty electric trucks require batteries with high capacity to meet their needs for heavy-duty cycles and long-range operations. Today most of the batteries in electric trucks, of which the models are in various stages of commercialisation, range from 70-300 kilowatt-hours (kWh) for medium freight trucks (from 3.5 to 15 tonnes gross vehicle weight [GVW]) and from 200 kWh to 1 megawatt-hour (MWh) for heavy-freight trucks (with more than 15 tonnes GVW). To recharge the batteries for daily operations in a reasonable amount of time, electric trucks require high power charging and a wide range of power needs, which reflects the diversity of truck sizes and operational patterns. Recharging the batteries can be via fast, ultra-fast and/or mega charging technologies.

Electrification of trucks currently is taking place in urban areas, for reasons detailed in *Global EV Outlook 2019* (IEA, 2019b). Generally, these tend to be medium-duty trucks and hence have smaller payloads and limited ranges. Urban operations offer more opportunities to optimise charging stops and more accessibility to charging infrastructure both along routes and at depots for overnight charging. Such truck operations have lower requirements for battery capacity than regional and long-haul trucks. Moreover, electric trucks may be granted special access in areas that regulate noise and air pollution compared with diesel trucks, thereby offering a potential competitive advantage.

Municipal and urban delivery trucks in circulation today typically share charging infrastructure. Most are operating at a demonstration scale. For instance, Göteburg in Sweden has opened 175 kilowatt (kW) chargers for its fleet of distribution and waste collection electric trucks (Volvo FL and FE models) (Göteburg Energi, 2019). In Shenzhen in China the deployment of heavy-duty electric trucks has been able to leverage charging infrastructure built for the rapidly growing and large-scale adoption of electric LCVs.

Electrification of longer distance routes, such as regional distribution, long-haul trucking and intercity bus services will require development of adequate dedicated high power charging stations. Some are likely to be private and used exclusively by the fleet operators. Nonetheless, tailored policies to promote the roll-out, as well as to ensure inter-operability and standardisation of certain technical and operational specifications of public rapid charging infrastructure can help spur the transition to electric and fuel cell powertrains in these operations (see Chapter 2 for discussion and examples of such polices).

Activities underway on a demonstration basis for large electric trucks with big payload and long-range capabilities rely on dedicated charging infrastructure that has been installed and maintained either privately or jointly among logistics companies. Corporate trials of models like Tesla's Semi and Daimler's e-Cascadia are following this model, relying on chargers that have power ratings from around 100 kW to more than 1 MW (the latter consisting of four 350 kW charging plugs). Charging standards for ultra-high power charging are being developed and are moving broadly toward harmonisation. In collaboration with Tesla and Daimler and other members of its High Power Charging for Commercial Vehicles task force, the Combined Charging System (CCS) initiative CharIN is developing a CCS compliant charging plug with a power of more than 2 MW. It will charge in the range of 200 - 1 500 Volts and 0 - 3 000 Amps (CharIN, 2019). The CHAdeMO Association and the China Electricity Council are working jointly on a next-generation ultra-high power charging standard (up to 900 kW), dubbed "ChaoJi" (CHAdeMO, 2019).[42] The hardware of the new ChaoJi plug will be harmonised into one for the next-generation CHAdeMO as well as China's GB/T standards, ensuring backward compatibility with

[42] CHAdeMO stands for CHArge de MOde. It is one of several charging plug (and vehicle communication) standards for DC fast charging. Other standards for DC charging are CCS1 & 2 (Combined Charging System), Tesla (two types: US/Japan and rest of world) and the Chinese GB/T system.

all the existing standards (GB/T, CHAdeMO and possibly CCS) to ensure inter-operability across standards. Numerous real-life demonstration projects using a variety of prototypes (both vehicles and chargers) have been ongoing since the beginning of 2019. The development team, in collaboration with the broader international community, published the ChaoJi technical requirements for the CHAdeMO protocol (used globally) in April 2020, and aims to achieve the Chinese protocol in 2021. ChaoJi will concurrently be proposed to the IEC/ISO committees to be added to the direct current (DC) fast charging systems, while the first production for vehicles is expected to enter the market as early as 2021 (CHAdeMO, 2020). In Europe, OEMs and public and non-governmental organisations are incorporating plans for the roll-out of rapid charging infrastructures (see Chapter 2 for further discussion).

Product packages that couple the purchase of electric trucks with the installation of charging equipment will be particularly critical for ensuring the viability of deployment, especially for regional and long-haul operations. In the fuel cell domain, Nikola's bundled leasing model, where the company plans to work with corporate partners – such as Nel ASA of Oslo, which produces electrolysers – and customers to roll out hydrogen refuelling stations that draw upon hydrogen produced from renewable electricity, is an example of such a business model.

The range of charging product options for heavy-duty electric trucks entering the commercial market is expanding. New installations in 2019 build upon standards and technologies that have been developed or are being proposed, and that have been summarised in previous *Global EV Outlooks*.[43] For instance, Penske has opened 14 DC fast charging stations in southern California to charge the Daimler Freightliners that it has been testing (Engadget, 2019).

Electric road systems (ERS), which rely upon dynamic conductive or inductive power transfer to enable vehicles to charge while driving, offer promising potential to expand the operations that could be performed by vehicles with electric powertrains, particularly in heavy-duty regional and long-haul operations, and intercity bus routes. These systems can be installed within the roadway itself or with overhead catenary lines. In both cases, trucks would require dedicated power transfer equipment to make use of the ERS infrastructure (e.g. pantographs, in the case of catenary lines). If installed on stretches of the most heavily trafficked corridors, ERS can mitigate the

[43] For a review of charging standards up to 600 kW for urban electric buses, see the *Global EV Outlook* 2018 (IEA, 2018b). For a review of charging standards for trucks, and the companies – including Tesla and Chargepoint – and technologies enabling so-called "mega chargers" for heavy-duty electric trucks, see Box 2.1 in *Global EV Outlook 2019* (IEA, 2019b).

constraints and costs imposed by batteries, which may still be too large and heavy to make all-electric operations feasible for operations that are long distance, with high daily mileages and heavy and bulky cargo needs.

By virtue of being capable of providing power to any electric powertrain (i.e. PHEVs, BEVs and FCEVs), provided that connections or inductive power receiving equipment are installed on the vehicle, ERS can further serve as a powertrain neutral infrastructure to expand the scope and operational flexibility of road electrification. Several ERS technologies are at various levels of development from early prototypes to first-of-a-kind commercial scale (IEA, forthcoming). Research and demonstration on various ERS concepts are being championed across the United States, Sweden and Germany, and several other European countries are considering their potential. However, successful market diffusion of ERS would require a strong commitment from industry and policy makers. In many countries today the lack of co-ordinated commitments from multiple stakeholders to concrete ERS deployment plans is a major barrier, in contrast to the case of the infrastructure needed for fuel cell or battery electric trucks, where a similar degree of co-ordination and commitment is increasingly evident.

Shipping: electrification in port

The electrification of maritime shipping is progressing, but is currently limited to ferries and other short-distance vessels.[44] In the near term, purely electric ships are expected to be economically competitive with other low-carbon powertrains only for distances up to 200 km (IEA, forthcoming). The Nordic countries are leading the electrification of short-distance ferries. Norway had about 20 electric ferries in operation in 2019 and is planning to launch 50 more in the next two years (Plugport, 2020). Purely electric motive power does not appear to be a feasible technology for ocean-going vessels in the foreseeable future (due to limitations in battery energy density and their vast range of distances).

"Cold ironing" is an industry term for using onshore power supply while berthed.[45] It is a way that ports can contribute to reduce emissions from the shipping industry by simply plugging into an electrical supply point in port and cutting back on use of the vessel's engines. Through cold ironing, the ship's electricity needs while berthed (e.g. for lighting, pumps, refrigerators and services to crew and guests) are provided by the electricity grid instead of via the auxiliary diesel generator on the ship. Therefore,

[44] See *Global EV Outlook 2019* (IEA, 2019b).

[45] Also called onshore power supply, shore-side electricity or alternative maritime power.

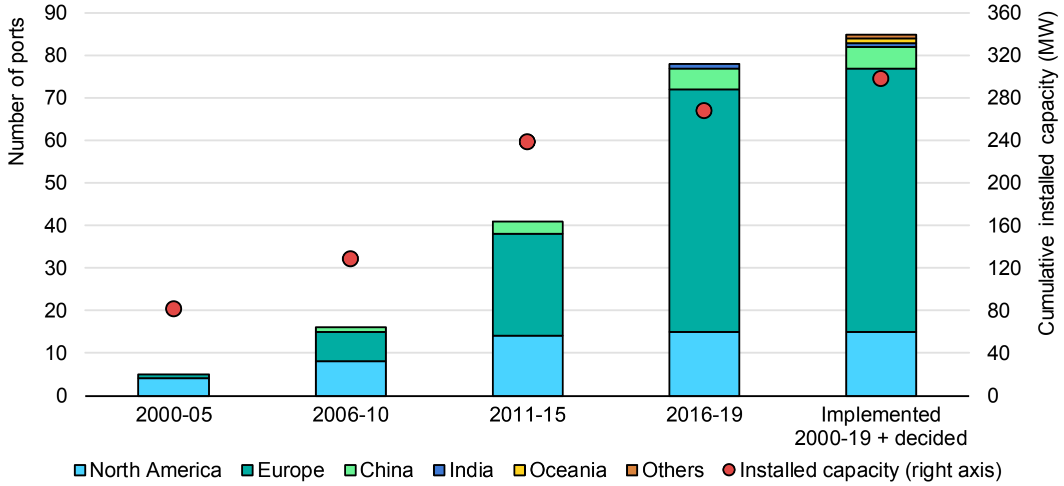
ships avoid the consumption of maritime diesel when at berth,[46] both reducing air pollutant emissions in harbours – among the most polluted and often densely populated areas in the world (UN Environment Programme, 2020) – and cutting fuel expenses.[47] It is estimated that cold ironing of large ships can cut their fuel consumption by half when at berth. Moreover, depending on the efficiency of the auxiliary generator and carbon intensity of the power grid, cold ironing can reduce CO_2 emissions (Zis, 2019).

One of the main challenges of providing cold ironing connections at ports is that ships, even when in at berth mode, have significant power needs, normally higher than any other mode of transport. Power requirements range from about 700 kW for vehicle-carrying ships up to about 15 megawatts (MW) for cruise ships (T&D Europe, 2015).[48] In order for a ship to be able to cold iron when at berth, it must be equipped with appropriate on-board electrical components. Generally vessels have not been equipped with such components. Now major shipping lines have started to retrofit their vessels to enable cold ironing and all new cruise ships and container ships larger than 6 000 twenty-foot equivalent units (TEU - a measure of container ship cargo capacity) are already equipped for cold ironing (T&D Europe, 2015; Port of Los Angeles, 2018).[49,50]

On the port side, the berth must be outfitted to enable cold ironing for ships that call. While it is difficult to have precise and up to date statistics on the number of cold ironing facilities, Figure 1.6 shows the evolution over time of the number of ports with at least one berth capable of cold ironing. US ports were the pioneers in adopting cold ironing in the early 2000s, since then most development has been at European ports. Today, at least 78 ports worldwide are capable of providing cold ironing, of which three-quarters are located in Europe. Cumulative installed capacity is estimated to be at least 300 MW.

[46] Some fuel consumption still takes place for large vessels, as the ship's boilers continue running.
[47] Other advantages of cold ironing are the reduction of noise and vibration on board, reduction of the machinery wear and thus reduction of maintenance needs and extension of machinery lifetime.
[48] The additional power needs for providing cold ironing services can rapidly lead to exceedance of the maximum capacity of the power connection between the port and the grid connection. The need to reinforce grids can make the installation of cold ironing connections in port more costly (Innes and Monios, 2018; T&D Europe, 2015).
[49] Electrical equipment a ship needs to cold iron include a cable reel, connection switchgear, transfer and switchboard (Agarwal, 2019).
[50] Two options are available to retrofit vessels for cold ironing: install the necessary components on board or install a container in the stern that holds all the power electronics required (Wärtsilä, 2017).

Figure 1.6 Global number of ports equipped with cold ironing facilities and cumulative installed capacity, 2019



Notes: Decided = ports that have formally approved the installation of cold ironing connections. Data on power capacity are not always available, thus it could be significantly higher than what is shown in the figure.
Sources: EAFO (2020b); DNV-GL (2020); T&D Europe (2015).

Almost 80 ports worldwide offered cold ironing in 2019, mostly in Europe.

The uptake of cold ironing reflects increasing adoption of policies and regulations at national, international and individual port levels. Policies that have encouraged the development of cold ironing facilities include:

- Since 2011, China has put in place a strategy advising that all new terminals for container ships, bulk carriers, cruise ships and ropax51 ships should include shore connection equipment (T&D Europe, 2015).
- In Europe, a directive requires that by 2025 all ports install infrastructure for shore side electricity supply (European Union, 2014).

In parallel, policies are being rolled out that encourage ships to install the equipment needed for cold ironing. Examples include:

- Since 2010, operators of container ships and cruise ships calling at California ports are required to reduce at berth emissions from the auxiliary engines. The emissions reduction requirement increases incrementally and is 80% in 2020 (CARB, 2020).

[51] *Ropax* is an acronym for a roll on/roll off (*ro-ro*) ship that carries passengers in addition to vehicles, i.e. a ro-ro vessel built for freight vehicle transport with passenger accommodation.

- China has a two-step strategy: from 2019 cold ironing capability is mandatory for new domestic ships; from 2020, many types of new built ocean-going China-flagged vessels must be equipped with shore side connection equipment (Si, 2018).[52]

While in 2019 almost 80 ports worldwide were able to provide cold ironing service, many more ports could install cold ironing equipment in the coming years to reduce some of the local pollutant and CO_2 emission impacts of maritime shipping. Ports can play a fundamental role in encouraging the roll-out of cold ironing by setting regulatory measures: for instance, ports can require ships to be equipped with cold ironing connections or can differentiate port taxes based on whether ships connect. The 20 largest harbours in the world account for 60% of maritime cargo transport activity (UNCTAD, 2019), so even if a few of these major ports were to champion cold ironing and establish appropriate regulatory mechanisms, rapid adoption of cold ironing worldwide could be bolstered

Aviation: electrification in aviation ground operations

A growing number of start-ups and established aviation companies are developing small electric turboprop planes and several demonstrations of small battery electric aircraft flying over very short distances have been completed (IEA, 2019b). The first all-electric commercial passenger aircraft flight took place in December 2019, when a retrofitted seaplane took a 15-minute flight from Vancouver, British Columbia.

Even if the rapid increases in battery energy densities achieved over the past decade were to continue unabated, battery chemistries at most would be capable of enabling all-electric mode to fly distances of around 1 000 km. Thus it would displace only about 20% of jet fuel demand (IEA, forthcoming). The requisite technology developments in battery chemistries and in airframe designs will take decades to develop. Hybrid electric aircraft could emerge in the next generation of aircraft. But even in the near term, there are opportunities for electrification to reduce fuel burn and emissions in aviation ground operations.

High costs for fuel and increasing attention on the environmental impacts of aviation have spurred the industry and researchers to seek solutions to reduce fuel use and emissions, particularly from the landing and take-off cycles (LTO).[53] Solutions for the taxi phase of LTO face fewer operational constraints compared to those for cruise,

[52] The types of vessels regulated are: container ships, cruise ships, ropax vessels, passenger ships of 3 000 tonne class and above, and dry bulk carriers of 50 000 tonne class and above.
[53] Landing and take-off cycles (LTO) include activities occurring up to 3 000 feet (914.4 metres) above ground level. It comprises the flight stages: taxiing out, taking off, climbing out for departures, descending for landing, touching down and taxiing-in for arrival.

where safety is paramount (Guo, Zhang and Wang, 2014). Fuel burn and emissions from LTO are significant for short and medium-distance flights, and have important implications for local air quality.

One of the most promising solutions to reduce LTO fuel use and emissions is electric taxiing, which uses on-board electric motors powered by the auxiliary power unit (APU). For flights on a typical narrow-body aircraft (e.g. the Airbus A320), taxiing accounts for 5-10% of fuel burn (Nicolas, 2013). Electric taxiing could reduce fuel used for taxiing by half and overall fuel use by 1-4% compared to two engine taxiing (Nicolas, 2013; Re, 2012; Dzikus et al. 2011). External pushback[54] and electric taxiing systems are widely available, with even larger fuel and CO_2 savings than systems installed on the aircraft itself. Other benefits and challenges are summarised in Table 1.1.

Table 1.1 Technology options for electric taxiing in commercial passenger aircraft

	Description and examples	Fuel use and emissions reduction	Cost savings	Other advantages or challenges
On-board electric taxiing systems	Additional motor at nose, on landing gear or on main wheels powered by an on-board APU (e.g. WheelTug; Electric Green Taxi System (EGTS); DLR; Safran).	Fuel use: 50% of taxi fuel or 1-4% reduction overall compared to two engine taxiing. Tailpipe emissions: around 60% CO_2; 50-75% for NOx, CO and hydrocarbons.	USD 240 000-500 000 per year.	Time savings of 2-6 minutes on average. Extra weight and fuel consumption in cruise phase and APU modification needs.
External pushback and electric taxiing systems	Electric pushback-only systems (Mototok) or hybrid diesel-electric tractors tow the aircraft during the entire ground movement (TaxiBot).	Mototok: 100% on pushback fuel. Taxibot: 98% on taxi fuel and 98% reduction in CO_2, but potential increase in NOx.	USD 100 000-5.4 million per year	Time savings of 54% on pushback. Extensive equipment investment, system development and operations, congestion and safety concerns, increased NOx.

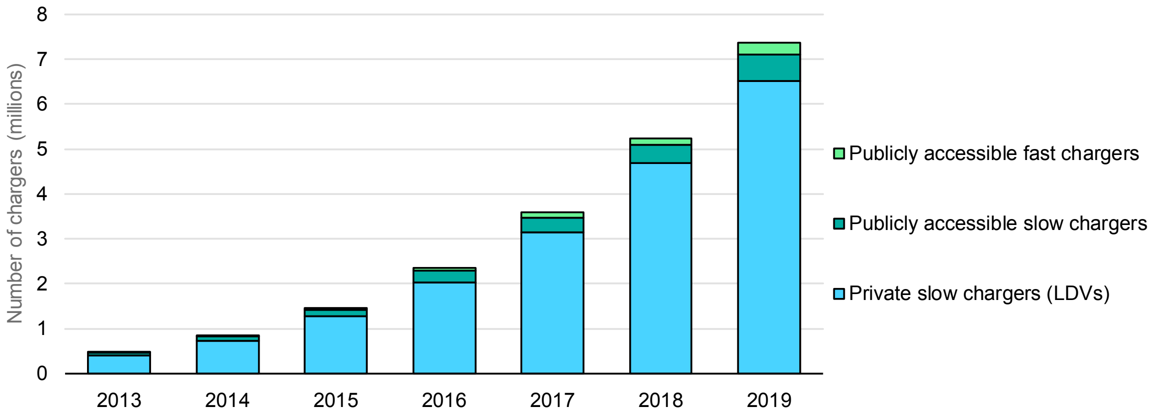
Sources: Guo, Zhang and Wang l. (2014); Lukic et al. (2019).

[54] Pushback refers to the process in which an aircraft is moved backwards away from an airport gate, typically by dedicated, low-profile vehicles called pushback tractors or tugs, or by the aircraft itself with engines on.

Electric vehicle charging infrastructure deployment

By the end of 2019, there were 7.3 million electric vehicle chargers installed worldwide, of which 6.5 million chargers were private light-duty vehicle (LDV) slow or normal chargers.[55] The stock of chargers increased by 40% from 5.2 million in 2018 (Figure 1.7).

Figure 1.7 Global stock of electric LDV chargers, 2013-19



Notes: Private chargers include electric vehicle supply equipment (EVSE)[56] charging via both dedicated circuits and non-dedicated charge points.[57] Estimates for private chargers assume that each electric car is serviced by 1.1 private chargers on average (level 1 or level 2, either at home or workplace). These account for the majority of EV charging in all countries except China and Japan.[58] The estimates for China and Japan are lower (EVs are being deployed in dense urban areas), at 0.7 chargers per EV for 2019. This is based on a sample survey of 30% of electric car owners conducted by the China Power Consortium and China Electric Vehicle Charger Infrastructure Promotion Alliance (Chinabaogao, 2019; EVCIPA, 2020). The survey estimates that 70% of EV owners have access to at least one private charger at home and/or workplace, and this fraction is assumed to be representative of the population. For years prior to 2018, a ratio of 0.8 chargers per EV is used for China and Japan, in line with analysis conducted in *Global EV Outlook 2018 (IEA, 2018b)* and *Global EV Outlook 2019* (IEA, 2019b).

Sources: IEA analysis based on EVI country submissions, complemented by AFDC (2020b); Chinabaogao (2019); EAFO (2020a); ECF (2018); Engel (2018); EV-Volumes (2020); Mathieu (2018); Nicholas (2019); T&E (2020); ZapMap (2019).

LDV chargers topped 7 million in 2019 and the vast majority are private chargers.

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[55] Normal or slow charging refers to charging power less than or up to 22 kW and the distinction is mostly region specific. For example, in the European Union, the European Alternative Fuels Observatory (EAFO) classifies chargers rated up to 22 kW as normal, whereas in the United States, they are classified as slow charge (EAFO, 2020a; AFDC, 2020). Nomenclature on slow and fast charging is specific to the context of EV charging and their relative comparison is not based on fuelling rates at conventional liquid fuel pumping stations. Throughout the remainder of this section as well as in any other section in the report where charging rates are referred, no distinction is made between slow and normal charging. Home and workplace chargers are slow chargers that provide power less than or up to 22 kW. Fast chargers provide more than 22 kW. For additional details about charger classification by rated power, refer to Global EV Outlook 2019 (IEA, 2019b).

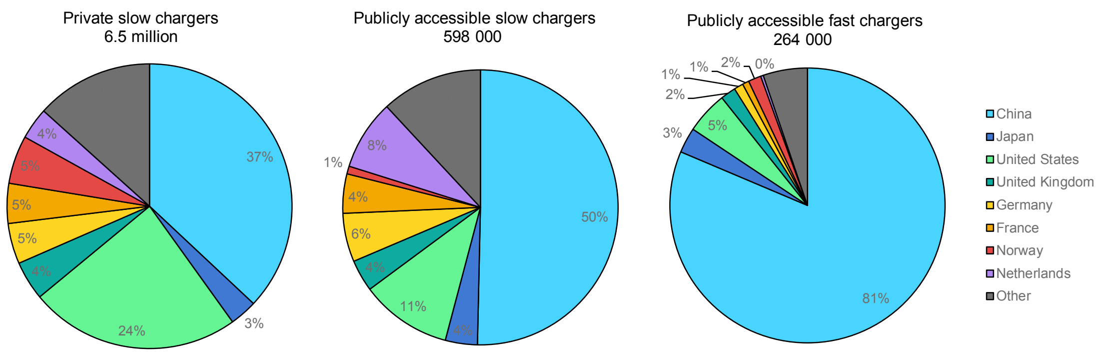
[56] EVSE is generally used to denote any off-board equipment to supply energy to charge the vehicle. It consists of charging cord, charge stands, attachment plugs, power outlet, vehicle connector and miscellaneous hardware for protection (SAE, 2017).

[57] Dedicated circuits are capable of both converting power (from direct to alternating current) and of modulating the rate of power transferred to ensure charging power does not exceed the on-board rated power capabilities of the vehicle. Non-dedicated charge points are typically 110/220 V sockets.

Private chargers

Private chargers accounted for about 90% (6.5 million) of the worldwide LDV chargers in 2019. Convenience, cost-effectiveness and a variety of support policies (such as preferential rates, equipment purchase incentives and rebates) are the main drivers for the prevalence of private charging (Beach, 2019). Across many EV markets, private home and workplace charging are the preferred locations. Home charging accessibility depends on the built environment and is closely associated with population density, penetration of dwelling units with a garage or carport, and the local EV adoption rates (Wolbertus, 2020). Since the minimum infrastructure for home charging, namely a compatible electrical socket and charger plug, already exists in homes, it is difficult to accurately estimate the number of private chargers. The second most preferred private charging modality is workplace charging.[59] On average, the share of total energy for EVs charged at home and workplace is estimated to be more than 85% in the European Union, United Kingdom and United States (Göhlich, 2018; Cenex, 2018; Mathieu, 2018; T&E, 2020). The China EV Charging Infrastructure Promotion Alliance in a 2019-20 report and survey estimates that 70% of EV owners in China have access to private chargers. (Chinabaogao, 2019; EVCIPA, 2020).

Figure 1.8 Private and publicly accessible chargers by country, 2019



Sources: IEA analysis based on country submissions, complemented by Chinabaogao (2019) and (EAFO, 2020a).

The vast majority of electric light-duty vehicle chargers are private chargers. China accounts for 80% of publicly accessible fast chargers compared to 47% of the world's electric light-duty vehicle stock.

[59] Workplace charging typically limits access to individuals affiliated with the employer.

Publicly accessible chargers

Light-duty vehicles

Publicly accessible chargers accounted for 12% (862 000) of global LDV chargers in 2019, of which 598 000 (8%) were slow and 263 000 (4%) were fast chargers.[60] The global number of publicly accessible chargers per electric LDV slightly decreased from 0.13 in 2018 to 0.12 at the end of 2019 with the expanding electric LDV stock, but is still higher than the European Union recommended target of 0.10 (Spöttle, 2018; European Commission, 2019). Globally, the number of publicly accessible charging points (slow and fast charging) increased by 60% in 2019 compared with the previous year. Much of this increase was in China, which continues to lead with the implementation of publicly accessible chargers, accounting for nearly 60% (515 000) of worldwide publicly accessible chargers installed in 2019. China was home to 80% of global publicly accessible fast chargers and 50% of publicly accessible slow chargers installed in 2019 (Figure 1.8). Substantial regional variations exist in the power capacity (kW) of publicly accessible chargers. Publicly accessible slow chargers dominate in the United States and the European Union accounting for 80-85% of the new charger installations, whereas in China, they represent less than 60%.

Buses

The global stock of electric bus chargers rose 17% in 2019 (184 000 units) compared to 2018 (157 000).[61] China continues to be the forerunner in electrifying its buses and accounts for 98% of the global electric bus stock and 95% of the global stock of dedicated bus chargers. In the European Union, Sweden leads in number of bus chargers installed in 2019.

The charging infrastructure needs of electric buses are determined by service frequency and dwelling times (the time that a vehicle stops at a scheduled stop without moving), occupancy and most importantly by the charging strategy. Compared to passenger cars, the driving routes and origin-destination choices of buses are more uniform, but they have higher charging energy requirements. These operational aspects dictate the number of chargers, capacity or rated power of the charger and its location.

[60] The number of publicly accessible fast chargers nearly doubled from 141 000 in 2018 to 263 000 in 2019. The number of publicly accessible slow chargers increased by 47% in 2019 (from 396 000 in 2018 to 583 000 in 2019).
[61] It is assumed that they are publicly accessible since the majority of the bus stock is used for public transport. Disaggregation of bus stock into public bus fleets and private bus fleet is not included due to lack of data.

Overnight depot charging and on-route opportunity charging are the usual charging strategies for electric bus fleets in many cities in China, the Europe Union and the United States (Houbbadi, 2019; Horrox, 2019; Göhlich, 2018). There are three main technology options in commercial use for charging: plug-in, pantograph and inductive or wireless charging. Plug-in chargers rated 150-250 kW are commonly used for overnight depot charging. Pantographs are better suited for on-route opportunity charging in the United States and the European Union. Plug-in chargers up to 400 kW are being deployed in China (ResearchAndMarkets, 2020). Though not as widely deployed as conductive or pantograph charging, high power (300 kW or more) wireless inductive charging is increasingly being tested in pilot projects (Electrive, 2020; RTA, 2020). High power chargers are especially important for heavy-duty fleet electrification.[62]

[62] For further details refer to the Charging infrastructure for heavy-duty electric trucks section in this report.

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Chapter 2. Policies and strategies to deploy electric vehicles and charging infrastructure

Electric vehicle policies

Introduction

The deployment of electric vehicles over the past decade was driven by ambitious government policies to reduce oil demand in transport, not least with a view to the environmental benefits of tackling air pollution and climate change. This chapter provides an update of electric vehicle (EV) policy status and an overview of key policy developments in 2019, and to some degree early 2020. It provides focussed EV policy updates for Canada, Chile, People's Republic of China (hereafter, "China"), European Union, India, Japan and United States.

Policies and targets around the world

Governments around the world have introduced policies to support the transformation of the transport sector. These policies take a variety of forms: national greenhouse gas (GHG) reduction targets for transport; fuel efficiency targets and carbon dioxide (CO_2) emission standards; EV stock and sales targets and/or mandates; financial support to consumers and manufacturers; charging infrastructure regulations and deployment support. An overview of EV targets and their role in decarbonising transport for selected countries is provided in Annex B.1 (light-duty vehicles) and Annex B.2 (heavy-duty vehicles).

In recent years these policies increasingly have been accompanied by a longer term vision to phase out internal combustion engine (ICE) vehicle sales in the mid to long term and to achieve 100% EV sales or stock, in particular in Europe (Table 2.1). Norway has announced a target that all new cars and light vans sold in 2025 shall be zero-emission vehicles (ZEVs). Several other countries have announced targets for 2030, and the United Kingdom by 2035. In December 2019 France passed a law that aims to phase out sales of cars that burn fossil fuels by 2040 (Assemblée Nationale, 2019).

Similar objectives by 2040 are under consideration in Spain. Beyond Europe, policy target announcements have been made by Canada for 100% light-duty ZEVs by 2040 and similarly by Cabo Verde, Costa Rica, Israel, Japan, Mexico and Sri Lanka with target dates between 2030 and 2050 (Table 2.1).

Ambitious targets and policies will send a strong signal both to industry and new car buyers, as well as affecting resale value. Such objectives complement ICE restricted access zones that have been established or are under consideration in some major cities.[1] Many include a vision for the mid and long term with EV deployment targets and schedules for phasing out ICEs set out in policy documents (see Annex B.1 and B.2). Nevertheless many governments need to develop more detailed implementation plans and bring clarity to the scope of the bans (for example whether hybrid vehicles are included) (Plötz et al., 2019).

Table 2.1 National electric car deployment targets

Country	2021-22	2025	2030	2035	2040	2050
Colour code	Green: relative to vehicle sales		Blue: relative to vehicle stock		Yellow: full ICE phase out or 100% EV target	
Asia[a]						
China (EV30@30 signatory)[b]		25% NEVs (PHEV, BEV, FCEV)				
Indonesia		2 200 EVs				
Japan (EV30@30 signatory)			30-40% HEV, 20-30% BEV, PHEV, 3% FCEV			100% sales of HEV, PHEV, BEV, FCEV
Korea	430 000 BEVs 67 000 FCEVs (2022)		33% BEV, FCEV			

[1] Examples include: Hamburg and Stuttgart where diesel cars are banned. Rome will ban diesel cars in 2024. Paris aims to ban diesel cars by 2024 and all fossil fuel powered cars by 2030. Bans on ICE vehicles by 2025 in Athens, Madrid and Mexico City. Ban on ICE vehicles by 2030 in: Amsterdam, Barcelona, Copenhagen and London (Plötz et al., 2019; Reuters, 2020a; Bavarian News, 2019).

Country	2021-22	2025	2030	2035	2040	2050
Malaysia			100 000 EVs			
Pakistan			30% EV		90% EV	
Sri Lanka					100% electric or hybrid vehicle stock	
Thailand				1.2 million EVs (2036)		
Europe						
European Union		13 million ZEV, LEV				
Denmark			1 million electrified vehicles	100% ZEV sales		
			no sales of new diesel or petrol car			
Finland (EV30@30 signatory)			250 000 BEV, PHEV, FCEV			
France (EV30@30 signatory)		500 000 PHEVs 660 000 BEVs (2023)	1.8 million PHEVs 3 million BEVs (2028)		No sales of new cars and vans using fossil fuels	
Germany			7-10 million BEV, FCEV			All passenger vehicle sales to be ZEV[c]
Iceland			No new registrations of diesel and gasoline cars			
Ireland			500 000 EVs			
			No new registration			

Country	2021-22	2025	2030	2035	2040	2050
			s of ICE cars			
Italy			6 million “electrically powered” vehicles of which 4 million BEVs			
Netherlands (EV30@30 signatory)		15 000 FCEVs	300 000 FCEVs			
			100% ZEV sales			
Norway (EV30@30 signatory)		100% ZEV sales				
Poland		1 million EVs				
Portugal			30% ZEVs		No sales of ICE (tbc[d])	
Slovenia			17% EV			
			100% EV sales			
Spain			5 million EVs		100% ZEV sales	
Sweden (EV30@30 signatory)			No sales of new diesel or petrol cars			
United Kingdom (EV30@30 signatory)			50-70% EV	No sales of new ICE[e]		
North America						
Canada (EV30@30 signatory)		825 000 ZEVs (PHEV, BEV, FCEV)	2.7 million ZEVs		14 million ZEVs	
		10% ZEV	30% ZEV		100% ZEV sales (BEV, PHEV, FCEV)	
United States (selected states)		3.3 million ZEVs (PHEV, BEV,		.		All passeng er

Country	2021-22	2025	2030	2035	2040	2050
		FCEV) in 11[f] states				vehicle sales to be ZEV in 10 [g] States
Other countries						
Cabo Verde		35% EV	70% EV	100% EV sales		
Colombia		10% ZEV	600 000 EVs			
Costa Rica				25% ZEV		100% ZEV sales
Chile						40% EV
Israel*		177 000 EVs	1.4 million EVs 100% EV or NG vehicle sales			
New Zealand	64 000 EVs (2021)					

* 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 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.

Notes: In this table, the acronyms used reflect how the vehicle technologies are referred to in the various announcements:
EV = electric vehicles (used when announcements mention electric vehicles without further precision); HEV = hybrid electric vehicle; plug-in hybrid electric vehicle (PHEV), battery electric vehicle (BEV) and fuel cell electric vehicle (FCEV) are used when announcements refer specifically to those technologies; ZEV = zero-emission vehicles; NEV = new energy vehicles; LEV = low-emission vehicles (LEV in the European Union context refers to vehicles with tailpipe emissions below 50 grammes per kilometre); NG = natural gas.

[a] Within Asia, India is also an EV30@30 Campaign signatory.

[b] Countries that joined the EV30@30 Campaign set a collective aspirational goal to reach 30% sales share for EVs across passenger light-duty vehicles (PLDVs), light-commercial vehicles (LCVs), buses and trucks by 2030 (CEM-EVI, 2019).

[c] As part of the ZEV Alliance membership.

[d] Tbc = to be confirmed. Portugal raised the question of an ICE ban in 2018 (Publico, 2018). It has not been decided yet.

[e] A phase out of ICE vehicles by 2040 had been announced in the United Kingdom. Though in February 2020 a consultation process got underway which is considering an earlier target of 2035 and whether HEVs and PHEVs will be part of the phase-out.

[f] The California Air Resources Board (CARB) manages the Zero-Emission Program (ZEV) which includes PHEV, BEV and FCEV. Ten other states have adopted the programme: Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont.

[g] As part of ZEV Alliance membership: California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont and Washington.

Source: All sources can be found in the detailed tables in Annexes B.1 and B.2.

EV purchase incentives

Many countries are encouraging EV purchases with financial support in order to address the higher upfront cost of an EV and to stimulate market development. Table 2.2 gives an overview of selected national electric car purchase incentive policies that are applicable to private consumers. These incentives generally are also valid for company cars and in some cases are accompanied by dedicated measures that apply to company cars. The Netherlands, for example, applies income tax reductions on the private use of electric company cars. Such measures for company cars can be a significant driver of EV sales.

The vast majority of subsidies for the purchase of a battery electric vehicle (BEV) are in the range of EUR 4 000-6 000 (USD 4 500-6 800). Norway does not offer a purchase rebate but provides a substantial tax exemption.[2] Buyers of BEVs in Japan benefit from both a purchase rebate and a tax exemption. In some countries, customers can also rely on additional financial support at the sub-national level. In addition, many countries have introduced CO_2 based taxes that penalise fossil-fuelled vehicle sales. To some extent, this provides a mechanism that tends towards revenue-neutrality for governments to promote low- and zero- emission vehicles (e.g. the "bonus-malus" type schemes in France and Sweden).

Some countries that are planning for mass EV deployment, such as China, are restructuring their incentive programmes and reducing direct subsidies. Other countries are introducing subsidy caps based on the vehicle retail price, which aims to avoid subsidising the purchase of premium EVs, such as Belgium, Canada, France, Germany, India, Spain and United Kingdom (Table 2.2).[3]

[2] Analysis of purchase subsidies and tax exemption schemes in Nordic countries is detailed in *Nordic EV Outlook 2018: Insights from leaders in electric mobility*, in particular Figure 2.5 (IEA, 2018a).

[3] For further information on the evolution of EV support policies in the main markets, i.e. China, Europe and United States, see Chapter 1 sections: Electric mobility developments in the 2010s and Electric car market in 2019.

Table 2.2 National electric car purchase incentives in selected countries

Country	Purchase subsidy	Tax reduction	Comments
Austria	EUR 1 500 (USD 1 700) (BEV, FCEV) EUR 750 (USD 850) (PHEV)		Electric range to be >50 km. For cars with maximum retail price of EUR 50 000 (USD 56 000). Diesel powered PHEVs excluded.
Belgium	EUR 2 000 - 4 000 (USD 2 300 - 4 500)		Four rebate levels, depending on retail price. In Flanders region, EV purchase incentives were abolished in January 2020.
Canada	CAD 5 000 (USD 3 700)* (BEV, FCEV, PHEV**)		* For cars with maximum retail price under CAD 45 000-60 000 (USD 33 600-44 800) (depending on car type). ** PHEV with battery capacity > 15 kWh.
China	CNY 16 200 (USD 2 300) (BEV*) CNY 22 500 (USD 3 200) (BEV**) CNY 8 500 (1 200) (PHEV***)	Exemption of purchase tax (10%).	Maximum retail price CNY 300 000 (USD 42 400). Depending on electric range * If 300 km ≤ range <400 km. ** If range ≥400 km. *** If range ≥50 km.
France	EUR 6 000 (USD 6 800)* / 3 000 (USD 3 400)** (BEV, FCEV and PHEV < 20 gCO_2/km)	No registration tax in many sub-national regions.	* Maximum retail price EUR 45 000 (USD 50 800), ** EUR 60 000 (USD 67 800) (not applying to FCEV). Subsidy can be increased if an old car is scrapped (depending on revenues).
Germany	EUR 6 000 (USD 6 800)* / 5 000 (USD 5 600)** (BEV)		* Maximum retail price EUR 40 000 (USD 45 200).

Country	Purchase subsidy	Tax reduction	Comments
	EUR 4 500 (USD 5 100)* / 3 750 (USD 4 230)** (PHEV)		** Retail price between EUR 40 000 (USD 45 200) and 65 000 (USD 73 400).
India	INR 10 000 (USD 130) / kWh* Capped to INR 300 000 (USD 4 000)	Income tax deduction of INR 150 000 (USD 2 000) on interest paid on electric vehicle loans.	* For PHEV and BEV, with a cap of 20% of vehicle retail price and for cars with retail price < INR 1 500 000 (USD 19 900).
Italy	0-20 gCO_2/km: EUR 6 000 (USD 6 800)* / 4 000 (USD 4 500)** 21-70 gCO_2/km: EUR 2 500* (USD 2 800) / 1 500 (USD 1 700)**	BEV exempt from annual ownership tax during five years after registration.	* When scrapping an old car (Euro 1-4 generations) at the same time as buying the EV. ** Without scrapping an old car.
Japan	Up to JPY 200 000 (USD 1 800) (PHEV*) Up to JPY 400 000 (USD 3 700) (BEV**) Up to JPY 2 250 000 (USD 20 800) (FCEV)	No purchase and weight taxes.	* Depending on electric range: JPY 200 000 (USD 1 800) if range > 40 km. ** Depending on range: JPY 400 000 (USD 3 700) if range > 400 km.
Korea	KRW 8 000 000 (USD 6 700) (BEV) KRW 22 500 000 (USD 18 800) (FCEV)		
Netherlands	Purchase subsidy under preparation (likely to apply in July 2020).	Several tax exemptions and reductions.*	* Since 2018, taxes on ZEV purchase increase progressively and will reach standard levels in 2026.
Norway	No purchase subsidy	BEV exempt from VAT (25%) and three purchase taxes.*	* Weight-, CO_2- and NOx-based taxes.
Portugal	EUR 3 000 (USD 3 400)		Maximum retail price EUR 62 500 (USD 70 600).

Country	Purchase subsidy	Tax reduction	Comments
Spain	EUR 1 300 - 5 500 (USD 1 500 - 6 200)* (PHEV and BEV)		* Depending on electric range: EUR 5 500 (USD 6 200) > 72 km. Only applicable if retail price < EUR 40 000 (USD 45 200).
Sweden	SEK 60 000 (USD 6 500)* (BEV and FCEV)		* Payable after six months of ownership. Capped at 25% of retail price.
United Kingdom	Up to GBP 3 000 (USD 3 800)* (BEV and PHEV**)		* Capped at 35% of retail price. Only for cars < GBP 50 000 (USD 63 600). ** If < 50 gCO_2/km and electric range >112 km.
United States		Tax credit up to USD 7 500 (PHEV and BEV)*	* Depending on battery capacity (min. 5 kWh). Gradual phase out for each manufacturer after it has sold 200 000 cars.

Notes: VAT = value-added tax; NOx = nitrogen oxides. This table applies mainly to private cars and displays incentives applicable in March 2020. In some cases, incentives can be increased for large capacity cars (seven seaters). Company cars can benefit from additional tax exemptions.

For China: battery energy density and energy efficiency are also considered in the calculation of the subsidy. Incentives shown are those applicable in April 2020 (the purchase subsidy was reduced by 10% from end-2019 levels). At maximum, 2 million vehicles can be subsidised per year.

For Germany: the EUR 6 000 subsidy for BEVs can be provided at 50% from the government and 50% directly from the automaker.

For France and Germany: changes in incentives were announced at the end of May 2020, and at the beginning of June 2020, respectively. These changes are not reflected in this table. For further details, see section Major EV strategy and purchase support changes in EU member states.

Sources: Austria: Umwelt Foerderung (2020); Belgium: Vlaanderen (2019); Canada: Government of Canada (2020a); China: Ministry of Finance (2020); France: Ministère de la Transition Ecologique et Solidaire (2020); Germany: ADAC (2020), Autobild (2020), Reuters (2020b); India: FAME II (2019), World Economic Forum (2019); Italy: Government of Italy (2019); Japan: METI (2018); Korea: Electrive (2019); Netherlands: National Climate Agreement (2019), RVO (2020), Rijksoverheid (2020); Norway: Norsk Elbilforening (2020), Reuters (2020b); Portugal: Fundo Ambiantal (2020); Spain: Boletín Oficial del Estado (2019); Sweden: Transport Styrelsen (2019); United Kingdom: UK Government (2020); United States: US DOE (2020a), US DOE (2020b).

Policy developments in major markets

This section updates the policy landscape for EVs in seven important markets: Canada, Chile, China, European Union, India, Japan and United States.[4]

Canada

Canada has set zero-emission vehicle targets of 100% of new vehicle sales by 2040. The national government provides a comprehensive suite of measures in support of these targets, ranging from consumer awareness, infrastructure development and deployment to purchase incentives. It is supported by the Alternative Fuel Infrastructure Deployment Initiative which aims to establish a coast-to-coast network of fast charging infrastructure. An additional 2019 budget of CAD 130 million (USD 97 million) was established to support the deployment of ZEVs over five years (April 2019 to March 2024) (Government of Canada, 2019a).

Vehicle policies

Federal level

The national government has set ambitious targets for the transformation of the transport sector. The targets are to reach ZEV sales of 10% by 2025, 30% by 2030 and 100% by 2040. By comparison, sales of ZEVs in 2019 accounted for 3.5% of new car sales.

Several incentives at the federal level support the development and deployment of ZEVs. The main ones are a point-of-sale incentive and a tax credit for ZEVs purchased or leased after 1 May 2019. The incentives apply to BEVs, PHEVs and FCEVs, while the tax credit supports companies purchasing vehicles for commercial use.

Canada has introduced a GHG emissions standard for light-duty vehicles. Historically, the Canadian standards have been aligned with the US fuel economy standards due their integrated vehicle markets. Canada's government is currently undergoing a mid-term evaluation of the GHG emissions standard, in line with the underlying regulation. Considerations will be taken to the recent final rule on the US fuel economy standards (Government of Canada, 2014).

[4] Specific policies related to the traceability and life-cycle impacts of EV batteries are discussed in Chapter 5.

New funding of CAD 300 million (USD 220 million) in the 2019 budget is available to support the ambitions of the ZEV targets. Among other approaches, the federal government will provide additional funds to encourage companies to purchase medium- and heavy-duty ZEVs through accelerated capital cost allowances (Government of Canada, 2020b).

In December 2019, the prime minister requested the minister of Infrastructure and Communities to work with the provinces and territories to introduce new funding for the purchase of 5 000 zero-emission school and transit buses over the next five years (Government of Canada, 2019b).

Provincial level

Provinces in Canada have the right to adopt policies and incentives on top of existing incentives at the federal level. At the forefront, British Columbia and Québec are the only provinces that currently offer financial incentives for the purchase of ZEVs (CAA, 2019). ZEV sales in the two provinces combined represented almost 80% of the total Canadian ZEV market in 2019.[5] In March 2020, the Québec's government approved a budget for 2020-21 that allocates additional funding to support ZEVs deployment. It extends, *inter alia*, the purchase rebate for EVs until March 2026 (Transition Energétique Québec, 2019). Québec is also the first province in Canada to adopt a ZEV mandate for car manufacturers: it targets a sales share of 15.5% light-duty ZEVs by 2025 to help bolster the market. The mandatealigns with the regulations in California and 14 other states (UCS USA, 2019). British Columbia joined this group by adopting a 100% ZEV target in its Zero Emissions Vehicle Act in May 2019 (Government of British Columbia, 2019). The provincial government recently renewed funding for the Clean Energy Vehicle point-of-sale programme, which offers up to CAD 3 000 (USD 2 200) off the purchase price for BEV and FCEV cars, and CAD 1 500 (USD 1 100) for PHEVs (CEVforBC, 2019).

Charging infrastructure policies

The federal government allocated CAD 180 million (USD 130 million) in the 2016-17 budget to support: the development of a coast-to-coast fast charging EV network along the national highway system; natural gas refuelling stations along freight corridors; hydrogen refuelling stations in metropolitan areas; demonstration of next-generation charging technologies and the development of enabling bi-national codes and standards. In 2019, CAD 130 million (USD 97 million) was allocated in the

[5] The Canadian ZEV sales in 2019 reached 56 000 vehicles. Around 17 000 of these were sold in British Columbia and 27 000 in Québec.

new Zero-Emission Vehicle Infrastructure Program to support the deployment of charging in public places, multi-unit residential buildings, workplaces and commercial areas, as well as for fleets and transit applications. (Government of Canada, 2019a).[6]

The provinces of British Columbia and Québec provide rebates for the purchase and installation of chargers in individual homes, multi-unit buildings and workplaces. Since April 2019, employers in Québec are no longer required to provide free charging to their employees (Transition Energétique Québec, 2019).

Chile

Chile has a relatively low-carbon electricity mix which offers opportunities to electrify parts of the transport sector to reduce CO_2 and pollutant emissions. Significant progress to deploy EVs has been made over the past three years. Chile has set out short- and long-term targets for the electrification of private cars and public transport. To support the targets, considerable legislative efforts have been taken to stimulate demand for EVs and charging infrastructure, as well as providing funding to boost the domestic lithium industry and lithium-based products.

Vehicle policies

Chile's Energy Roadmap 2018-2022 sets a target to increase the existing number of electric cars tenfold by 2022 compared to 2017 (2 430 units by 2022) (Ministry of Energy, 2018). The National Electromobility Strategy includes targets to electrify 100% of public transport by 2040 and to achieve a 40% penetration rate of electric cars in the private stock by 2050 (Ministry of Energy, 2017). In 2019, under a public-private partnership, Enel X, BYD and Metbus (an electric utility, a bus manufacturer and a bus operator, respectively) launched Latin America's first 100% electric bus corridor.[7]

The Taxi Renewal Programme (Renueva tu Colectivo) provides access to financing schemes for the renewal of taxis, including for the acquisition of electric and hybrid vehicles (Chile Atiende, 2020). In 2019, three-quarters of Chile's regions opened a

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[6] The first stage of the programme delivered 102 fast charging stations for EVs and 3 hydrogen refuelling stations. Current projects are to deliver 526 fast charging and 12 refuelling stations. The second stage intends to deploy 900 EV fast chargers and 12 hydrogen fuel cell stations by 2026 (Government of Canada, 2019a).

[7] More information on Santiago de Chile's electric bus deployment is in the section on Electric bus deployment in cities: lessons learned in this chapter.

call for submissions from taxi owners to benefit from the scheme (Ministry of Transport and Telecommunications, 2019).[8]

A new energy efficiency law is in the approval process (Senate, 2019). Part of it seeks to establish energy efficiency standards for new vehicles sold by car manufacturers or importers. To encourage more electric and hybrid vehicles, multipliers of up to three per vehicle may be applied in the calculation of the sales average car efficiency for manufacturers or importers (Ministry of Energy, 2019a).

In November 2019, a decree establishing technical and safety requirements for EVs entered into force (DS 145 of the Ministry of Transport and Telecommunications). Among other aspects, it requires electric vehicles to be identified by a badge and imposes requirements regarding signage in high-voltage circuits. These standards also regulate the types of connectors allowed for EV charging.

Charging infrastructure policies

The government set a goal of installing 150 publicly accessible charging points by the end of 2019 and used public-private approaches which had installed 112 by year's end. The government has committed to developing standards for electric mobility, including for charging infrastructure (Ministry of Energy, 2019b).[9] The Ministry of Energy is mandated to regulate the inter-operability of the EV charging infrastructure.

A technical paper on electromobility was set out for consultation by the government in December 2019 for a period of two months (Circular No. 21826). It includes technical provisions related to the installation of charging points, including technical standards (SEC, 2019b) (Ministry of Energy, 2019a).

Industrial policies

Chile accounts for 52% of the world's lithium reserves, mainly in the form of brines (Ministry of Mining, 2019). Lithium is in high demand worldwide, particularly for use in producing batteries for EVs.[10]

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[8] Antofagasta, Araucanía, Arica and Parinacota, Atacama, Aysén, Bío Bío, Los Lagos, Los Rios, Magallanes, Maule, O'Higgins and Valparaíso.

[9] Current standards and procedures are the Electronic Procedure for Installation of Charging Points (TE-6) by the Superintendence of Electricity and Fuels (SEC, 2019a), which in particular allows geo-localisation data collection of the charging infrastructure. With the TE-6 database, the Ministry of Energy, through the Electromobility Platform, recently launched the "EcoCarga" application which indicates the locations of all public charging stations in the country, in addition to the technical characteristics of each point (Ministry of Energy, 2019c).

[10] In 2017, Chile produced 80 417 tonnes of lithium carbonate equivalent (LCE) and expects to increase the production to around 240 000 tonnes by 2022 (Ministry of Mining, 2018).

The government is strongly promoting the domestic lithium industry. This extends from extraction of raw material through the production of lithium-based products by national and foreign companies, specifically focussing on EV batteries. Policies to attract value-added battery industries offer local lithium products at preferential rates for a pre-determined duration.[11]

China

China has held a strong lead in electrifying road transport for a number of years. It accounts for almost the entire global stock of electric two-wheelers, buses and heavy-duty trucks. In addition, today almost every second electric car in the world is in China. This reflects the government's ambitious objectives and history of policy support to the New Energy Vehicle programme which includes BEVs, PHEVs and FCEVs. The government proposed an upwards revision of its NEV sales target in 2019, envisioning 25% by 2025, from 15-20% by 2025 previously (MIIT, 2019a).

At the national level, the policy framework for EVs has seen a gradual transition from direct to more indirect forms of subsidies and incentives, plus regulations. This has been accompanied by increasing support for charging infrastructure and other support services. As the level of national direct subsidies has been gradually reduced since 2016, provincial level governments stepped in to promote NEVs based on local circumstances and economic priorities.

Early signs related to the economic impacts of the Covid-19 pandemic show that many segments of China's automotive market have been significantly impacted by reduced demand, as well as by challenges along the complex automotive supply chain. Central policy makers have identified the automotive market as a primary target for economic stimulus packages with a number of policy updates expected to boost vehicle purchases in the remainder of 2020.

[11] See in particular the "Call for Added Value of Lithium" (Convocatoria de Valor Agregado de Litio)" (CORFO, 2019). In 2019, two of the three companies involved in the project withdrew their investment intentions, citing concerns about the timely scale-up of lithium supply in the country (Reuters, 2019). A new call is open and expected to be awarded in May 2020.

Vehicle policies

National level

NEV credit mandate

In 2018, the government introduced a mandatory credit policy for vehicle suppliers to boost domestic sales of NEVs. Major vehicle suppliers are required to reach NEV credit targets for their fleets (MIIT, 2017). The percentage targets are not for sales numbers but for credits. Each NEV is assigned a specific number of credits depending on metrics including electric driving range, energy efficiency and rated power of fuel cell systems. High performance vehicles get more credits (IEA, 2018b). This instrument has been critical in the reshaping of China's vehicle industry and the uptake of EVs, which help to address air pollution issues in urban areas.

The Ministry of Industry and Information Technology (MIIT) proposed an updated and tightened NEV credit scheme in 2019 by both setting new NEVs credit targets for 2021-23 and by establishing a new calculation method for NEV credits beyond 2021 (MIIT, 2019b). Automakers are obliged to reach NEV credit targets of 14%, 16% and 18% over the period 2021-23. Compared to the previous system, the revised approach implies a reduction in the number of credits allocated to BEVs and PHEVs and an increase in credits for FCEVs (Table 2.3).

Box 2.1 China NEV credits and sales: The example of the BJEV EU series

Take an example of the best-selling BEV car in China in 2019, the BJEV EU series. In the previous credit scheme such a vehicle would have been allocated 4.4 NEV credits, which would decline to 2.2 credits after 2021. So assuming that the weighted-average credits of EVs sold by a particular manufacturer in 2021 were 2.2 (and noting that the exact number of credits depends on the electric driving range, energy efficiency and rated power), to reach the NEV credit target for 2021 of 14%, the automaker would have to ensure that 6.4% (14 / 2.2) of their sales would be NEVs in 2021.

Collectively, the revision of the NEV credit calculation, the new credit targets and the additional revisions in the NEV mandate credit policy provide a significant stimulus to the supply of EVs in China's domestic market.

Table 2.3 Range of credits per vehicle type and targets in China's NEV programme

Year	Range of credits per vehicle BEV	PHEV	FCEV	NEV credit targets
Until 2020	1-5	2	1-5	2019: 10% 2020: 12%
From 2021	1-3.4	1.6	1-6	2021: 14% 2022: 16% 2023: 18%

Notes: Before 2020, the number of NEV credits was calculated as: i) BEV - (0.012 x electric range + 0.8) x efficiency adjustment factor; ii) PHEV - 2x efficiency adjustment factor; iii) FCEV - 0.16 x FCEV system rated power x efficiency adjustment factor. The efficiency adjustment factor depends on the vehicle energy consumption (kilowatt-hours [kWh] per 100 km) relative to its kerb mass (in kilogrammes). For further details about the adjustment factors before 2020 see ICCT (2018). After 2021, the number of credits per vehicle will be determined as: i) BEVs - (0.006 x electric range + 0.4) x efficiency adjustment factor; ii) PHEVs - 1.6 x efficiency adjustment factor; iii) FCEVs - (0.08 x FCEV system rated power x efficiency adjustment factor). For BEVs and PHEVs, after 2021 the threshold of the vehicle's efficiency to get an efficiency adjustment factor above 1 will be tightened.

Sources: MIIT (2017); IEA (2018b); MIIT (2019b).

NEV subsidy programme

China's NEV programme started in 2016 and its subsidy component is updated each year. The level of subsidy is determined based on three characteristics: vehicle electric driving range, energy efficiency and battery pack energy density. In 2019, the vehicle electric driving range threshold for the subsidy was raised to 250 km, up from 150 km in 2018. The subsidy for each vehicle category was reduced in 2019 by an average of 50% across categories, relative to 2018.[12] It was set to expire at the end of 2020. It has been extended to 2022 to cushion the impacts of the Covid-19 epidemic on NEV markets[13], with the following schedule: starting April 2020, the subsidy for cars will be reduced by 10% until end 2020 and by an additional 20% and 30% in 2021 and 2022. The subsidy is attributed for cars with a sticker price below CNY 300 000 (USD 42 400) (MOF, 2020).

[12] Subsidies for FCEVs have been stable in recent years (CNY 6 000/kW [USD 850/kW] with a limit of CNY 200 000 [USD 28 300] for passenger vehicles).They are included in the schedule for a gradual phase out. Though the Ministry of Finance is considering to allow local governments to provide direct subsidies for FCEVs after 2020 (EnergyTrend, 2019).

[13] During the EV-100 forum in January 2020 (and before Covid-19 began to have a major impact on China's auto industry), the minister of the MIIT announced that in order to stabilise market expectations and ensure the healthy and sustainable development of the industry, the 2020 NEV subsidy policy would remain relatively stable and the amount of (direct) subsidy would not be drastically reduced (to zero) (People's Daily, 2020)

Fuel economy standard

A fuel economy standard for light-duty vehicles has been in place in China since 2005. An updated version for 2021-25 was announced in January 2019, with further details finalised in January 2020. The standard, to be phased in gradually from 2021, sets a 4L/100 km target for the country's new vehicle fleet in 2025. Through a fuel economy credit scheme, OEMs are obliged to reach that target, or cover any credit deficit by either transfers, past carry-overs, or NEV credit surplus. Otherwise, OEMs will be unable to obtain approvals for new models less efficient than the fuel economy standard. During the period, EV and efficient ICE vehicles will receive favourable treatments when calculating each OEM's fuel economy. A separate standard on EV efficiency sets a voluntary target on energy consumption based on weight classes (MIIT, 2019c).

Subnational level

More than 29 provinces and cities in China have announced non-subsidy EV promotion policies. Many provide buyers of electric cars easier access to licence plates, waivers from traffic restrictions, and/or reductions in parking fees or free parking (Table 2.4). In light of the Covid-19 pandemic, in February 2020 China’s president underpinned the need to stabilise automobile sales and encourage a relaxation of car permit quotas in cities (Wall Street Journal, 2020); hence many of the city and provincial level policies outlined below have been temporarily relaxed or suspended. This was followed by an announcement from the Ministry of Commerce and the National Development and Reform Council requesting that local governments support NEV markets through a variety of measures.[14] Measures have been announced in China’s largest car markets: Beijing, Shanghai and Guangzhou.

Such measures do not only target NEVs; they are meant to provide a stimulus to the car market as a whole. This bears risks for NEVs in 2020. For example, additional permit quotas can have a negative impact on the NEV market as most cities with quota policies exclude NEV purchases from these restrictions, and so relaxing quotas may lead to increased ICE vehicle sales. The exception is Beijing, where the expected new quotas are all intended for NEVs.

Hainan province, an island in the south, was the first of China’s 31 provinces to develop a comprehensive plan and official targets for a full transition to NEVs by

[14] In addition to an optimisation of car licence plate permit measures, these include subsidies, cash-for-clunker programmes, promoting the second-hand car market and relaxing restrictions on the use of pick-up trucks.

2030. The provincial government set out its Development Plan for Clean Energy Vehicles in 2019 (The People's Government of Hainan Province, 2019).

Table 2.4 EV promotion policies based on plate access, traffic restrictions and parking in China, 2019

Province or city	Car plate restrictions	Direct/easier access to car plate[15]	Circulation restrictions[16]	Waivers from traffic restrictions	(Partially) free parking
Beijing	Yes	Yes, independent quota for BEV	Yes*	Yes, for BEV only	
Tianjin	Yes	Yes	Yes*	Yes	
Hangzhou	Yes**	Yes	Yes*	Yes	
Shanghai	Yes**	Yes			
Hubei					50% off
Guangzhou	Yes**	Yes			
Shijiazhuang					
Gansu					50% off
Harbin					When charging
Yantai		Yes, plate ID			
Nanjing					First hour
Hainan	Yes	Yes			Yes
Shenzhen	Yes**	Yes***			First 2 hours
Xi'an			Yes*	Yes	First 2 hours
Chengdu			Yes*	Yes	First 2 hours or 50% off
Chongqing			Yes*	Yes	

[15] Chinese cities with licence plate lotteries, quotas and/or additional charges often provide reductions in the price, separate lotteries with better odds of success, or complete exemptions to these restrictions for NEVs. These are summarised in this third column of the table.
[16] Circulation restrictions restrict private cars from driving within a certain designated area of the city (often, within one of the outer concentric ring roads that encircle Chinese cities) on one out of five weekdays, based upon the last numbers of their license plates.

Province or city	Car plate restrictions	Direct/easier access to car plate[15]	Circulation restrictions[16]	Waivers from traffic restrictions	(Partially) free parking
Inner Mongolia					Yes
Shanxi					Yes
Yunnan					First 2 hours
Xinjiang					When charging
Hubei					50% off

Notes: Provinces are shown in underlined italics in the first column, and cities are shown in normal typeface. All restrictions listed here refer to privately owned light-duty vehicles; various other restrictions apply to commercial trucks. This table was compiled based on publically available information by Lei Xiang, and was verified and updated by colleagues at the China Automotive Technology and Reseach Center Co., Ltd (CATARC).

* During the outbreak of COVID-19 in 2020, the city generally suspended the implementation of traffic restrictions. Chengdu began gradually putting back in place circulation restrictions on 7 April (Daily News, 2020), Beijing's restrictions went back into effect from 1 June, 2020 (Beijing Traffic Management Bureau, 2020); Xi'an's and Tianjin's restrictions both came back into force on 8 June (Bendibao.com, 2020);

** Hangzhou, Shanghai, Guangzhou, and Shenzhen have increased the quota for conventional car plates in 2020.

*** Shenzhen has added 10 000 car plates on the quota for PHEVs with lower application requirements in 2020.

Charging infrastructure policies

In March 2019, the Ministry of Finance, the MIIT and the National Development and Reform Commission issued a new subsidy policy. It sets out the aim to shift from subsidising local vehicle purchases to supporting infrastructure roll out (The People's Government of China, 2019).

China has been promoting three types of EV charging infrastructure:

- publicly accessible charging in cities
- private charging in residences
- enterprise/company based charging.

Many companies responded with new investment in charging infrastructure in 2019.[17] A number of local governments have also announced subsidies for charging

[17] In December 2018, the State Grid Electric Vehicle Service Co., China Southern Power Grid and three private companies (Teld New Energy Company, Star Charge and Lantian Weiye Clean Energy Fund Management Company) founded the Xiongan Lianxing Network Technology Company, China's largest EV charging operator. Located in the Xiongan Special Economic Zone (Hebei Province), the company now controls 80% of China's charging stations. Between late 2018 and mid-2019, five Chinese charging operators (Star Charge, CarEnergyNet, YKCharge, EVCDX and Kakuka) joined Germany's Hubject, a platform that aims to expand charging networks globally, thus adding 35 000 charging points to Hubject's network. The top-three companies operating public charging points in China are: TELD with 148 000; Star Charge with 120 000 and State Grid with 88 000.

infrastructure. For example, Shenzhen is proposing to provide CNY 400 (USD 60) per kilowatt-hour (kW) in subsidies for direct current (DC) charging facilities, CNY 200/kW (USD 30) for alternating current (AC) charging facilities over 40 kW and CNY 100/kW (USD 15) for those under 40 kW (Justice Bureau of Shenzhen Municipality, 2019).

As part of the central government's economic stimulus package to tackle the economic impacts of the coronavirus, subsidies for new charging facilities are expected. The State Grid has announced plans to increase investment in charging stations. The City of Beijing has outlined a policy to provide up to CNY 200 000 (USD 28 300) in subsidies per station for operators.

Industrial policies

To further promote the expansion of the NEV industry and to promote the development of a NEV industry that is well positioned for the export market, the government has introduced a ban on investment in newly established enterprises for ICE car manufacturing that does not respect a number of energy performance related requirements (IEA, 2018b). In addition, to address NEV production overcapacity challenges while ensuring the manufacturing of high quality vehicles, the Chinese Government introduced in January 2019 new requirements on NEV investments. For instance, NEV manufacturing companies must have an established research and development group, own patents related to EV technologies and offer after sales services to their customers (Sohu, 2019a; NDRC, 2019).

New extensive guidance for the battery recycling industry was issued in 2019 (see Chapter 5).

European Union

The European Green Deal, a major initiative that aims to bring the European Union towards net zero GHG emissions by 2050 and promote strong "clean" growth was presented by the European Commission in December 2019. It incorporates a number of actions across all economic sectors including more stringent CO_2 standards in order to accelerate the transition to sustainable and smart mobility. It reaffirms the European Union and its member states commitment to electrify portions of the transport sector (European Commission, 2019a). Over the last year, many EU member states introduced ambitious policies with the aim to accelerate the deployment of EVs and charging infrastructure.

Vehicle policies

New CO_2 emission performance standards for light-duty vehicles were adopted in April 2019 (European Union Regulation 2019/631). It extended the 2020 targets for new cars (95 grammes of carbon dioxide per kilometre [gCO_2/km]) and new vans (147 gCO_2/km) and sets specific emission targets for each manufacturer.[18] The new targets are defined as a percentage reduction with 2021 as starting point: 37.5% reduction for cars and 31% for light-commercial vehicles (LCVs). If a manufacturer exceeds its average emissions target, it has to pay a penalty. In order to support the uptake of new zero- and low-emission vehicles, the scheme gives credits to manufacturers that register high shares of vehicles emitting less than 50 gCO_2/km. Manufacturers exceeding production shares of 15% of zero- and low-emission cars and vans in 2025, and in 2030 production shares exceeding 35% for cars and 30% for vans, will be rewarded in the form of a less strict overall CO_2 target (European Commission, 2019b). The EU climate and energy 2030 targets will be hard to reach without including EVs.[19]

In 2019, the European Union introduced a CO_2 emissions performance standard for heavy-duty vehicles (European Union Regulation 2019/1242). The standards apply for large trucks which account for around 65-70% of the CO_2 emissions from heavy-duty road transport in the European Union. On an average, these trucks will need to be 15% more fuel efficient by 2025 and at least 30% more efficient by 2030, relative to a mid-2019 to mid-2020 period. As part of the 2022 review of the legislation, the Commission will assess whether the scope should be extended to other types of vehicles (European Commission, 2019c).

The Clean Vehicles Directive was revised in 2019 and sets mandatory minimum public procurement targets for LDVs, trucks and buses for the periods 2021-25 and 2026-30 to further promote the market uptake of EVs. The EU member states have various requirements based on their economic situation and air pollution exposure levels (European Commission, 2019d).[20]

Charging infrastructure policies

With the aim to raise ambition for EV charging infrastructure, as part of the European Green Deal, it was announced in 2019 that the Alternative Fuels Infrastructure

[18] This corresponds to 4.1 litres per 100 km (L/100 km) of petrol or 3.6 L/100 km of diesel.
[19] More information is available in *Global EV Outlook 2019*, in particular Box 3.2 (IEA, 2019).
[20] The targets for light-duty vehicles range from 17.6 % to 38.5 % for 2021-25 (vehicles with maximum tailpipe emissions 50 gCO_2/km) and 2026-30 (vehicles with 0 gCO_2/km) while targets for heavy-duty vehicles vary from 6 % to 15 % for 2021-25 and from 24 % to 65 % for 2026-30 among the EU member states.

Directive (AFID) (EU/2014/94) and the Trans-European Network for Transport (TEN-T) regulation will be reviewed in 2021. To date, the AFID has required EU members to set deployment targets for publicly accessible chargers for 2020, 2025 and 2030, with an indicative ratio of 1 charger per 10 electric cars (European Commission, 2019e). At the start of 2020 the number of publicly accessible charging points in the European Union was around 165 000 (European Fuels Observatory, 2020). The European Commission projects the need for 1 million charging points across the European Union by 2025 to support the accelerated deployment of EVs expected as an outcome of the new policies in the European Green Deal (European Commission, 2019a).

In May 2018, the European Union introduced stricter codes on new and renovated buildings to require EV charging infrastructure (Energy Performance of Buildings Directive EU/2018/844). Member states were obliged to transpose the new requirements into national legislations by 10 March 2020. As of 12 May 2020, 12 out of 27 EU members had done so (European Commission, 2020a).

Industrial policies

The European Commission's New Industrial Strategy for Europe in 2020, featured in the European Green Deal, is viewed as the main European Union growth strategy and is at the heart of the goal of becoming the world's first carbon-neutral continent by 2050. This strategy was re-confirmed in April 2020 by the European Commission as the impacts of Covid-19 pandemic were being recognised.

Moving forward and building upon the New Industrial Strategy, the European Commission will present a strategy for smart mobility in 2020. Several funding mechanisms including Horizon Europe and the EU Innovation fund as well as Important Project of Common European interest are in this context expected to be further developed with the aim to support the EU's industry objectives, which also benefit the EV industry. In addition, the European Battery Alliance is expected to be the main driver and industrial platform for building a European battery technology industry (European Commission, 2020b).

Major EV strategy and purchase support changes in EU member states

In 2019, several EU member countries advanced their ambitions to further deploy EVs. Germany and Italy announced new deployment targets. The Netherlands announced new commitments that will increase their existing EV objectives.

France

In late 2019, France issued the *Loi d'Orientation des Mobilités* (Mobility Orientation Law). It aims to decarbonise land transport by 2050 and sets out measures to reach this goal. Among them, it phases out the sale of vehicles that directly emit CO_2 as from 2040. It also defines EV deployment targets: in 2028, a combined stock of 3 million BEV and/or FCEV cars and 500 000 BEV and/or PHEV and/or FCEV LCVs. The law sets provisions to facilitate installation of charging points in collective buildings and higher quotas of low emissions vehicles when renewing large fleets of public or private vehicles. For areas that are regularly exceeding air pollutant limits, establishing low-emission zones will be mandatory by the end of 2020 (Assemblée Nationale, 2019).

In response to the Covid-19 crisis and its impact on the automotive industry, the French government has announced support measures for the sector at the end of May 2020 (Government of France, 2020). They include an increased subsidy for BEVs (EUR 7 000 [USD 7 900] instead of EUR 6 000 [USD 6 800]) and a subsidy for PHEVs (EUR 2 000 [USD 2 300]). The existing cash-for-clunker scheme is made available to a wider portion of French households and is increased for the 200 000 first demands (EUR 5 000 [USD 5 700] for electric cars, instead of EUR 2 500 [USD 2 800]). In order to generate a rapid recovery of car sales, these measures are only valid from June to December 2020. As part of this plan, the French government committed to accelerate charger deployment, targeting 100 000 publicly accessible chargers by the end of 2021, instead of 2022 previously.

Germany

In September 2019, Germany revealed its Climate Action Programme 2030, including to cut transport-related emissions by 40-42% by 2030. A package of measures was set out to encourage increased electrification of transport. Germany is targeting a combined BEV and FCEV stock of 7-10 million cars by 2030. Notably, Germany introduced provisions for all petrol stations in the country to also provide charging services. It also simplified the rules regarding the installation of charging infrastructure. To promote EV sales, the subsidy for the purchase of an electric, hybrid or fuel cell vehicle was increased in early 2020. It was reinforced in early June 2020 as part of a post Covid-19 national plan (Government of Germany, 2020). The subsidy applies to EV purchases below a sticker price of EUR 40 000 (USD 45 200) and the level of the subsidy varies by powertrain type: for BEVs it was increased to up to EUR 6 000 (USD 6 800)[21] and for PHEVs to EUR 4 500 (USD 5 100). This will

[21] Plus a possible EUR 3 000 (USD 3 400) additional subsidy directly from the automaker (Autobild, 2020)."

apply until the end of 2021. For EVs and PHEVs with a higher sticker price (up to EUR 65 000), the subsidy level is lower (Table 2.2). As of June 2020, the reduced tax for electric company cars is made available for cars up to EUR 60 000 (USD 67 800) (previously EUR 40 000 [USD 45 200]). Although not specific to cars, the national decrease of VAT rate from 19% to 16% for six months in 2020 (July to December) will also positively impact the sticker price of EVs. In late 2019, Germany announced a five-year extension of the annual vehicle tax exemption for EVs - which was due to expire in 2020 - and in June 2020 it was further extended from 2025 to 2030.[22]

Italy

The revised Integrated National Plan for Energy and Climate was released by the government in 2019. It highlights electric and hydrogen mobility as an essential instrument to reach the target of reduced carbon emissions in transport by 2030. According to the plan, Italy is targeting 6 million electrically powered vehicles by 2030, including 4 million BEVs. Italy recorded a huge increase in EV sales in 2019 relative to 2018. This reflects the 2019 introduction of a subsidy of up to EUR 6 000 (USD 6 800) for cars with rated emissions of less than 20 gCO_2/km (i.e. a few highly efficient PHEVs, or BEVs / FCEVs), if the buyer scraps an old car rated Euro 1-4, otherwise the incentive is capped at EUR 4 000 (USD 4 500). Moreover BEVs are exempt from the annual vehicle tax during the first five years and benefit from reduced tax level afterwards.

Netherlands

The National Climate Agreement was announced in 2019 and includes a target to reduce GHG emissions by 49% by 2030 relative to 1990 levels. It includes a 30% reduction in CO_2 emissions from inland and continental transport. Besides its former commitment to reach 100% of ZEVs in new passenger cars sales by 2030, the government introduced targets for taxis and FCEVs. By 2025, half of the taxi fleet should be ZEVs, and by the same year the ambitions is to have 15 000 FCEVs on the streets, aiming for 300 000 FCEVs by 2030. By 2025, it aims for all new public bus sales to be electric, preparing for a full stock of electric buses in public systems by 2030. Further it aims to deploy 3 000 FCEV heavy-duty vehicles. The 30-40 largest municipalities have to implement a zero-emission zone for freight vehicles (LCVs and HDVs) by 2025 and long-haul freight has to improve its CO_2 intensity by 30% by 2030.

[22] Depending on engine size and CO_2 emissions, it represents typically about EUR 100 (USD 110) per year for a medium-size vehicle and about EUR 500 (USD 560) per year for high-end cars.

India

India's roadmap for vehicle electrification, outlined in the National Electric Mobility Mission Plan (NEMMP) 2020 launched in 2013, highlights the vision to boost adoption and manufacturing of EVs. Over the years India's approach to EV deployment has been evolving. The current EV policy framework is a mix of incentive-based policies accompanied by regulatory reforms, and public-private partnerships to encourage EV adoption, expand charging infrastructure and support domestic EV and supply equipment manufacturing capacity and battery manufacturing. Energy security and clean air considerations have also prompted the adoption of stricter performance and efficiency standards for the overall vehicle fleet, and led to new policies focussing on the development and market adoption of electric and hybrid vehicles. With an emphasis on sustainable transport, the current strategy for electric mobility includes a wide array of shared and public mobility solutions. In addition to electrification, India is exploring options such as energy efficiency regulations and fuel diversification to reduce its oil import dependence by 10% in 2022.

Vehicle policies

Phase I of the Faster Adoption and Manufacturing of Electric Vehicles (FAME) ran for four years from 2015. Phase II (FAME II) was approved by the government with a budget of approximately INR 100 billion (USD 1.3 billion) for a three-year period from April 2019 (Government of India, 2019a). FAME II provides incentives for the purchase of electric and hybrid vehicles, accounting for about 86% of the allocation and deployment of charging stations.

Several changes as part of FAME II relate to the types of vehicles covered and incentive volumes. Electric buses, two/three-wheelers, PHEV and HEV cars are covered: the largest share of the incentives is reserved for buses (41%), followed by three-wheelers (29%) and two-wheelers (23%). By August 2019, incentives had been approved for 5 595 electric buses for both intercity (across 64 cities) and local operations. Several cities, e.g. Kolkata, Nagpur and Delhi, are procuring electric buses under the FAME II scheme. Several new electric car models with expanded ranges of over 300 km were launched in 2019 and early 2020. However, FAME II specifies a maximum sticker price of about INR 1 500 000 (USD 19 900) for cars to be eligible, making most of the available car models beyond the scope of the scheme because of higher prices. Overall, 2019 saw a decline in sales of electric cars. In addition, given that only advanced battery chemistries (excluding lead-acid) are eligible under FAME II, with incentives based on battery size, 2019 also saw an immediate negative impact on the sales of electric two-wheelers, which fell about 94%. Most electric two-wheelers sold in India have lead-acid batteries and are low-speed and therefore not eligible for incentives under the FAME II scheme. However, as some compensation, the federal budget for 2019-20 announced an income tax exemption of INR 150 000 (USD 2 000) on loans for EV purchases as an incentive. It is premature to measure the effects on personal EV sales from this tax measure.

The Energy Efficiency Services Limited (EESL), India's largest energy savings company (ESCO), has been leading a bulk procurement programme for EVs since 2017. It aims to transform government vehicle fleets across the country. It set out an initial intent for bulk procurement of 10 000 EVs.[23] However, the initial 1 500 cars took about two years to roll out with some technical issues raised due to vehicle range and quality. Drawing from that learning from the first tender, EESL floated a new tender for an additional 1 000 electric cars in 2020 with more advanced technical specifications, to accommodate for the fast changing technology.

Charging infrastructure policies

Key decisions to expand the charging infrastructure network in India were taken in 2019. In October, the Bureau of Energy Efficiency was named as the Central Nodal Agency for the roll out of publicly accessible charging infrastructure (Gouvernment of India, 2019b). This provides administrative clarity that was missing in India's EV charging governance framework. Also in October 2019, the previous guidelines and standards for charging infrastructure for EVs were revised and improved. The guidelines set out targets for the installation of at least 1 publicly accessible charger within a 3 x 3 km grid in cities, and 1 charging station every 25 km on both sides of highways. There would also be 1 fast charging station every 100 km on highways.[24] These guidelines also include information on the specifications of the Electric Vehicle Supply Equipment (EVSE) and related aspects of charger deployment. Further, under FAME II, about INR 10 billion (USD 130 million) has been allocated to deploy networks of charging stations, with incentives that range from 50-100% of the cost of a charger based on its location and access.

In addition to aggregating demand for vehicles, EESL is also deploying 498 publicly accessible chargers in government offices along with 68 publicly accessible chargers across the country. The 2020-21 target is 1 500 additional publicly accessible chargers in and around major metro rail systems and government offices.[25]

[23] EESL awarded a tender for installing 10 000 EVs and 2 125 chargers across the country to Tata and Mahindra primarily targeting LDV governmental fleets (Government of India, 2018).
[24] In phase 1 (years 1-3) of this plan, cities with a population of over 4 million and important highways connecting these cities would be targeted. In phase 2 (years 3-5), all state capitals and key highways connecting them would be included.
[25] In major metro rail systems and government offices in Jaipur, Chennai, greater Hyderabad, Noida, Nagpur, New Delhi and South Delhi.

Industrial policies

With an aim "to leapfrog and envision India as a global hub of manufacturing of electric vehicles" the government is using a range of policy measures to promote domestic EV and EVSE manufacturing. The broad manufacturing scope includes solar equipment, battery storage and charging infrastructure. The National Mission on Transformative Mobility and Battery Storage was established in 2019 for the period to 2024 and includes a Phased Manufacturing Plan for the entire value chain to support the evolution of "large-scale export-competitive integrated battery and cell manufacturing "gigaplants" in India" (Government of India, 2019c). Supplementing national policies, India's states have specific incentives for EV manufacturing.

To alleviate end-of-life battery concerns, India's Ministry of Environment, Forest and Climate Change updated its 2001 Battery Waste Management rules in 2020 with more stringent compliance requirements for nickel, cadmium and lead by weight in new and discarded batteries, and for overall battery waste management and recycling (Government of India, 2020).

State level policies

Given the structure of the government in India, several aspects of road transport policy making and deployment are within the jurisdiction of its 28 states and 8 union territories. While overarching targets for EVs and charger deployment are set by the federal government, the deployment is largely executed by the states. Several states are providing financial incentives, duty waivers, exemptions from permit fees, streamlined registration processes and supporting infrastructure to encourage EV uptake and charging station deployment. While specific policy approaches vary by local context, states such as Andhra Pradesh, Delhi, Gujarat, Karnataka, Maharashtra, Tamil Nadu, Telangana and West Bengal have developed state level roadmaps and policy guides to aid policy consistency.

Japan

Japan has set a target for "next-generation vehicles"[26] to account for 50-70% of new car sales by 2030, including a target of 20-30% for BEVs and PHEVs (Government of Japan, 2018). The government has implemented policies for vehicles and chargers, as well as broader industrial policies, to help achieve these targets.

[26] Including HEVs, BEVs, PHEVs, FCEVs and clean diesel vehicles.

Vehicle policies

In 2019, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism set new fuel-efficiency standards for LDVs for 2030 and HDVs for 2025.

For light-duty vehicles, the standards require a corporate average fuel efficiency of 25.4 kilometres per litre (km/L) by 2030, representing an improvement of 32.4%[27] compared to the fleet average for 2016 (19.2 km/L) (METI, 2019a). The scope of the new standards has expanded to EVs, replacing standards for 2020 which covered gasoline, diesel and liquefied petroleum gas vehicles only. The standards are established on a well-to-wheel (WTW) basis to allow for comparisons of energy consumption efficiency across all fuel types, including BEVs and PHEVs.[28] The standard for heavy-duty vehicles[29] also has relevance for electric mobility due to its capacity to improve efficiency, but it does not include specific provisions for EVs.[30]

Japan provides subsidies for the purchase of PHEVs (up to JPY 200 000 [USD 1 800]), BEVs (up to JPY 400 000 [USD 3 700]) and FCEVs (up to JPY 2 250 000 [USD 20 800]). PHEVs, BEVs, FCEVs and very fuel-efficient vehicles are also exempt from purchase and weight taxes.[31] Plus these vehicle types have lower annual vehicle taxes, though this will be limited to only PHEVs, BEVs and FCEVs starting in FY 2021 (METI, 2019b).

Charging infrastructure policies

The government provides subsidies to support the installation of charging infrastructure. It provides between half to two-thirds of the costs (depending on location, charger type). In 2019, these subsidies totalled JPY 1.1 billion (USD 10 million).

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[27] Since this improvement is based on an efficiency metric, as opposed to an intensity metric (such as litres per 100 km), it cannot be directly compared with other targets that are expressed in intensity terms.

[28] The standards also incorporate the expected power generation mix in 2030 to account for differences in generation efficiency across generation types.

[29] The regulation applies to vehicles with a total weight of more than 3.5 tonnes.

[30] It requires new trucks and other heavy vehicles to have weighted average fuel economy of 7.63 km/L by 2025 (implying an efficiency improvement of 13.4% relative to the 2015 standards), and a level of 6.52 km/L for buses by 2025 (implying an efficiency improvement of 14.3% relative to the 2015 standards).

[31] In 2017, subsidies for very fuel-efficient vehicles had a budget allocation of JPY 13 billion (USD 120 million) (Sato, 2018). In the same year, this was complemented by JPY 1 billion (USD 9 million) to accelerate the introduction of HEV, PHEV and BEV trucks and buses, and JPY 2.6 billion (USD 24 million) to promote FCEV buses utilising hydrogen generated by renewable energy (Sato, 2018).

Japan is also supportive of the development of new international charging standards. The CHAdeMO Association[32] and the China Electricity Council are working jointly on a next-generation ultra-high power charging standard (up to 900 kW), dubbed "ChaoJi" (CHAdeMO, 2019; CHAdeMO, 2020). The development team aims to publish ChaoJi for CHAdeMO by the end of 2020 for global use. ChaoJi will be concurrently proposed to the International Electrotechnical Commission / International Organization for Standardization (IEC/ISO) committees to be added to the DC fast charging systems.

Japan is also supporting the development of hydrogen fuelling stations. Government subsidies support between half to two-thirds of station and equipment costs, depending on the size of hydrogen station (300 normal cubic metres per hour [Nm^3/h] or 50–300 Nm^3/h) and style (onsite, offsite, mobile) (NeV, 2019). The property tax for hydrogen fuelling stations and equipment are reduced by 25% for three years.

Industrial policies

METI launched a strategic commission for a "new era of automobiles" in 2018 that includes a 2050 goal to reduce specific GHG emissions per kilometre by 80% across all vehicles produced by Japanese automakers on a WTW basis, together with efforts to fully decarbonise the energy supply (electricity and hydrogen) (Government of Japan, 2018).[33]

METI launched the Council for Electrified Vehicle Society (CEVS) in July 2019 to help accelerate EV deployment (METI, 2019c). CEVS promotes collaboration and information sharing among the public and private sectors on maximising the advantages of EVs.[34]

The government released its Strategic Roadmap for Hydrogen and Fuel Cells in March 2019 (METI, 2019d). It includes targets to reduce the average price difference between FCEVs and HEVs from JPY 3 million (USD 27 700) to JPY 700 000 (USD 6 500) by 2025.[35]

[32] CHAdeMO is one of the earliest and most widespread DC charging standards for electric vehicles in the world.
[33] Further details on this strategy are available in *Global EV Outlook 2019* (IEA, 2019).
[34] Specific guidance is provided by working groups on topics such as EV promotion and battery reuse (METI, 2019c).
[35] It also includes cost targets for fuel cell stacks to be reduced from JPY 20 000/kW (USD 180/kW) to JPY 5 000/kW (USD 45/kW) in same period.

United States

The United States has a long history of promoting more efficient vehicles at the federal level (the Corporate Average Fuel Economy Standards date from the 1970s), as well as low-emitting vehicles. The last few years have seen an increasing debate between federal and state governments on the path forward for fuel-efficiency standards.

Vehicle policies

Federal level

In late March 2020, the US administration proposed substantial revisions to the vehicle fuel-efficiency standards in the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, Corporate Average Fuel Economy (CAFE) standards (NHTSA/EPA, 2020). The proposed standards constitute a significant roll back from the current federal standards that were passed in 2012. The proposed modifications lower the annual improvement in fuel-economy standards from 4.7% in the current regulation to 1.5% for model years 2021 through 2026.

Various analyses suggest that the costs of this roll back on the US economy outweigh the benefits (ICCT, 2020b; NHTSA/EPA, 2020). They find that the additional fuel expenditures that the revised standards will impose on US consumers exceed the costs of compliance for automakers. There is an additional expectation of reduced competitiveness of US automakers in international car markets, suggesting that the revised CAFE rules could result in domestic job losses.

Further, the US Congress decided to not extend the federal tax credit that provides USD 2 500-7 500 in tax exemptions for the purchase of electric cars. This credit is subject to a gradual year-long phase out on models made by automakers beyond a limit of 200 000 vehicle sales.

State level

The proposed SAFE rule have provoked negotiations among automakers, state legislatures and judicial authorities on whether a compromise between the SAFE Act and the 2012 CAFE standards can be reached, or whether to continue following California's Low Emission Vehicles (LEV III) pollutant emissions and GHG regulations would be the pathway for 14 US states (including California)[36] (New York Times, 2019; CARB, 2019; CARB, 2020). California's proposed compromise with five automakers is much closer in scope to the previous CAFE standards than it is to the SAFE rule. The four automakers that have supported the less stringent SAFE standards, General Motors, Fiat Chrysler, Toyota, and Volvo collectively account for just under half of the North American car market. Whether or not US states have the authority to set their own rules via the special pre-emption waiver under the 1970 Clean Air Act is the subject of a current lawsuit.[37] Hence, whether fuel- economy and emissions standards will move forward along two tracks, reach a compromise, be settled in a judicial finding, or another outcome that could lead to nationwide regulation, is unknown at the time of writing.

Individual US states have the prerogative to adopt policies and regulations to promote the deployment of EVs and other low-carbon mobility modes. Both the Alternative Fuels Data Centre[38] of the US Department of Energy (US DOE) and the Centre for Climate and Energy Solutions (C2ES) track state level initiatives to support zero-emission and alternative fuel vehicles, and their supporting infrastructure on an interactive and hyperlinked map (AFDC, 2020; C2ES, 2019). According to the Alternative Fuels Data Centre, all but 4 US states have policies supporting the commercial deployment of alternative fuel vehicles and/or their supporting infrastructure. Of these, 16 states offer statewide subsidies, tax credits, or waivers or reductions on inspections that explicitly support EV purchase for private individuals. These can be usefully distinguished from support for efficient or alternative fuel vehicles more generally, which are offered by 29 states (excluding a few states that include subsidies for vehicle conversion), many of which are overlapping with the aforementioned 16 states. Moreover, 42 states have policies to help financing of installing or operating charging infrastructure deployment (e.g. low-interest loans, leasing, opt-in time-of-use pricing), and 17 for fleet owners to purchase electric medium- and/or heavy-duty vehicles.

The differing positions between the federal and state governments have catalysed momentum at the state level to either follow California's low-emission vehicle (LEV)

[36] These are the so-called "177 States", as they follow California's exemption under Section 177 of the Federal Clean Air Act. For the list, covering all updates through August, 2019, see: ww2.arb.ca.gov/sites/default/files/2019-03/177-states.pdf.

[37] The One National Program Rule, which aims to enable the US federal government to provide nationwide uniform fuel-economy and GHG emission standards, was passed in September 2019 (US EPA, 2019). There are disputes on this rule between the federal and state level governments and until there is resolution, the LEV III GHG emissions standards remain in place for those states that have adopted them.

[38] The AFDC search engine for federal and state laws and incentives is available at:https://afdc.energy.gov/laws/search.

and ZEV regulations, or to assert their authority to craft similar standards on their own.[39] In 2019, Minnesota and New Mexico announced the development of clean car standards with GHG emission reductions generally aligned with California's LEV regulations, and with ambitions in both states more robust than the proposed federal SAFE Act.[40] Minnesota's plans include provisions to spur EV uptake to achieve 2030 market penetration targets.[41] Colorado, among the states that already follow California's fuel economy regulations, adopted a new Zero-Emission Vehicle rule in September 2019, under which automakers must increase the ZEVs available for purchase as part of their LDV stock by a minimum percentage by January 2022.[42] New Jersey proposed legislation for wider adoption of electric vehicles, calling for 2 million plug-in electric vehicles by 2035.[43]

In recent years, momentum has increased in several states to extend zero emission targets and regulations to medium- and heavy-duty vehicles. In 2018, California adopted the Innovative Clean Transit Regulation to reduce emissions from HDVs, a programme that also requires a gradual transition to a 100% zero-emission bus fleet in public transport.[44] In late 2019, California, together with seven other US states, committed to accelerate the adoption of zero-emission medium- and heavy-duty vehicles in proposing the Advanced Clean Trucking rule and investigating mandates, comprising sales targets and reporting requirements. California aims to adopt the clean trucking measures in 2020 (CARB, 2019). In March 2020, Washington became the first US state to implement a medium- and heavy-duty ZEV programme (State of Washington, 2020).

[39] In a role reversal, some state legislatures and governors are calling on the federal administration to recognise their authority to enact and enforce legislation that applies in their jurisdictions.

[40] The Minnesota and New Mexico clean car standard will increase the average fuel economy to 52 miles per gallon, compared with the 37 miles per gallon in the federal SAFE proposal (Office of the Governor State of New Mexico, 2019).

[41] The targets call for 20% of all passenger vehicles in Minnesota to be electric by 2030. The Minnesota Pollution Control Agency has the authority to adopt clean car standards through a formal rulemaking process. It began a fifteen month process in October 2019 to ensure that voices in the state are heard (Minnesota Pollution Control Agency, 2019).

[42] The alternative rule references proportional and/or early action credit options. This would facilitate the availability of these models in Colorado as soon as 2021 (model year) (State of Colorado, 2019).

[43] Proposed bills No.A4819 and S2252 consider a series of mandates, including additional obligations under the Advance Clean Cars Program, deployment of a EV fast charging network, provision of rebates up to USD 5 000 for purchasing eligible EVs, and requiring transit authorities to purchase only electric buses by 2032 (Bloomberg, 2020).

[44] By 2029, 100% of new purchases by public transit authorities must be ZEVs, aiming for a full transition to clean transport by 2040. The regulation covers standard, articulated, over-the-road, double-decker and cutaway buses. The programme differentiates between large and small transit authorities by fleet size and defines a purchase schedule: starting in 2023 for large transit authorities (25% of purchases) and 2026 for small transit authorities (25% of the purchases) (CARB, 2019).

Charging infrastructure policies

Federal level

Despite not extending the federal tax credit on EVs, the US Congress did extend the federal charging infrastructure tax credit in 2019. It covers up to 30% of the installation cost of new EVSE (limited to USD 1 000) through fiscal year 2020 (The Edison Electric Institute 2019).

The International Code Council (ICC) approved a new voluntary guideline to make all new homes built in the United States EV-ready (EV-Ready Buildings Code). With the adoption of the provision, ICC expects homeowners should be able to charge at least one full-size EV overnight.[45]

State level

Michigan recently passed a legislative package intended to increase access to EV charging infrastructure at state-owned properties, businesses, multi-unit buildings and workplaces. Legislation in Colorado allows electric public utilities to install EV charging stations (or an electric motor vehicle infrastructure programme) as regulated services and thus allow for cost recovery from ratepayers for the investment (State of Colorado, 2019). Hawaii has launched a two stage rebate programme to support the near-term installation of EV charging stations which provides for two types of rebates (State of Hawaii, 2019).[46]

In 2020, New Jersey approved an ambitious EV deployment programme that set a target of 330 000 EVs on the road by 2025 and 2 million by 2035, in addition to the charging infrastructure required to meet the goal.[47,48] California has introduced a programme for EV charging infrastructure funded by the California Energy

[45] For multi-unit buildings, two parking spots per building will need to be "EV-ready", in addition of others that can be easily fitted with an outlet or charger ("EV-capable"). Homeowners will still need to install an adequate EV charger. The ICC codes are used by all US states, but they can decide whether or not to adopt the latest standard (Quartz, 2020).

[46] USD 4 500 (new) or USD 3 000 (upgrade) rebates for Level 2 AC multiport charging station. USD 35 000 (new) or USD 28 000 (upgrade) rebates for DC fast charging stations; Stage 1: USD 150 000 in rebates for installations completed between 1 January 2020 and 30 June 2020. Stage 2: USD 250 000 in rebates for installations completed between 1 July 2020 and 30 June 2021 (State of Hawaii, 2019).

[47] For the second target, the New Jersey legislation set the following goals: At least 400 DC fast charging stations in no less than 200 different locations by December 2025. At least 75 of the 200 or more charging locations must be in travel corridors, equipped with at least two DC fast charging points per location. At least 100 of the 200 or more charging locations must be in community locations.

[48] Additional incentives in the legislation include a rebate programme and targets for public transport electrification.

Commission and implemented by the Center for Sustainable Energy. The programme budget is USD 71 million with a potential for up to USD 200 million (CALeVIP, 2019).

The hyperlinked map from the Center for Climate and Energy Solutions (C2ES) outlines further state level programmes promoting ZEVs and alternative fuel infrastructure (C2ES, 2019).

Industrial policies

US Electrify Forward Act

In January 2020, the US House of Representatives proposed the Electrify Forward Act (US Government, 2020). It is a comprehensive plan to support the domestic development, production and distribution of EVs and charging infrastructure. The bill aims to "promote American leadership in vehicle manufacturing, job creation, improved air quality and climate protection through domestic manufacturing of low- and zero- emission vehicles and development of electric vehicle charging networks".

The Act has the following objectives:

- To accelerate domestic manufacturing of batteries, power electronics and other technologies in plug-in vehicles.
- To update residential and commercial building codes to encourage the installation of EV charging infrastructure.
- To modify and reauthorise the Advanced Technology Vehicles Manufacturing Incentive Program, a grant and loan programme at the US DOE, beginning in fiscal year 2021 through 2030.
- To require states to consider new measures to encourage deployment of electric vehicle charging stations.

Deploying electric buses in cities: Lessons learned from Helsinki, Kolkata, Santiago de Chile and Shenzhen

Cities are often at the forefront of transport electrification (IEA, 2017). Many local projects complement national programmes as highlighted in the country profiles. Efforts in urban areas often focus on electric buses, which are becoming increasingly common in cities to reduce GHG emissions and local air pollutants relative to diesel buses. Electric buses have the driving range needed to operate in most public transit systems. Many cities have demonstrated that obstacles related to upgrades to the distribution grid and to power chargers can be managed effectively. The ongoing decline in battery costs has brought electric buses closer to cost parity with other bus technologies; in many cases they are already the cheapest option in terms of total cost of ownership.

Yet, the strong trends for electric buses in recent years have been concentrated in just a few countries while others have introduced only small pilot fleets. Each public transit system is unique and the roll-out of electric buses faces context-specific challenges related to network size, ridership, degree of sector privatisation and the availability of funding streams other than fare revenues.

This section highlights four cases of city fleets operating in the public transit systems of Helsinki (Finland), Kolkata (India), Santiago de Chile (Chile) and Shenzhen (China). The case studies for Santiago and Helsinki take into consideration the operations of all the fleet operators in the metropolitan region, while for Shenzhen, it draws from the experience from one of the three major operators, and for Kolkata the focus is on the public sector operator that, along with private operators, services the demands of that metropolitan region.

These four cities have had very different approaches and trajectories for introducing electric buses. While Shenzhen has had several years of experience in deploying e-buses at scale and transforming their complete fleet, the other cities are at relatively early stages of deployment. The bus types, nature of charging infrastructure and patterns of use are also varied. The various paths for introducing e-buses under the specific circumstances provide insights on viable trajectories for public transit electrification, as well as obstacles that cities following in their footsteps should anticipate. (These cases benefit from collaboration with the cities which prepared detailed case descriptions. These case studies may be accessed at: https://www.iea.org/reports/global-ev-outlook-2020.

Table 2.5 Selected electric bus case studies at a glance

City profile	Buses	Chargers	Implementation
Helsinki introduced electric buses in 2017. Its public transit system accommodates 370 million trips per year, a third of these on its 1 400 buses. Helsinki, with a population of 1 490 000, is the smallest among the four cities discussed.	To date there are 48 electric buses (made by Linkker, Yutong, VDL) in operation. The e-bus fleet is set to quadruple by 2021. Helsinki aims to electrify 30% of its bus fleet by 2025.	E-buses use a mix of pantographs and fixed EVSE for charging under different regimes: 15 buses are equipped with pantographs and use opportunity charging while 33 charge at depots.[49]	The regional public transport authority, Helsinki Region Transport (HSL), has promoted the roll-out of electric buses as a part of tenders that include a minimum requirement to operate e-buses. The operators already exceed these provisions.

[49] Opportunity charging here means charging during operation hours at bus stops or line terminus. Depot charging describes charging outside of operation hours at bus depots, often at night.

City profile	Buses	Chargers	Implementation
			HSL has organised separate tenders to contract charging infrastructure operators for opportunity charging (bus operators are not responsible for operating the chargers).
Kolkata metro region has 925 bus lines and over 11 000 buses to serve about 14 million residents. The government-owned West Bengal Transport Corporation (WBTC) operates 1 553 of the buses on 348 lines.	Since 2019, WBTC has put 80 e-buses supplied by Tata Motors into operation on 12 lines. Another 150 vehicles will enter service in the mid-term and WBTC aims to fully electrify its fleet of about 5 000 buses by 2030.	Buses are charged at ten depots, most of which are equipped with seven chargers with power rating of 60 kW or 120 kW. All lines have one or two additional chargers at the line terminus.	WBTC's roll out of e-buses and chargers was made possible through the first phase of the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME I) scheme. This government programme made funds available for procurement of 80 e-buses with charging equipment. Forty of the 9 metre buses have 125 kWh battery packs and 40 of the 12 metre buses have 188 kWh battery packs.
Santiago de Chile has 6 756 buses on 380 routes that play a key role in its public transit system, Red Metropolitana de Movilidad (RED).[50] In 2018, the system served the metropolitan area of 7 million people with over 2 million trips a day. The city's first e- buses started service in 2019.	Santiago has over 400 e-buses (6% of its fleet) and aims to transform its entire public bus fleet to electric by 2040.[51] In 2019 operator Metbus leased 285 BYD manufactured e-buses for ten years from energy company Enel X. Metbus' electric fleet is set to expand to 435 in 2020.	The existing e-bus fleets use depot charging. Operators lease chargers served with renewables-based electricity from Enel X and Engie. Metbus buses use about 160 chargers of 80 kW each. Vule's fleet charges with 37 chargers of 150 kW, and STP	Santiago's decision to adopt the Euro VI standard in 2018 for buses laid the groundwork for e-bus deployment. The electric fleets were commissioned outside of the regular competitive licence renewal tenders; however, operators do not receive explicit subsidies. The regulator will commission future fleet additions under the

[50] Known as Transantiago before 2019. Transantiago was inaugurated as a public transport system in 2007.
[51] Estrategia Nacional de Electromovilidad, Chile.

City profile	Buses	Chargers	Implementation
	In a similar partnership, operators Vule and STP, together with energy company Engie, started operating 100 Yutong manufactured e-buses in 2019.	uses 13 chargers of 150 kW.	regular fleet renewal tenders.
Shenzhen, in 2019, became one of the first cities to have transformed its bus fleet to 100% electric. With a fleet size of 16 000 buses, distributed among three bus operators (Shenzhen Bus Group, Shenzhen Eastern Bus Company and Shenzhen Western Bus Company) it serves 42% of the public transit traffic (second only to a subway system that serves 50%). The urban population is more than 12 million inhabitants.	Of the three operators, Shenzhen Bus Group (SBG), the focus here, introduced e-buses in three stages, starting in 2011 with 127 e-buses, reaching 545 by 2015 to an all-electric fleet of more than 6 000 buses in 2017. The majority are BYD models, and now after eight years of operations several buses are also under refurbishment.	Buses charge overnight at depots. Only a few buses on long lines get a 30 minute extra charge during the day. Charging operators have more than 1 700 chargers of 150 kW and 180 kW at 104 terminals and depots.	The local government mandated fleet electrification and offered purchase subsidies of up to CNY 1 million (USD 140 000) per bus. SBG bought buses in partnership with a leasing company. The government supports the deployment of charging infrastructure with most of the existing chargers having received CNY 600/kW (USD 85) installed capacity.

Driving factors in deploying electric bus fleets and chargers

For bus operators, the motivation to opt for electric buses differs depending on the policy environment. Operators typically deploy e-buses with a strong partner from the government or private sector, which enables them to finance and/or mitigate the risks of the high upfront costs of e-buses.

In Helsinki, the deployment was guided by a requirement for e- buses in tenders to allocate line concessions.[52] The local transport authority, HSL, supports this by providing charging infrastructure.

[52] Another Nordic city, Oslo, started trials in 2017 with the aim of making the entire public transport system fossil fuel free by 2020 and fully electric by 2028.

Santiago's decision to introduce stringent emission standards (Euro VI) for buses supported the first large-scale introduction of e-buses in South America.[53] It materialised through partnerships between bus operators and energy companies that lease buses and chargers to operators on a per kilometre basis while supplying electricity. The strong involvement of energy companies is unique to Santiago and made the roll-out of electric buses possible without direct subsidies from the government. However, special conditions on bus concessions provided additional incentives for the operators.

In Kolkata, the purchase subsidies under the national FAME I scheme, with a 60% national and 40% state funding support, was instrumental in the deployment of e-buses, with the objective of reducing CO_2 and local air pollutant emissions. In this context, the government in West Bengal decided that in the City of Kolkata only compressed natural gas and electric buses are to be procured. The first phase of this programme offers funding to local transport authorities to acquire e-buses (either as an outright purchase or via payments per bus) or to operate e-buses (through a gross cost contract or payment per km). Kolkata opted for funding outright purchases, and its West Bengal Transport Corporation (WBTC) owns and operates e-buses and chargers. While Kolkata's approach for e-bus deployment has relied significantly on public funding till now, it is envisaged that with scale up and operational experiences, other models of financing will be explored to make the operations cost neutral.

Shenzhen, which has the longest experience of deploying e-buses among the cities considered, used a mix of instruments over the years to drive the roll-out of e-buses. A mandate for fleet electrification was accompanied by a programme for purchase subsidies with funds from both national and local governments. The local government also set up a separate programme to promote deployment of chargers. For the Shenzhen Bus Group (SBG), this programme also directly involved the local bus manufacturer BYD, a Chinese company, which, in addition to delivering 80% of the e-buses, is responsible for the maintenance of vehicle components that are part of the electric powertrain, and offers an extended vehicle warranty of eight years. This association has been useful particularly given that several SBG buses have come to their full eight-year life-cycle and require replacement. Original equipment manufacturers (OEMs) have played a similarly strong role elsewhere. For instance, BYD partnered with Metbus and Enel X in Santiago and is responsible for bus maintenance (payed on a fixed per/km basis).

[53] Other Latin American cities such as Bogota, which introduced 500 e-buses in 2020, are exploring similar options to deploy electric buses under similar models.

Deployment of chargers is a significant undertaking and may pose additional project risk. Helsinki and Shenzhen separated e-bus roll out and their operation and chargers. In Helsinki, HSL holds tenders to license charging operators. In Shenzhen, SBG offered subsidies to charger operators (most chargers received a subsidy of CNY 600 [USD 85] per kW installed capacity) and eased the application process for land-use permits to promote the roll-out of infrastructure. Santiago's bus operators lease chargers along with e-buses from their partnering energy companies. While operation of chargers and e-buses is not separate, the expertise of the energy companies reduces project risks when it comes to operating chargers and integrating their use both with the power grid and with bus schedules. There are also safety risks that need to be overcome by training bus operators in dealing with high voltage charging equipment. In India, support under the FAME programme bundles financial support for chargers and e-buses, and Kolkata is the only case, among those considered here, where WBTC, a state-owned undertaking, is solely responsible for both chargers and buses. While these have certain advantages for the public sector company to learn from these early operational experiences, as experience from other cities highlight, there may be efficiencies in looking at bus and charging infrastructure operations separately.[54]

Table 2.6 Policy drivers and responsibility for bus and charging infrastructure deployment at a glance

	Mandate for bus deployment	Purchase subsidy	Split ownership of buses and chargers
Helsinki	✓ *	✗	✓
Santiago de Chile	✗ **	✗	✗
Shenzhen	✓ ***	✓	✓
Kolkata	✗ ****	✓	✗

* Helsinki's tender documents for bus line concessions stipulate minimum quotas for electric buses, which operators have exceeded.

** Santiago de Chile's existing fleets entered the fleet without effective mandate. The city aims for full electrification of its bus fleet by 2025 and stricter technology requirements are expected for future fleet additions.

*** Supported by government incentives, Shenzhen's bus fleet was completely electrified by 2017.

**** Kolkata's first 80 electric buses entered the city's fleet without an effective mandate. WBTC aims for full electrification of its bus fleet by 2035 and stricter technology requirements are expected for future fleet additions.

[54] Experiences from Europe highlight that although charging concessions may have a duration of 5-7 years, charging infrastructure lasts much longer, thereby resulting in much higher costs at the onset. As a result, governments are exploring longer term concession periods for charging infrastructure of up to 15 years.

Experience from Helsinki and Santiago suggests that introducing e-bus fleets is possible without offering explicit subsidies. However, bus operators may receive other means to cover costs of e-buses. For instance, Santiago fleet operators get contracts for 14 years when they operate e-buses compared to ten years for ICE buses. Such non-fiscal incentives are innovative approaches that other fleets could emulate. Most public transit systems do not generate profits and bus operators receive public funds to boost revenues. In policy environments that mandate e-buses in competitive tenders for line concessions but do not offer explicit subsidies for e-buses, bus operators may need to consider the total cost of ownership (TCO) to establish their bid price even if the capital costs might be higher. While some cities that assume responsibility and costs for chargers, e.g. Helsinki and Shenzhen, also absorb some of the costs of operating the e-bus fleets; other cities have taken the non-subsidy route and employ usage-based charging contracts to incentivise e-bus roll out.

Economics of electric buses

Electric buses have higher purchase costs than ICE buses, but e-buses have lower fuel and maintenance costs. The difference in total cost of ownership (TCO) is context-specific and is influenced for instance by local prices for diesel and electricity, distance driven per unit of energy consumed, type of bus used for comparative purposes, the costs of finance and whether the fleet size helps to optimise the utilisation of existing assets such as maintenance facilities. For instance, in Santiago, Enel working with Metbus have contracted to provide certified renewable energy at a 40% discount rate for bus operations; while in Kolkata WBTC is exploring the opportunity to use a time-of-day tariff scheme to their advantage. The TCO of e-buses is set to further decrease in line with battery costs and may reach cost parity with diesel buses in most regions within the next few years.[55]

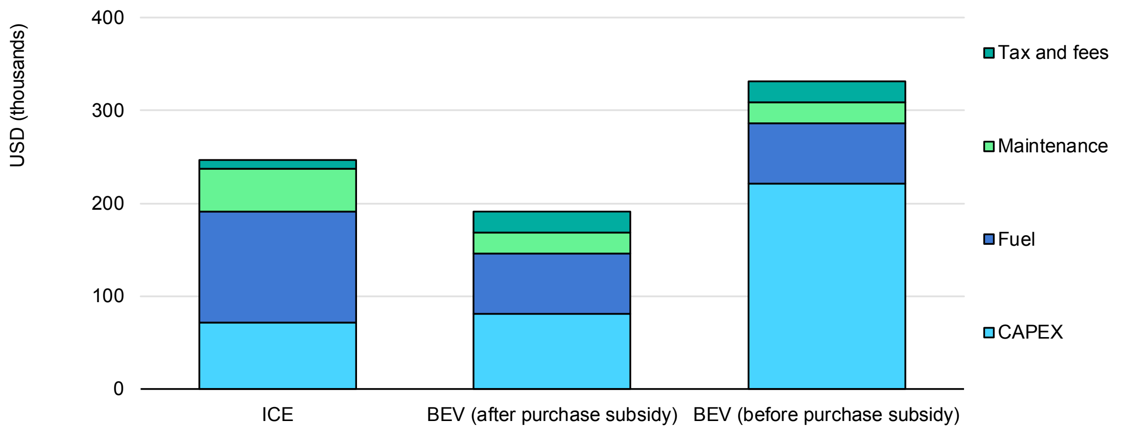
The high upfront costs of electric bus purchases were overcome in the four cases discussed with different approaches. Shenzhen and Kolkata report that the TCO for e-buses exceeded those of conventional buses. Over the bus lifetime, costs for maintenance and fuel of an electric bus in Shenzhen's fleet are about half of that for a diesel bus, but the e-bus purchase price were about three-times higher, particularly noting that Shenzhen was the earliest to adopt e-buses before they were widely deployed. A lower TCO for electric buses (24% less than conventional buses) was

[55] Battery costs, mileage and diesel prices have the biggest impacts on the comparative TCO of electric buses relative to diesel buses. E-buses travelling 40 000-50 000 km/year are competitive in regions with high diesel taxation regimes with battery prices below USD 260/kWh (IEA, 2019). Other local circumstances also influence TCO. (See World Bank (2019) for city-specific TCO analyses of electric buses.)

achieved only due to significant subsidies for capital costs (Figure 2.1). With the gradual phase out of such subsidies in China, TCOs for battery electric buses would be relatively uncompetitive with ICE counterparts. Kolkata reports that the TCO per vehicle-kilometre of electric buses are 20-35% higher than for conventional buses, but expects future bus models to reach cost parity within two-three years, with falling battery prices and larger base models. In Helsinki, the TCO of e-buses is similar to diesel buses.

Although public bus fleets often rely on government funding support, fiscal subsidies may not be continuous over a long period to support broadening e-bus systems given scare public resources. In that context, other options can contribute to a mix of non-fiscal incentives (as highlighted in the case of Santiago) and regulatory approaches could be explored. Also note that while TCO allows financial comparisons of operations of different vehicle types, given the large number of co-benefits associated with electric bus fleets, such as improved local air quality and health, and lower noise pollution, among others, capturing the true benefits of electric bus operations may be better reflected through cost-benefit analysis that accounts for the wider factors.

Figure 2.1 Total cost of ownership for various bus types in Shenzhen



Notes: Capex = capital expenditure; ICE = internal combustion engine; BEV = battery electric vehicle. Conversion rate: CNY 1 = USD 0.14. The figure shows the TCO for the operations over the vehicle lifetime, which typically is eight years in Shenzhen. While the capital costs for e-buses in Shenzhen appear to be high relative to their ICE counterparts, the cost of Euro VI 12 metre diesel bus is around USD 300 000 to 400 000, far exceeding these prices and also higher than the non-subsidised BEV costs in Shenzhen. Costs of battery replacement (if any) have not been explicitly considered as part of this comparison.

Source: Case study on Shenzhen by Berlin, Zhang and Chen (2020).

The TCO of owning and operating e-buses can be competitive with conventional ICE buses by providing purchase subsidies. Costs of fuel and maintenance for e-buses can be half those of a comparable diesel ICE bus.

Clean fleets, blue skies: Positive externalities of electric buses

The TCO of electric buses does not take into account their societal and environmental benefits relative to conventional diesel buses, such as reduced emissions of local air pollutants and of GHGs. The extent to which e-buses reduce GHG emissions depends on the carbon intensity of the final electricity provided, the performance of the buses they replace, as well as on the electric vehicle fleet size. The e-buses of Santiago's network run on 100% renewable electricity provided by the electricity companies Enel X and Engie as part of their contract. Shenzhen's SBG has by far the largest e-bus fleet of the four cases and reports net savings of 0.26 million tonnes of CO_2 per year.[56] However, SBG is one of the three major operators in Shenzhen, implying that the total emissions savings due to e-bus operations in the city is significantly higher. In terms of air pollution, the conventional bus fleet in Kolkata predominantly consists of buses with comparatively high pollutant emissions (most buses there meet only Euro III or Euro IV standards), meaning that in Kolkata a third of particulate matter pollutants from transport stems from buses. This means that expanding the e-bus fleet can reduce direct transport emissions and improve air quality. Increased satisfaction of passengers and drivers is another positive externality and was observed in all four cities. While TCO analyses demonstrate the cost benefits of e-buses, policy makers can make use of additional tools, such as cost-benefit analyses for insights on broader project impacts.

Vehicle reliability and distribution grid factors

In the four cases considered here, all bus operations report that e-buses have reached the same or better reliability as conventional models. Although initial challenges had to be overcome, e.g. hurdles related to charging and range anxiety in Kolkata and shorter driving ranges in Shenzhen. Integrating electric vehicles in a bus network requires optimising asset utilisation of buses and chargers. Bus projects that deploy opportunity charging tend to face challenges to maintain bus service frequency despite needing to allow sufficient time at stops to recharge. For buses that use depot charging, limitations in daily driving range can be a challenge. Sound planning and management of buses and chargers to match operational profiles and constraints can prevent the need to increase fleet size to maintain service levels.

The four cities did not experience detrimental impacts on the reliability of bus operations with the introduction of e-buses. On the contrary, SBG reports lower breakdown rates for e-buses in Shenzhen than for their conventional counterparts; in

[56] This assessment compares emissions from electric buses (including electricity use during operation and battery manufacturing) relative to tailpipe emissions from conventional buses.

Helsinki and Santiago, as well, breakdown rates were equal or lower than for diesel buses. Kolkata reports reliability levels for e-buses of 98%. Three cities – Kolkata, Shenzhen and Santiago – opted for a charging solution that primarily relies on depot charging, with some extra terminal chargers to top up during hours of operation. Santiago and Kolkata started their roll out on lines that are suitable to the range of electric buses. Shenzhen reports that e-buses replaced diesel vehicles without the need to adjust its network plan, by taking advantage of continuous maintenance support and feedback learning from BYD, the manufacturer.

Providing charging infrastructure demands careful planning, as it can be a key stumbling block for building an e-bus transit system. Electricity network operators are responsible for distribution system upgrades, which were necessary in Santiago and Shenzhen and appear to be more demanding given the larger fleet sizes. Kolkata reports only minimal investment in distribution system upgrades, thanks to the city power utilities (West Bengal State Electricity Distribution Company Limited and CESC Limited) that allowed e-bus charging under existing supply codes, meaning that the WBTC did not have to pay fees associated with upgrading the distribution grid. This is another form of non-fiscal incentives provided for e-buses that contribute to lower costs for operators. In Santiago, Enel X performed grid upgrades at two terminals with appropriate smart charging to help optimise the charging demands. Shenzhen's SBG by far has the largest e-bus fleet considered, which translates into the highest requirements on grid infrastructure. The pre-existing grid zoning did not account for concentrated power demand of charging depots and local grid reinforcements were necessary. The Shenzhen government eased the land-use permitting application process for charging infrastructure, however, land rent reaches 90% of costs for charging infrastructure, a phenomenon also observed in other parts of the world.[57]

Lessons from early adopters can aid the deployment of electric buses

The four case studies give a glimpse into some of the factors that drive e-bus deployment in major urban centres, the challenges they face in converting from conventional fleets to electric and the nature of electric bus operations. While the upfront capital costs of electric buses relative to diesel equivalents remain significantly higher, cities have adopted strategies ranging from innovative operating models to providing subsidies to encourage e-bus uptake. Experience from cities also highlights that even without direct fiscal incentives, which are often apportioned from scare public resources, it is possible for cities to incentivise the uptake of e-buses using a host of non-fiscal incentives and regulations. TCO, which do not reflect

[57] ElaadNL has observed this trend in the Netherlands.

the costs of externalities, remains ambiguous as the defining factor for choosing electric over diesel buses. Urban air quality concerns and the potential to reduce emissions provided by e-buses in most instances have been key factors in driving decisions to electrify bus fleets. Moreover, while the planning and deployment of charging infrastructure for e-bus fleets vary depending on the nature of fleet operations, urban energy companies are taking novel approaches to manage the increased grid load that comes from integrating these fleets. With this view, Kolkata's WBTC is planning to meet part of its e-bus charging demand from renewable energy (solar photovoltaic) and battery storage, which can also contribute to manage demand in the context of time-of-day electricity tariffs.

As cities across the world gradually move from pilots to larger scale deployment of electric buses, lessons from early adopters such as these four above and others around the world offer insights for others seeking to replicate their successes and avoid obstacles (World Bank, 2019).

Electric truck policies

Electric and fuel cell electric trucks and their supporting infrastructure are at very early stages of deployment, mostly only in city level pilot projects. As such, adoption will be more dependent on policy support than for other EV types given the bigger gap in purchase price and higher requirements for fast or dynamic changing than light-duty vehicles. Indeed, in cities and countries where zero-emission heavy-duty truck models have been deployed, adoption has been spurred by either policy incentives or corporate initiatives, and most commonly by a combination of the two.

In general, there are three approaches for electric truck recharging: depot charging (usually overnight at the operator's depot); distribution charging (at distribution centres during the day while loading and unloading freight) and public charging (charging along highways or at charging hubs in urban areas). Looking forward, the policy toolkit for promoting electric trucks will be able to build upon successes with LDV deployment, but will need to expand beyond those for cars to focus on infrastructure. As with LDVs, regulations that set minimum performance such as fuel-economy or GHG standards, as well as pollutant emissions standards "pull" innovation and investment toward manufacturing and sales of cleaner trucks. Further, fiscal policies such as road tolls and fuel taxes that account for the impacts of heavy-duty trucks on road infrastructure and the various externalities of fuel consumption (e.g. pollutant emissions, energy security) incorporate some of the true costs of incumbent polluting ICE technologies. Purchase incentives, direct subsidies and/or favourable loan terms for fleets of heavy-duty trucks and their requisite infrastructure can help spur deployment. As part of their "Drive to Zero" campaign, CALSTART, an organisation that works with the public and private sectors to build a high-tech clean transportation industry, outlines and provides examples of these and other policies. They include financial incentives (e.g. purchase incentives, direct subsidies, congestion pricing and zero- and low-emission zones), incentives to spur the deployment of rapid charging infrastructure, as well as policies that are better suited for municipal and corporate fleets, such as exclusion zones and procurement requirements.[58]

Countries and states are beginning to incorporate explicit electrification targets for heavy-duty vehicles. In its recent 2030 Climate Action Programme, the German government set the goal of electrifying one-third of its truck fleet by 2030 (Transport and Environment, 2020). The Pakistan government approved an ambitious EV policy in November 2019 that aims for electric trucks to constitute 30% of new truck sales by 2030 and 90% of new truck sales by 2040. Under this policy, Pakistan will offer lower electricity tariffs for EV charging stations and electric trucks will benefit from a general sales tax rate of 1% rather than the standard 17% (Uddin, 2020).

In the United States, California has led in adopting ambitious and concrete policies to promote zero-emission medium- and heavy-duty powertrain technologies. In late 2019, California, together with seven other states, committed to accelerate the adoption of zero-emission medium- and heavy-duty electric trucks by investigating ZEV mandates, which would comprise sales targets and reporting requirements.[59] California aims to adopt the standards in 2020 (CARB, 2019). Some of the other participating states are already promoting zero-emission buses and trucks, by both directly introducing electric transit buses and by allocating the settlement funds from the Volkswagen emissions scandal toward medium- and heavy-duty vehicle electrification. In March 2020, the Washington State legislature became the twelfth US state to adopt California's ZEV mandates, and the first to expand the ZEV mandate beyond LDVs to include medium-duty vehicles (Senate Bill 5811).

In April 2020, the California Air Resources Board (CARB) released the final draft of its Advanced Clean Trucks standard, a proposal that will require truck manufacturers that sell more than 500 trucks annually in the state to produce and sell electric trucks. Under the proposed policy, starting in 2024 and for each year through 2035, a given percentage of the sales of truck manufacturers in California must be electric – with different targets for different truck types (i.e. class 2b-3, class 4-8 or "straight trucks", and class 7-8 or "tractors"). The proposal will be subject to a vote by the CARB in late

[58] For more information on CALSTART, see: http://toolkit.globaldrivetozero.org/policies-and-actions/; http://toolkit.globaldrivetozero.org/financial-incentives/ and http://toolkit.globaldrivetozero.org/non-financial-incentives/.

[59] The other states are Connecticut, Maine, Massachusetts, New Jersey, Oregon, Rhode Island and Vermont.

June 2020 (Union of Concerned Scientists, 2020). California is further leading an initiative among the 12 ZEV states to extend ZEV mandates to medium- and heavy-duty vehicles based on the light-duty ZEV policy framework.

On the infrastructure side, San Diego Gas & Electric (SDG&E), a utility that provides services to two populous counties in California, has been authorised by the California Public Utilities Commission to spend USD 107.4 million to install charging infrastructure for medium and heavy-duty EVs in its service territory.[60] The programme is expected to provide charging infrastructure capable of serving around 3 000 vehicles ranging from forklifts to heavy-freight trucks in the next four years (Nikolewski, 2019).

Electric trucks stand to benefit from technology-neutral efficiency and emission standards and regulations. Fuel-efficiency and/or GHG emission standards for HDVs have been put in place across markets covering around 70% of sales globally. In particular, EVs and other zero-emission powertrains will be increasingly competitive *vis-à-vis* incumbent technologies with: the new HDV CO_2 emission standards in the European Union; the HDV fuel-economy standards put in place in India in 2018; and stricter standards in the United States, China and Japan. Korea is designing HDV standards and expects to promulgate them in 2022. Argentina, Brazil, Mexico and Korea are in various stages of developing policies to improve the efficiency of their HDV fleets.

While the electric truck industry in Europe is still in early pilot demonstrations, all major European truck manufacturers are embracing relevant technology. The adoption of electric trucks in Europe will be driven by improving technology and an expansion of models on offer (see next section), the newly adopted HDV CO_2 emission standards and urban air quality restrictions such as zero and low-emission zones. It will further be promoted by amending regulations to account for how they might disadvantage electrification; for instance, Europe has eased maximum weight allowance limits for zero-emission trucks, permitting them to carry two extra tonnes (Transport & Environment, 2020).

The EU's Alternative Fuels Infrastructure Directive (AFID) sets a regulatory framework for the roll-out of recharging and refuelling infrastructure. However it does not include charging infrastructure for electric trucks and vans, and only sets targets for natural gas refuelling infrastructure for trucks.

[60] Although medium- and heavy-duty vehicles represent only 10% of all vehicles in the state, they are responsible for 25% of the GHG emissions from the transportation sector.

In the European Union, almost 47% of road freight transport trips are less than 300 km, and for urban deliveries trucks with a range of 200-300 km fulfil most of the delivery requirements (Transport & Environment, 2020). In a study on charging demand for trucks within the Amsterdam region, CE Delft, an independent research and consultancy organisation, found that depot charging could account for 78%, destination charging for 16% and public charging of 6% of total charging demand for electric trucks (Transport & Environment, 2020). While depot charging can fulfil most of the European Union's charging requirements, studies suggest that legislation on infrastructure for trucks should tackle all depot, destination and public charging with effective tailored measures (Transport & Environment, 2020).

Finally, having achieved a battery electric sales share of 97% for urban buses on the domestic market, and with sales shares growing also in urban delivery and municipal service (e.g. garbage and street sweeping) trucks, China is reportedly investigating extending its NEV mandate policy framework to medium- and heavy-duty vehicles in early 2021.

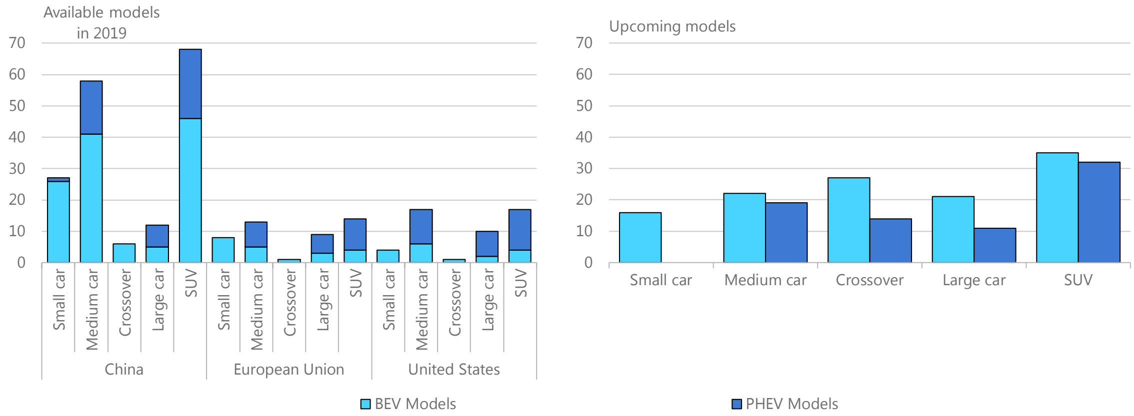
Industry announcements

Expansion of electric car models

Electric vehicle models are available for most vehicle segments and in all major markets (Figure 2.2). We estimate that in 2019, 279 electric vehicle models were available globally, a 26% increase from 2018.[61] China has the largest number of available vehicle models at 171, while the European Union has 45 and the United States has 49 models. In China, model availability is wider for BEVs than for PHEVs, while the opposite is true in the United States and European Union. BEV models tend to be mostly available for small and medium cars (with the exception of China, where there are many electric sport utility vehicles (SUVs). PHEV models, on the contrary, are more concentrated in the large vehicle and SUV segment.

[61] The number of models does not take into account variants of the same model: if a model comes with two different battery ranges, it is considered as only one model. Including all variants, the estimate for 2019 is more than 300 models.

Figure 2.2 Electric vehicles models available and announced, 2019



Notes: Available models are extracted from the Marklines database, upcoming models sourced from EV-Volumes. Crossovers refer to smaller SUVs, SUVs are full sized.
Source: IEA analysis based on Marklines (2020), EV-Volumes (2020).

New EV models, mostly in the medium car and SUV segments, were introduced in 2019. The outlook is for wider EV model availability worldwide.

For the next five years, OEMs have announced plans to release 197 new EV models. Upcoming BEV models are more evenly distributed across vehicle sizes than are currently available as automakers aim to offer EV solutions for all market segments. Upcoming PHEV models, on the other hand, remain focussed on larger vehicles. This can be partially explained by the fact that installing two powertrains is more challenging for smaller vehicles; PHEV powertrains would take up a large share of the vehicle volume and cost.

Box 2.2 Transport electrification commitments from the private sector: the EV30@30 Campaign and The Climate Group's EV100 initiative

Clean Energy Ministerial EV30@30 Campaign

The EV30@30 Campaign was launched at the 8th Clean Energy Ministerial meeting in 2017. The Campaign aims to accelerate the adoption of electric vehicles within the participating countries. It sets a collective goal to reach a 30% sales share for electric vehicles by 2030. Recognising the importance of multi-stakeholder dialogue and cooperation, the EV30@30 Campaign also receives the support of organisations and private businesses that committed to contributing to the realisation of this goal via their own activities and operations. By 2020, nine companies in the utility, automotive and EV services sectors support the EV30@30 Campaign.[62,63]

The Climate Group EV100

Now in its third year, the Climate Group's EV100 initiative comprises 70 global businesses that have committed to 100% electric fleets and/or company-wide roll out of EV charging by 2030.[64]

Sixty-three companies have committed to electrify their corporate owned/leased fleets by 2030. The combined total fleet encompassed by these commitments totals around 350 000 vehicles, of which more than 150 000 are light-commercial vehicles. In addition, three leasing companies are targeting the electrification of approximately 2.3 million vehicles combined across their customer fleets.

To date, 82 000 vehicles have been electrified. BEVs represent 91% of the EVs in corporate owned/leased fleets, indicating a strong current preference for BEVs over PHEVs or hydrogen fuel cell vehicles.

About 55 companies have committed to company-wide charging for staff, accounting for some 2 200 locations. Seventeen business-to-customer brands have made a similar commitment for their customers (totalling 2 000 locations). Some 9 500 individual charging units have been deployed across 1 100 locations for staff and/or customers. More than 40% of EV100 members rely on 100% renewable electricity for their EV charging.

According to a survey of the EV100 companies in 2019 , the most commonly cited barriers to the EV transition were identified as:

- Immature EV product offering in target markets (cited as significant or very significant by 78% of EV100 members).
- Capital cost of EVs (71%).
- Lack of charging infrastructure (65%).
- Operational change impacts (46%).
- Uncertain/underdeveloped policy landscape (30%).

[62] The private sector companies supporting the EV30@30 Campaign are ChargePoint, Energias de Portugal (EDP), Enel X, E.ON, Fortum, Iberdrola, Renault-Nissan-Mitsubishi Alliance, Schneider Electric, The Tokyo Electric Power Company Inc and Vattenfall.
[63] For more information regarding the efforts being carried out by EV30@30 countries, and supporting organizations and companies, see: https://iea.blob.core.windows.net/assets/a7571ce8-70dd-43a8-9ed7-915cb05fc638/3030CampaignDocumentFinal.pdf
[64] EV100 membership data as of May 2020. For more information, see: www.theclimategroup.org/sites/default/files/downloads/ev100_annual_progress_and_insights_report_2020.pdf

Automakers ambitions for EV production and sales

The dynamism of the EV market was clearly demonstrated in 2019 by the increased level of ambition in automakers plans to manufacture and sell electric cars. Table 2.7 summarises these announcements (which reflect the ambition before the Covid-19 pandemic and might be downscaled as a consequence). Daimler, Maruti Suzuki, Toyota and Volkswagen have all set plans for the roll-out of electric cars through 2030 and beyond, suggesting that electric powertrains could become a central technology in this decade. During 2019, Fiat Chrysler Automobiles (FCA) and General Motors have escalated their plans to sell electric cars in the short term, and Hyundai-Kia and General Motors declared new targets for 2025. The BMW Group advanced their EV roll-out plan from 2025 to 2023. Honda has both increased its electric car deployment target and advanced the target year of its plan from 2025 to 2022 for the European market from its aim announced in 2018. Exceptions in the general trend of OEMs boosting their EV plans are Chongqing Changan and Maruti Suzuki. Chongqing Changan has proposed only 25 new EV models by 2025 instead of the 33 it had announced and set a target to sell half a million EVs on a cumulative basis by 2020.[65] Maruti Suzuki has delayed the launch of its first electric car model from 2020 to 2021, and the CEO recently expressed concern about the acceptability of EVs (Bhalla, 2019). Despite Maruti Suzuki's reduced pace, the long-term plan to fully embrace electric mobility is demonstrated by the confirmation of its electric car sales target for 2030. Of course, with the outbreak of the coronavirus pandemic in early 2020, the extent to which OEMs remain committed to the announced EV targets and investment plans within the named timeframes remains to be seen and will be an important market dynamic to monitor.

In terms of manufacturing capacity, OEMs in China currently lead the global EV market. The estimated production capacity of NEVs for 2020 is 10-20 million vehicles per year (Yanjiao, 2018; Sohu, 2019a). This capacity is much larger than current demand levels (even without factoring in likely market contraction, at least on a temporary basis, as a consequence of the Covid-19 pandemic).

[65] This announcement comes after a target of 1.7 million EV sales by 2025. It is unclear whether this replaces the previous target or whether both are complementary.

Table 2.7 OEM announcements related to electric cars

Original equipment manufacturer	Announcement
BMW	15-25% of the BMW Group sales in 2025 and 13 new EV models by 2023 (out of 25 electrified models).
BJEV-BAIC	0.5 million electric car sales in 2020 and 1.3 million electric car sales in 2025.
BYD	0.6 million electric car sales in 2020.
Chery Automobile	0.2 million electric car sales in 2020.
Chongqing Changan	0.5 million cumulative electric car sales by 2020, 25 new EV models by 2025.
Daimler	0.1 million sales in 2020, 10 new EV models by 2022 and 25% of group sales in 2025. More than 50% of sales will be PHEV and BEV by 2030.
Dongfeng Motor CO	0.3 million electric car sales in 2020 and 30% electric sales by 2022.
FAW	15 new EV models by 2025, 40% of all sales will be electric in 2025 and 60% in 2030.
FCA	34 new EV models by 2022 (10 BEV models, 24 PHEV models).
Ford	40 new EV models by 2022 (16 BEV models, 24 PHEV models).
Geely	1 million sales and 90% of sales in 2020.
GM	22 EV models by 2023. More than 1 million EV sales around 2025.
Guangzhou Automobile Group	10% of all car sales in 2020.
Honda	15% EV sales share in 2030 (part of two-thirds of electrified vehicles by 2030 globally and 100% of electrified vehicles by 2022 in Europe).
Hyundai-Kia	29 EV models by 2025 (23 BEV models, 6 PHEV models). 560 000 BEV sales by 2025.
Mahindra & Mahindra	0.036 million electric car sales in 2020. 3 new EV models by 2022.

Original equipment manufacturer	Announcement
Mazda	One new EV model in 2020 and 5% of Mazda sales to be fully electric by 2030.
Other Chinese OEMs	3.4 million sales in 2020.
PSA	0.9 million sales in 2022. 14 new EV models by 2021 (7 BEV models and 7 PHEV models).
Renault-Nissan-Mitsubishi	Renault plans 12 new EV models by 2022 and 20% of the brand's sales in 2022 to be fully electric. Nissan targets eight new BEV models by end 2022. Infiniti plans to have all models electric by 2021.
Maruti Suzuki	A new EV models in 2021 and up to 1.5 million electric car sales in 2030.
SAIC	0.2 million EV sales in 2020, 20 EV model by 2025 and 30 (13 BEV and 17 PHEV) in the future.
Tata Motors	A new EV model in 2020 and 4 new EV models by 2022.
Tesla	0.5 million annual production capacity for Model 3 by 2020, a new EV model in 2020 and a new EV model in 2030.
Toyota	10 new BEV models by the early 2020s and more than 1 million BEV and FCEV sales in 2030.
Volkswagen	0.3 million EVs sold by summer 2020, 1 million EVs produced by 2023, up to 3 million electric car sales in 2025, 25% of the group's sales in 2025, 75 new EV models and about 26 million cumulative sales by 2029.
Volvo	50% of group's sales to be fully electric by 2025. A new EV model will be launched every year until 2025. 50% of Volvo sales will be fully electric by 2025.

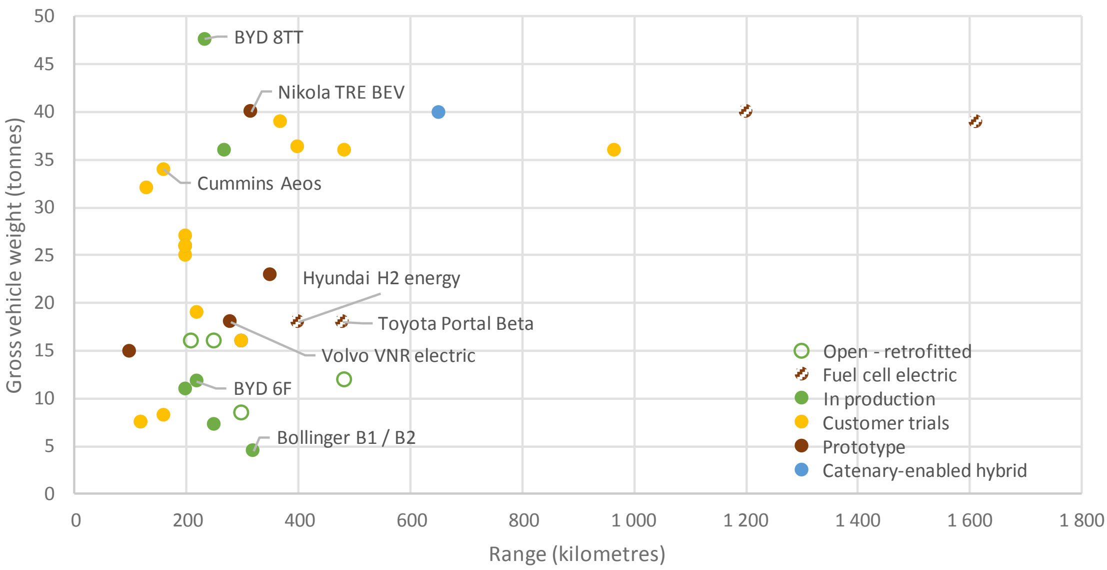
Note: These announcements reflect the situation before the coronavirus pandemic, and thus may be overly optimistic at present. This table is based on the information of companies' announcements available to the authors and may not be complete. It intends to present announcements only related to electric cars (PHEVs and BEVs), therefore other announcements by OEMs that include hybrid vehicles and that provide no specific indication regarding the PHEV/BEV share are not included here. Electrified vehicles include hybrids (HEVs), plug-in hybrids (PHEVS) and battery electric vehicles (BEVs).

Sources: BMW - BMW Group (2017); BMW Group (2019). BAIC - Xinhua (2017); Finance Sina (2017); Dixon (2017). BYD - China Economic Net (2018). Chongqing Changan – Xinhuanet (2020); AutoSina (2018). Chery – Yue (2019). Daimler – Daimler (2018); Daimler (2019). Dongfeng Motor Co. – Nissan Motor Corporation (2019); Chejiahao (2019). FAW – Jlntv (2018); FCA - Fiat Chrysler Automobiles N.V. (2019). Ford - Carey and White (2018). Geely – Sohu (2019b); National Business Daily (2018); GM - General Motors (2020). Guangzhou Automobile Group – Xinhuanet (2018). Honda –Riley (2019). Hyundai-Kia –Kane (2020b). Infiniti – Bloomberg (2019). Mahindra & Mahindra - The Economic Times (2018); LiveMint (2019). Maruti Suzuki – Bhalla (2019); Nikkei Asian Review (2018). Mazda – Mazda (2018); Schmidt (2019). Other Chinese OEMs - personal communication with Jiang Liu (Energy Research Institute of the National Development and Reform Commission, China); Chejiahao (2019); Nengyuanjie (2019). PSA – Reuters (2017); Groupe PSA (2019). Renault-Nissan-Mitsubishi (2019); Nissan Motor Corporation (2017); Groupe Renault (2017). SAIC – Xinhuanet (2017). Tata Motors – Contractor (2020); Tesla – Tesla (2019). Toyota – Toyota (2019a). Volkswagen – Lambert (2020); Volkswagen (2019); Reuters (2018). Volvo – Volvo (2019); Korosec (2019).

Expansion of heavy-duty truck models

The variety of electric truck models available continues to expand. In 2019 and early 2020 prominent new models were announced by Bollinger and Toyota in North America, Tata in India and BYD and Chanje in China (Figure 2.3). In October 2019, Daimler Trucks – the world's largest truck maker – committed to sell only ZEVs by 2039 and to abandon the development of natural gas powered trucks. The CEOs of Volvo and Scania have recently expressed views that the electrification of HDVs is a viable and crucial strategy to help reach climate targets. Both Volvo Trucks and Renault Trucks started production of electric trucks in 2019 (Transport & Environment, 2020). Scania deployed two battery electric urban distribution trucks of 27 tonnes GVW in early 2020 (Kane, 2020a).

Figure 2.3 Company announcements of medium- and heavy-duty electric truck models



Notes: Models announced prior to May 2019 are included in Figure 2.2 in the *Global EV Outlook 2019* (IEA, 2019). Models announced since June 2019 are shown in this figure. Unless otherwise noted, all models are battery electric. The figure is not comprehensive, and in particular does not include many models produced by OEMs in China for the domestic market. Tevva e-trucks are not shown, as the Tevva line-up of e-trucks range from 7.5-12.5 tonnes GVW and have all-electric drive ranges up to 150 km, plus optional range extenders (Tevva, 2019). The latest models offered by Tata Motors are not included in the figure (EV reporter, 2020);

Sources: For new models announced in 2019-2020: BYD (2020); CaliforniaHVIP (2020); Cummins (2017); Electrek (2018); FDG (2020); Hyundai (2020); Lion Electric (2020); Lockridge (2020); NeuronEV (2020); Toyota (2019b); Turpen (2018); Volvo Trucks (2020).

Available models of electric trucks are expanding and prototypes are coming to market in the early 2020s.

To complement the "Drive to Zero" campaign spearheaded by CALSTART, the "Zero-Emission Technology Inventory" (ZETI) provides governments and fleets with up to date information on the rapidly expanding availability of medium- and heavy-duty ZEV models.[66] ZETI provides a zero-emission technology inventory, and an interactive online data and resource clearinghouse with commercially available medium- and heavy-duty truck and bus models that can be queried by region, manufacturer and vehicle type.

[66] Available at: https://globaldrivetozero.org/resources/zero-emission-technology-inventory/

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Chapter 3. Prospects for electric mobility deployment to 2030

This chapter analyses the outlook for electrification of road transport to 2030. It considers deployment of electric vehicles (EVs) and charging infrastructure, battery capacity and related materials demand as well as the implications for energy demand and GHG emissions.

The projections in this analysis rely on the gross domestic product (GDP) assumptions in the *World Energy Outlook 2019* (IEA, 2019a) as at the time of writing there was not yet an updated GDP projection. Given the economic disruption related to the Covid-19 crisis, the assumption in this outlook implies an economic recovery following the pandemic that leads to a similar level of economic activity over the next few years as was previously estimated, which means a relatively speedy global recovery. The analysis also assumes that policy targets that were in place by end-2019 for transport in general and EVs in particular (highlighted in Chapter 2) remain in the context of the Covid-19 pandemic and its economic repercussions. Box 3.1 presents possible impacts from the Covid-19 pandemic on EV deployment to 2030.

Scenario definitions

Two scenarios, the Stated Policies Scenario and the Sustainable Development Scenario, are the basis for this outlook for road transport electrification.

Stated Policies Scenario

The Stated Policies Scenario (STEPS) is the central scenario of the IEA Energy Technology Perspectives (IEA, forthcoming) and the World Energy Outlook (IEA, 2019a) reports. This scenario aims to illustrate the likely consequences of existing and announced policy measures. It takes into account the policies and regulations that governments around the world have put in place, as well as the expected effects of announced targets and plans from governments and industry. Chapter 2 includes a summary of EV deployment targets and internal combustion engine phase out plans (Table 2.1) and purchase incentives (Table 2.2), and the EV policy framework (Policy developments in major markets section). It also includes announcements from original equipment manufacturers (OEMs) regarding plans to expand the range of EV models on offer (Figure 2.2), and the scale-up in electric car production (Table 2.7).

Sustainable Development Scenario

The Sustainable Development Scenario features in the IEA Energy Technology Perspectives and the World Energy Outlook publications. There are three pillars to the Sustainable Development Scenario. These are to: ensure universal energy access for all by 2030; bring about sharp reductions in emissions of air pollutants; and meet global climate goals in line with the Paris Agreement. The Sustainable Development Scenario is based on limiting the global temperature rise to below 1.7-1.8 degrees Celsius with a 66% probability, reaching net zero emissions by 2070. For electric vehicles, the Sustainable Development Scenario incorporates the ambitions of the 11 countries that have joined the EV30@30 Campaign which collectively aims to achieve a 30% market share for EVs in all modes by 2030 (except for two-wheelers)[1]. In the Sustainable Development Scenario, the collective target of 30% sales share in 2030 for light-duty vehicles (LDVs), buses and trucks is achieved at the global level. To be able to assess the benefits of electric mobility on climate change mitigation, the scenario also accounts for relevant measures such as progressive reduction in the carbon intensity of electricity generation, ways to reduce average trip distances, fewer trips by car, and to enable a larger share of movements on public transportation and non-motorised modes of transport.

Electric vehicles

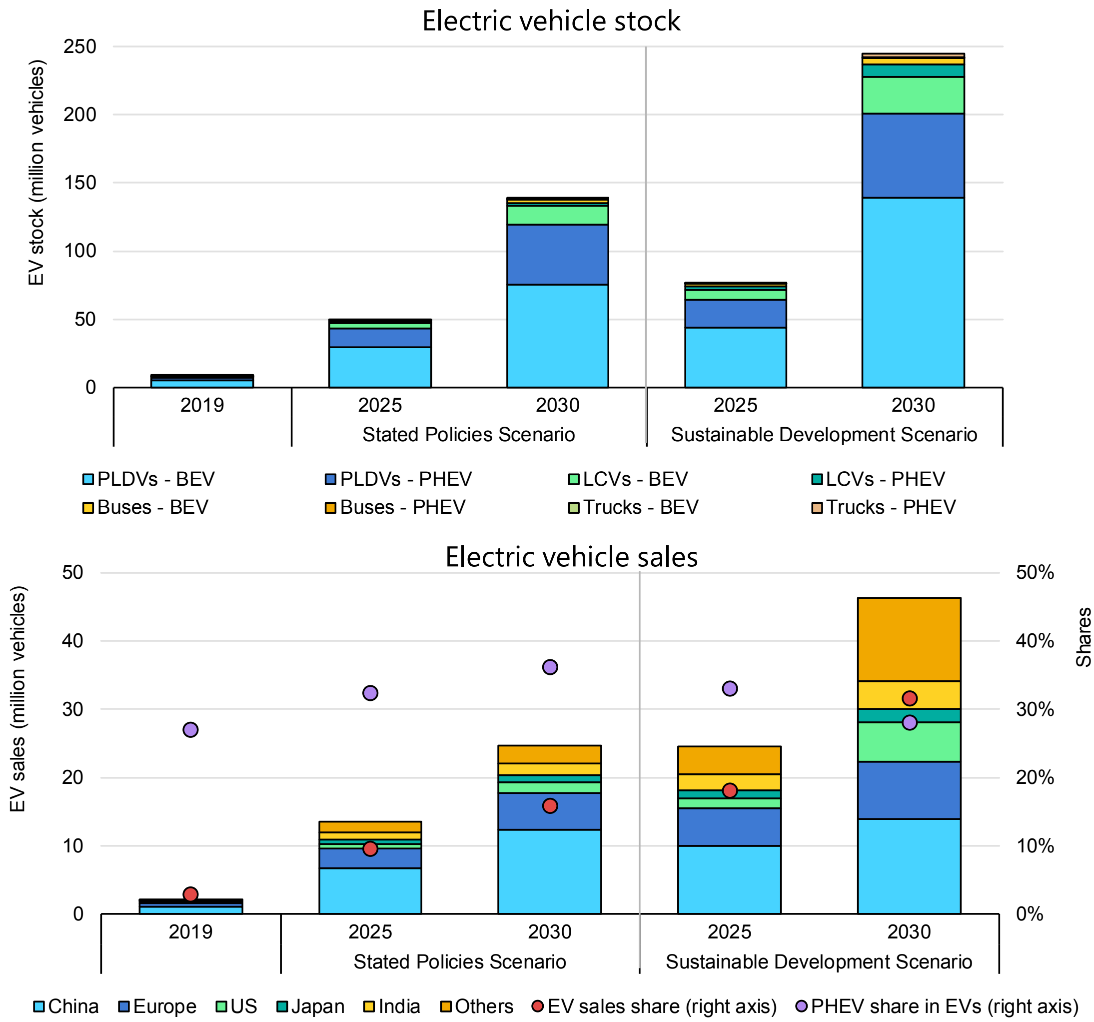
In the Stated Policies Scenario, the global EV stock[2] (excluding two/three-wheelers) expands from around 8 million in 2019 to 50 million by 2025 and close to 140 million vehicles by 2030, corresponding to an annual average growth rate close to 30% (Figure 3.1). Thanks to this continuous increase in sales share, EVs are expected to account for about 7% of the global vehicle fleet by 2030. EV sales reach almost 14 million in 2025 and 25 million vehicles in 2030, representing respectively 10% and 16% of all road vehicle sales.

[1] The EV30@30 Campaign was launched at the Eighth Clean Energy Ministerial in 2017. The participating countries are Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden and United Kingdom (CEM-EVI, 2019).

[2] Including cars, light-commercial vehicles, buses and medium- and heavy-duty vehicles.

In the Sustainable Development Scenario, the global EV stock reaches almost 80 million vehicles in 2025 and 245 million vehicles in 2030 (excluding two/three-wheelers).

Figure 3.1 Global EV stock and sales by scenario, 2019, 2025 and 2030



Notes: PLDVs = passenger light-duty vehicles; LCVs = light-commercial vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle. EV sales share = share of EVs (BEV+PHEV) out of total vehicles sales. PHEV share in EVs = share of PHEV sales out of EV (BEV+PHEV) sales.

Source: IEA analysis developed with the Mobility Model (IEA, 2020).

By 2030, the global EV stock (excluding two/three-wheelers) is about 140 million with sales of 25 million in the Stated Policies Scenario, while the more ambitious Sustainable Development Scenario sees about 245 million EV stock with sales of more than 45 million.

Two/three-wheelers

Electric two/three-wheelers represent the largest fleet of EVs. This vehicle category is most suited to completely transition from internal combustion engines to electric drives thanks to the combination of relatively short trip distances, low energy requirements per kilometre (km) driven, small battery size and ease of charging without need for dedicated charging infrastructure.[3] In the Stated Policies Scenario, the electric two/three-wheeler fleet is projected to increase from approximately 300 million in 2019 to 400 million globally in 2030, or around 40% of the entire two/three-wheelers stock. Sales reach almost 45 million units in 2030, representing a sales share of about 60% at global level. In the Sustainable Development Scenario, the global electric two/three-wheeler stock reaches nearly 490 million (almost 50% of the stock) and sales reach 55 million units (an 80% sales share). The future electric two/three-wheeler fleet is entirely constituted of battery electric vehicles (BEVs) and is concentrated in the People's Republic of China (hereafter, "China"), India and the ten countries of the Association of Southeast Asia Nations (ASEAN).

Light-duty vehicles

The current electric light-duty vehicle[4] fleet is the second-largest after two/three-wheelers, accounting for more than 90% of the EV fleet across all modes except two/three-wheelers. In the Stated Policies Scenario, the LDV stock increases from 7.5 million vehicles in 2019 to almost 50 million by 2025 and accounts for 3% of the total LDV stock. By 2030 the LDV stock is 135 million (120 million cars and 15 million LCVs) and accounts for 8% of the total LDV stock. In 2030, about two-thirds of the global EV fleet is composed of BEVs. The sales of electric LDVs increase from 2.2 million in 2019 to almost 25 million by 2030 (17% of sales of LDVs). In the Sustainable Development Scenario,100 million additional electric LDVs are projected to be circulating worldwide by 2030, so that a total of almost 240 million electric LDVs are on the road in that year (of which around 200 million cars), corresponding to a 14% stock share. Sales of electric LDVs are projected to reach 45 million in 2030 (a 33% sales share, which would realise the EV30@30 objective of 30% EV market share balancing the lower rate of electrification of trucks).

[3] Further details on the factors driving the electrification of two/three-wheelers are available in *Global EV Outlook 2019*, (IEA, 2019b).
[4] Light-duty vehicles include both passenger cars and light-commercial vehicles (LCVs).

Buses

Electric bus stocks reach 1.4 million units in 2025 and almost 3 million in 2030 in the Stated Policies Scenario (4% and 7% stock shares respectively). In the Sustainable Development Scenario, the deployment of electric buses accelerates, reaching 5 million units in 2030 (12% stock share). In both scenarios, electrification occurs primarily in urban buses, due to their shorter ranges and driving cycles suitable for electrification. Electric sales shares of intercity buses are far lower, and indeed the long charging times needed for this vehicle category will make it among the last operational vehicle categories to transition to electric drive. For this category, the share of PHEVs is likely to be high, not least to be able to drive long distances but switch to zero-emission capability when entering urban areas.

Medium- and heavy-duty trucks

The electric truck[5] fleet reaches 0.6 million in 2030 in the Stated Policies Scenario and 3 million in the Sustainable Development Scenario, hitting 1% and 3% of the total truck stock, respectively. The share of sales of electric trucks rises from less than 0.2% in 2019 to 1.5% over the projection period (8% in the Sustainable Development Scenario). By 2030, electric trucks gain share particularly in urban areas and regional delivery applications.

This progressive electrification of the road transport sector by 2030, in both scenarios, is accompanied by the emergence and consolidation of other powertrain technologies supported by governments and as necessary for the achievement of the goals represented in the Sustainable Development Scenario. In particular, hybridisation of ICEs, in light of significant technology and market progress over the past decade, continues to expand and reaches 7% of the global car stock by 2030 both in the Stated Policies and Sustainable Development scenarios.[6] Fuel cell electric vehicles (FCEVs) are starting to make inroads, with commercially available FCEV cars and growing sales in some areas such as California, and more FCEV truck models announced. However, their market share remains low throughout the 2030 decade, attaining 1% of global car sales by 2030 in the Sustainable Development Scenario. It is expected that with technology learning FCEV sales accelerate after 2030.

[5] Electric truck fleet includes medium freight trucks (3.5-15 tonnes gross vehicle weight (GVW) and heavy-freight trucks (heavier than 15 tonnes GVW).

[6] The *Global EV Outlook 2019* estimated the hybrid electric car sales in 2030 would need to reach about 40% of total car sales in the European Union in 2030, along with 26% electric cars, for the expected fleet sold in 2030 to meet the EU gCO_2/km emissions standards (IEA, 2019b).

Regional insights

EV deployment proceeds at different speeds across world regions. Figure 3.2 shows the outlook in 2030 for EV uptake by mode and scenario in key regions.

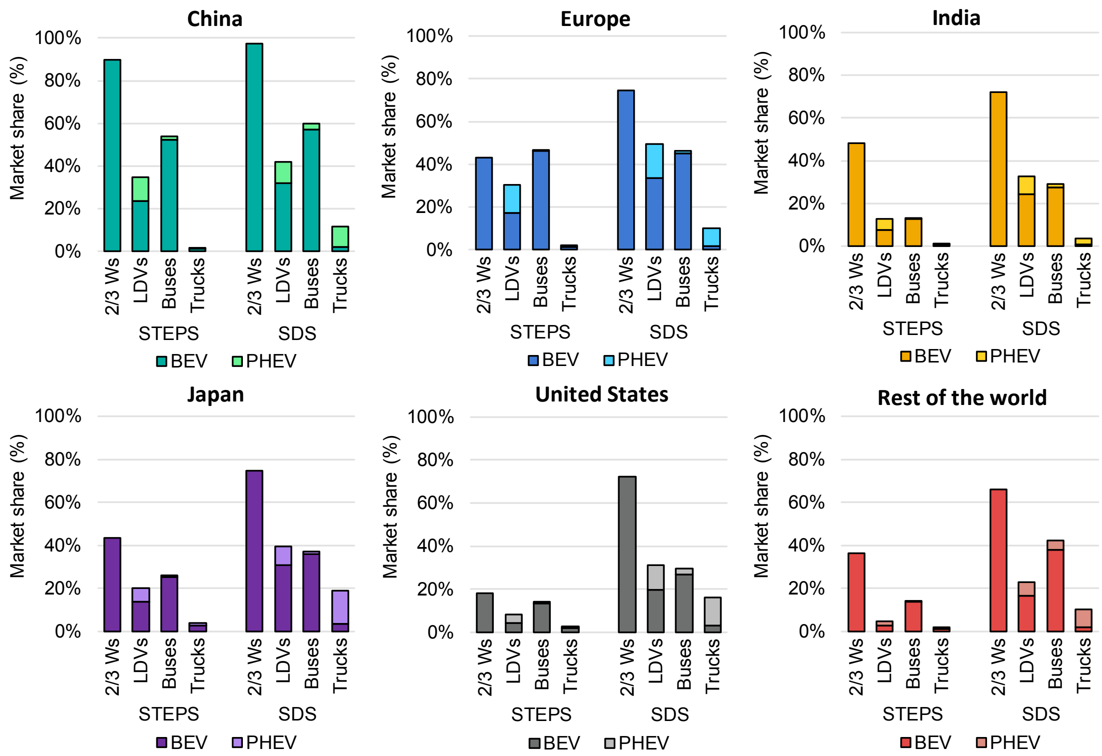
China

The outlook for 2030 in both scenarios is that China retains the lead in terms of absolute numbers of EVs deployed across all modes. In the Stated Policies Scenario, EVs reach almost 60% sales share in 2030 across all transport modes (around 35% excluding two/three-wheelers). The sales share of electric LDVs in China is among the highest worldwide throughout the projection period and reaches 35% in 2030.[7] Compared to the projections of the *Global EV Outlook 2019* (IEA, 2019b), electric LDV sales projections for China have been revised up due to the extended New Energy Vehicle (NEV) mandate targets to 2023 and new credits calculation method set in 2019, and the revision upwards of the 2025 NEV target[8] on the back of an expectation that the supporting measures adopted by the government to support NEVs due to the Covid-19 crisis will reap the expected effects (see Chapters 1 and 2). Over the projection period, the deployment of electric buses is also led by China, which reaches about 55% sales share in 2030. This reflects the emergence in China of many of the world's leading electric bus manufacturers (e.g. BYD, Yutong and others). Already mainstream today at almost 50% of the country's total two-wheelers fleet, electric two-wheelers in China (250 million units in 2019) account for 70% of the global two-wheeler stock and 90% of the China two-wheeler stock in 2030 in the Stated Policies Scenario.

In 2030 in the Sustainable Development Scenario, two-out-of-three vehicles sold in China across all modes are electric (more than 40% excluding two/three-wheelers). EVs account for more than 40% of all LDV sales, about 60% of all bus sales, virtually all two-wheeler sales and more than 10% of total truck sales.

[7] The sales share is higher in Norway, Denmark, Finland and Sweden, but they are smaller markets than China.
[8] The NEV sales target announced in 2019 envisions 25% by 2025, against 15-20% by 2025 previously.

Figure 3.2 EV share of vehicle sales by mode and scenario in selected regions, 2030



Notes: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; 2/3 Ws = two/three-wheelers; LDVs = light-duty vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle. Europe includes the countries of the European Union plus Iceland, Norway and the United Kingdom.

Source: IEA analysis developed with the Mobility Model (IEA, 2020).

China and Europe lead the electric vehicle markets in both scenarios.

Europe

Developments in electric mobility in Europe follow close behind those in China in the Stated Policies Scenario. The extent of potential support to EVs in European countries economic recovery measures related to the Covid-19 crisis is unknown at the time of writing, and so the main assumption is that CO_2 emissions standards for LDVs and heavy-duty vehicles (HDVs), plans to phase out ICE vehicles sales and EV deployment targets continue to promote electrification in Europe in the years ahead (see Chapter 2, Table 2.1). Europe here includes Iceland and Norway, which today have the highest sales of electric cars in total car sales, and the United Kingdom, which has set ambitious electric car deployment plans. In Europe, EV sales share across all modes exceed 30% in 2030 in the Stated Policies Scenario. Electric two/three-wheelers in Europe start from a low level compared to Asian countries but reach more than 40% sales share in 2030. Electric buses attain almost 50% sales share, spurred by the European Union Clean Vehicle Directive, which targets EV sales shares ranging from 24% to 45% by 2025 and from 33% to 65% by 2030 for publicly procured vehicles (European Union, 2019). Electric LDVs reach 30% market share in 2030 and electric trucks reach 2%.

In the Sustainable Development Scenario, by 2030, Europe has a combined EV market share (for electric LDVs, buses and trucks) of just under 50%.

India

EV sale shares across all modes (including two/three-wheelers) in India reach around 30% in 2030 in the Stated Policies Scenario. Reflecting the intentions of FAME II, EV deployment in India is mainly achieved through the electrification of two/three-wheelers, which reach a market share of almost 50%. The rate of electrification of buses and LDVs is lower, below 15% sales share in 2030.

In the Sustainable Development Scenario, EV sales shares in India scale up rapidly to 55% in 2030 across all road vehicle modes (30% excluding two/three-wheelers). By 2030 almost three-quarters of all two/three-wheelers sold are electric, as are almost one-third of all LDVs and about 30% of all buses.

Japan

In the Stated Policies Scenario, by 2030 EV sales in Japan across all modes (excluding two/three-wheelers) reach 20%, in line with the government's long-term goal for Japanese automakers to reduce vehicle GHG emissions by 80% (METI, 2018). Although several Japanese companies are at the forefront of EVs and automotive battery manufacturing, in the Stated Policies Scenario, Japan has lower domestic EV sales shares than the leading countries. This reflects fairly modest BEV and PHEV incentives compared to other countries and that fuel-economy standards in Japan do not include specific provision for EVs, unlike the CO_2 emission standards in the European Union.

In the Sustainable Development Scenario, Japan reaches EV sales shares of almost 40% across all modes (except two/three-wheelers), the same as for electric LDV sales shares.

United States

Electric mobility uptake in the United States proceeds at two speeds in the Stated Policies Scenario. At a faster pace are the 12 states that have implemented a zero-emission vehicle (ZEV) mandate (Berman, 2020) and the states that aim to continue to follow California's stricter GHG emission standards, rather than the proposed laxer federal standards in the 2020 Safer Affordable Fuel-Efficient Vehicle Rule (see

Chapter 2, Policy developments in major markets section). Electric mobility advances at a far slower pace in those states that are not aligned with the California standards or have a ZEV mandate. This reflects the less favourable value proposition of electric cars in the US context of a high reliance on personal vehicles for mobility, more common long-distance trips and low taxes on oil-based automotive fuels. Considering the combined fast and slow tracks, the outlook for the share of EV sales in the United States is 8% in 2030 across all modes (except two/three-wheelers) in the Stated Policies Scenario.

The Sustainable Development Scenario assumes that the United States rapidly adopts a regulatory framework supportive of electrification, whereupon EV deployment accelerates to reach a 30% sales share across all modes (except two/three-wheelers) in 2030. Lagging in deployment in comparison with China and Europe, in the Sustainable Development Scenario the United States in 2030 does not reach the same penetration of EVs as in those leading countries.

Other regions

This category includes two groups of countries. One includes countries with strong ambitions to electrify road transport and that have enacted policies and measures to boost EV adoption (e.g. Canada, Chile, Costa Rica, Israel, New Zealand, Pakistan). The second group includes countries that have not yet specifically expressed ambition to deploy EVs; their EV uptake will continue to lag global average adoption rates. Since the share of vehicle sales in countries in the second category overwhelms that of countries in the first group, in the Stated Policies Scenario, the overall EV sales share for the overall "other regions" category is lower than in key vehicle markets. EV uptake in the overall "other regions" category is mainly concentrated on two/three-wheelers and to a lesser extent on buses. However, some countries in the first group are projected to experience very rapid EV deployment, with Israel attaining almost 50% sales share across all modes (except two/three-wheelers) by 2030, Canada almost 30%, Colombia nearly 20% and Chile roughly 15%.

In the Sustainable Development Scenario, the level of ambition is assumed to rise across all world regions. This results in LDVs attaining more than 20% market share and buses about 40% by 2030 across the markets that are not covered explicitly in the individual countries/regions highlighted in this section.

Box 3.1 Covid-19 impacts on electric mobility to 2030: Exploring alternative futures

As cities and countries across the globe went into lockdown and as fears of contagion spread, the Covid-19 crisis affected mobility patterns: passenger travel activity came to a near-halt in urban centres and on intercontinental flights, and vehicle sales slumped. It is likely that Covid-19 will have long-lasting impacts on the transport sector, although its effects on the behaviour of individuals, the economy and policies are still uncertain.

Beyond the broader uncertainties around possible second waves of the pandemic or the pace of the economic recovery, the evolution of future mobility patterns emerging from the crisis might be different than before. For example, the experience of clean air that provided citizens in urban areas with bright skies to an extent often not seen in decades as a result of lockdown measures could drive change in urban policy and in mobility patterns. For many companies and their employees, the lockdown demonstrated the technical feasibility, and, in some cases, convenience and preference for the option among employees (The Brussels Times, 2020), as well as efficacy and potential for cost-savings of regular teleworking (Global Workplace Analytics, 2015; Arruda, 2020; Picchi, 2020; Routley, 2020). For companies where this is an option, encouraging the practice while reinforcing teleworking capabilities could reduce future commuting needs. On the other hand, early indications in some cities suggest a faster rebound in car activity than for public transport, partly because the use of public transport options is restricted (Bloomberg, 2020; Ipsos, 2020). Continued fears about the lack of social distance in public may well boost personal vehicle purchases and overall driving for commuting. This bears the risk not only of increased congestion but also, where these vehicles are not electric, of further increase in local pollution and additional GHG emissions.

Government responses to the Covid-19 crisis will therefore be critical in shaping future mobility patterns, grasping opportunities for changes in travel routines where they are sustainable and mitigating possible adverse effects. To illustrate potential longer lasting effects on future electric vehicle deployment, we identified two sets of drivers that may steer the future of mobility and electric mobility in opposite directions: a “bright” future, in which air quality concerns trigger policy changes in urban areas to reduce the number of cars on the road towards less space-, pollution- and GHG-intensive transport options. Cleaner powertrains such as EVs are prioritised both at municipal as well as national level.

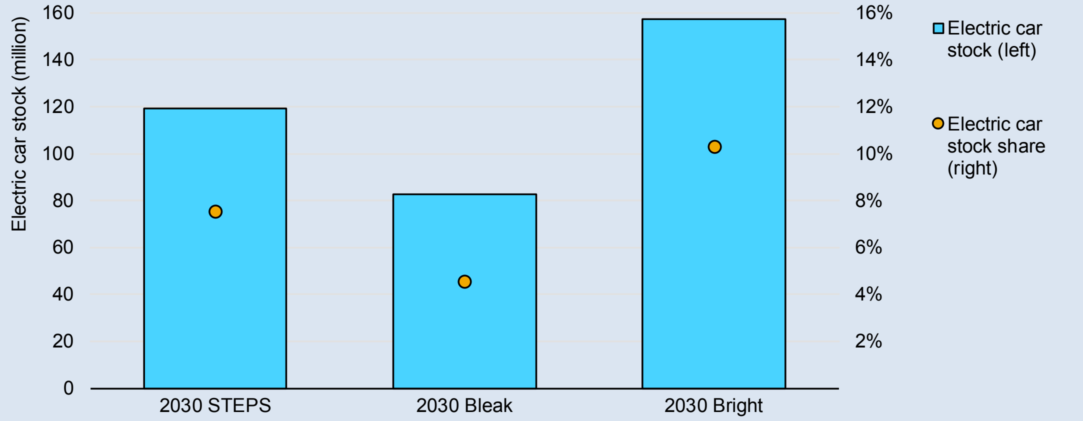
- a “bright” future, in which air quality concerns trigger policy changes in urban areas to reduce the number of cars on the road towards less space-, pollution- and GHG-intensive transport options. Cleaner powertrains such as EVs are prioritised both at municipal as well as national level.

- a "bleak" pathway, in which behavioural and economic consequences to the Covid-19 crisis result in stalling progress in EV deployment. Social distancing and health security measures make it more difficult to use public transport; commuters avoid public and shared transport for fear of contamination, leading to reduced revenues from fares and lower levels of services, in a vicious downward spiral. Left without a viable alternative, those who can afford to buy and use cars instead, resulting in overall increased personal car adoption and use. The Covid-19-related economic crisis leads governments to roll back policy support for EVs, and consumers favour cheaper car options at purchase.

Policy and behavioural responses to the Covid-19 crisis that could facilitate a "bright" pathway

Response	Description
Increased teleworking	Recognising the potential for cost savings and societal benefits, employers put in place measures to normalise and encourage occasional to regular work from home.
Accelerated support to modal shift to 'active' modes (walking and cycling) and public transit	Based on the need for alternatives to space-inefficient personal cars, cities around the globe continue to reallocate street space away from cars to walking and cycling and to public transit (e.g. dedicated bus lanes); and to allocate funding to supporting these modes
Increased support to quieter and lower-emission powertrains at the local level, including through congestion charges and low- and zero-emission zones	Low- and zero-emissions zones, and congestion charging schemes are already becoming more common, and more cities follow in adopting measures favourable to EVs after experiencing "cleaner air and brighter skies" during lockdown
Government support to economic recovery prioritises alternative technologies such as the EV industry	Governments use the opportunity, via their economic recovery plans, to implement measures and policies (including financial support to the industry and consumers) that prioritise lower-emissions and alternative technologies for transport.

Electric car stock in the Stated Policies Scenario and two alternative pathways depicting possible Covid-19 impacts, 2030



Notes: The possible impacts of the following factors are explored relative to the Stated Policies Scenario. “Bleak” pathway: increased personal car ownership as a result of lower public transport use and reduced EV adoption from reduced government support to alternative powertrains. “Bright” pathway: reduced personal car ownership as a result of teleworking and urban mobility policies and increased EV adoption from urban mobility policies and economic recovery measures prioritising cleaner technologies. STEPS = Stated Policies Scenario.

The combination of increased teleworking, an extension of the “blue skies” experience in urban areas and economic recovery measures that prioritise low-emission vehicles could bring up EV deployment in 2030 relative to the Stated Policies Scenario. In the “bright” pathway, the number of electric cars would reach close to 160 million by 2030, about 40 million more than in the Stated Policies Scenario. This would represent a big step towards the EV market uptake required for the Sustainable Development Scenario, although the latter would require larger-scale and structural efforts that span beyond direct responses from the Covid-19 crisis. In particular, it would require stringent fuel economy standards and/or EV mandates in all major car markets.

The “bleak” pathway would lead to the opposite effect, with increased car ownership and travel and a slower uptake of alternative powertrain technologies. In this pathway, EV deployment would slow down in comparison with the Stated Policies Scenario, to reach 80 million electric cars by 2030, i.e. a third less than in the Stated Policies Scenario. Direct CO_2 emissions from cars in the bleak pathway would increase by more than 400 Mt CO_2, or nearly 15%.

Charging infrastructure

Future charging infrastructure (or electric vehicle supply equipment [EVSE]) needs depend on the inter-relationships between vehicle stock, driving needs, charging equipment usage and technical capabilities (e.g. rated power and connectivity protocols). For electric LDVs, region specific factors such as population density, charging behaviour and driving range have direct implications on the geographical location of the EVSE and on charging rates. It is worthwhile to note that:

- Home charging access is positively correlated with the share of EV owners occupying single family houses, detached/semi-detached units, or that have access to a garage or carport (Dua, 2019; Melaina, 2016).
- Dense cities in China like Beijing, Hefei and Hangzhou, have higher proportion of publicly accessible chargers compared to major EV markets in Europe and the United States (Hall and Lutsey, 2017).
- Workplace and "away from home charging" is largely influenced by employer initiatives and local policy measures (Smart, 2014).
- The installed capacity of publicly accessible chargers and the relative allocation between fast and slow public chargers differ by region. Generally it depends on a combination of factors including: market share of PHEVs and BEVs; average battery capacities; driving and charging behaviour; population and housing densities; technology progress and government policies (Hove, 2019; Hall, 2019).

Electric buses (e-buses) have higher energy consumption per kilometre driven and drive longer daily mileages than LDVs, thus they are equipped with larger batteries. To recharge them in a reasonable time, fast (≥ 50 kilowatt [kW]) charging is common practice for e-buses. Yet, there is quite a degree of variation in the daily mission profile of buses (depending on region specific ridership trends, occupancy factors and degree of urbanisation), with consequential impacts on the supporting EVSE infrastructure:

- For electric buses covering relatively short distances (less than 150 km/day), a typical 50 kW fast charger can fully charge a 110 kilowatt-hour (kWh) e-bus in about two hours at a depot (McKinsey & Company, 2018).
- In large cities with higher ridership, service frequency and daily mileage, there is a stronger case for short-duration opportunity charging (e.g. at destinations and depots) at higher power rates.

Electrification of trucks poses a unique challenge for charging infrastructure deployment due to their high power and energy requirements, especially for long-haul trucks. To fully charge a commercial 550 kWh battery capacity equipped long-haul truck would require as much energy as the average daily energy consumption of 55 households in the European Union. [9, 10] In order for an electric truck to recharge in a reasonable amount of time, ultra-fast charging is being developed, reaching power rates of more than 500 kW up to a few megawatts (MW) (Ronanki, 2019; Spöttle, 2018; Electrive, 2019). This means an additional dimension to EVSE deployment challenges and their impacts on electricity networks, particularly at the distribution level (Plötz, 2019).

Assumptions

To address these points, the charging infrastructure projections in the two outlook scenarios are based on assumptions that draw on current evidence from across the world.[11] The assumptions follow three key metrics: EVSE to EV ratio; mode specific charging rates; and share of total number of charging sessions by EVSE type. Only conductive charging infrastructure is considered. EVSE classification is primarily based on access (publicly accessible or private) and charging power (Table 3.1). Overall, three types of EVSE are considered for LDVs: private (slow), publicly accessible (slow) and publicly accessible (fast).[12] Charging demand of buses and trucks is assumed to be met by dedicated fast chargers.

[9] Daimler eCascadia has a 550 kWh battery (400 km range) (Daimler, 2018).

[10] Estimated considering that in the European Union the total electricity demand from 220 million private houses was about 770 terawatt-hours in 2018 (Earl, 2018).

[11] For additional information regarding the methodology, refer to *Global EV Outlook 2019* (IEA, 2019b). .

[12] The distinction of 22 kW between slow and fast chargers is consistent with worldwide standards and connectivity protocols. In Japan and the United States, the Society of Automotive Engineers (SAE) standard J1772 single-phase AC level 1 (120 volt [V]/16 ampere [A], up to 1.9 kW) or level 2 (240V/32-80A, 7.6 kW – 19.2 kW) charging are considered to be the norm for private slow chargers (home and workplace) for LDVs (SAE, 2010). In China and the European Union, single phase AC (120V/16A-32A, 1.9 kW-7.6 kW) and tri-phase AC (240V/32A-80A, 7.6 kW-19.2 kW) according to the International Electrotechnical Commission (IEC) standards, are considered to be the available options for private (home and workplace) slow charging of LDVs (IEC, 2017). Differentiations by connector type and power supply phase are not included in the analysis. Today there are four types of plugs for vehicle charging: two each for AC (Type 1 single phase and Type 2 tri-phase) and DC (CHAdeMo and CCS) (IEA, 2018a).

Table 3.1 Key assumptions for projections of EV chargers in 2030

Mode	EVSE type	EVSE: EV ratio		Average charging rate (kW)	Share of charging by EVSE type (%)	
		RoW	Dense	RoW and Dense	RoW	Dense
LDVs	Private	1.07	0.93	6.7	87%	73%
	Publicly accessible slow	0.09	0.06	7.4	3%	7%
	Publicly accessible fast	0.02	0.04	150	10%	20%
		RoW and Dense		RoW and Dense	RoW and Dense	
Buses	Fast	0.13		190	100%	
Trucks	Fast	0.26		480	100%	

Notes: RoW = rest of world. Dense countries include China and Japan. LDVs = passenger light- duty vehicles and light-commercial vehicles Share of charging by EVSE types refers to the fraction of total number of charging sessions using that specific EVSE type.

Private *LDV* charging includes both home and workplace charging. *Publicly accessible* slow charging refers to AC level 1 and level 2 charging up to 22 kW. Publicly accessible fast chargers can provide power higher than 22 kW. The average power rate of LDV chargers is assumed to double from 3.3 kW today to 6.7 kW by 2030 The average fast charging power of 150 kW is assumed based on historical growth and anticipated progress in DC fast charging power in relation to the average battery capacities and the maximum power rate acceptable by the vehicles[13]. Publicly accessible fast chargers are assumed to be used for 10% of the charging events based on the European Climate Foundation study (Cambridge Econometrics, 2018).

Buses — average bus charging rate is assumed to increase from 55 kW today to 190 kW in 2030 considering the gradual replacement of current 50 kW DC fast chargers with ultra-fast chargers.

Trucks — It is assumed between now and 2030, conductive plug-in chargers will most likely dominate the truck charger market and these commercially deployed truck chargers will provide on average 500 kW. This aligns with the European Union wide initiative EUROP-E implemented by Ionity, that recommend 350 kW minimum by 2025 and at least 500 kW in 2030 (Ionity, 2019; EUROP-E, 2017).

Sources: ACEA (2020); AFDC (2020); CHAdeMO (2019); CharIN (2019); EAFO (2020); EVCIPA (2019); EV-Volumes (2020); GB/T (2019); Horrox, J. and M. Casale (2019); Houbbadi (2019); T&E (2020); ZeEUS (2017).

Private chargers

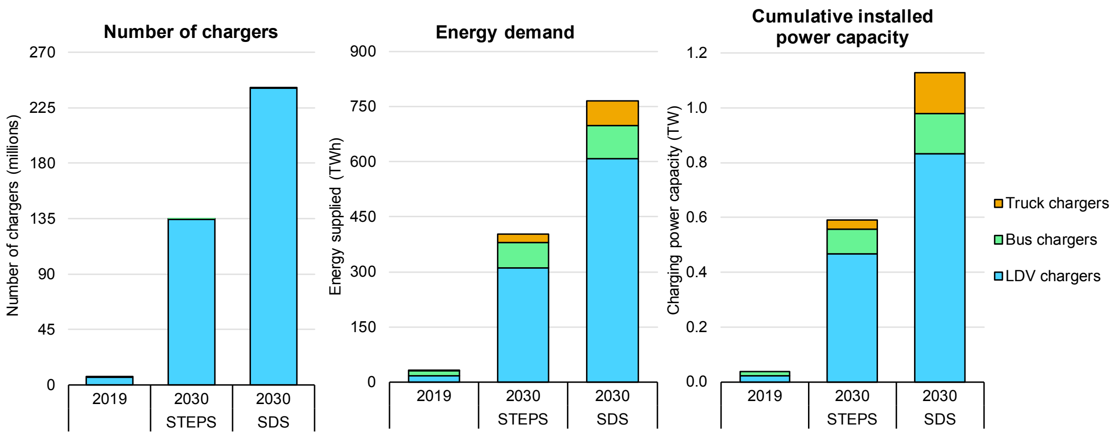
The number of private chargers for LDVs and dedicated chargers for buses and trucks expands from 6.4 million in 2019 to almost 135 million in 2030 in the Stated Policies Scenario, corresponding to more than 30% average year-on-year growth (Figure 3.3). The cumulative installed power capacity of those chargers

[13] Today the Tesla Supercharger v3 can provide up to 250 kW (Tesla, 2019) and and the European Union wide initiative EUROP-E implemented by Ionity is capable of up to 350 kW output using CCS (Ionity, 2019). Recently CHAdeMo 2.0 was launched with rated power of 400 kW and is expected to gear up to release CHAdeMO 3.0 or ChaoJi ultra-fast charger up to 900 kW of output (CHAdeMO, 2019). The limiting factor is the on-board power electronics which determine the rate at which the battery can be charged.

in 2030 is 0.6 terawatts (TW). In energy terms, private chargers consume approximately 400 terawatt-hours (TWh) of electricity by 2030. The Sustainable Development Scenario projects those variables to nearly double in 2030 compared to the Stated Policies Scenario: the number of private chargers is more than 240 million, installed power capacity is about 1.1 TW and electricity demand is about 770 TWh.[14]

In both scenarios, almost the entire stock of private chargers is for LDVs. However, buses and trucks together account for about one-fourth of total installed charging capacity and consume more than 20% of total energy supplied by private chargers in 2030. This is essentially due to the fact that buses and trucks require fast chargers with higher power rates than for LDV chargers, require a large amount of electricity to fulfil their higher mileages and have higher energy consumption per kilometre driven.

Figure 3.3 Number of private chargers, associated energy demand and cumulative installed charging power capacity in 2019 and by scenario in 2030



Note: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario.
Source: IEA analysis based on Mobility Model (IEA, 2020).

The number of private chargers, their energy demand and the needed cumulative installed capacity nearly doubles in 2030 in the Sustainable Development Scenario relative to the Stated Policies outlook.

In 2030, the total number of truck chargers is projected to reach more than 100 000 in the Stated Policies Scenario and around 650 000 in the Sustainable Development Scenario (Figure 3.3). The electrification of trucks envisioned in the latter scenario is attributable to an encouraging policy landscape and to responsive OEMs, battery and

[14] To put into perspective, the total installed capacity of air conditioning equipment in the world today is about 10 TW, eight-times higher than the installed capacity of EV chargers in the Stated Policies Scenario (IEA, 2018b).

EV charger manufacturers, utility companies, fleet operators and trucking companies. Trucks consume almost 70 TWh of energy in Sustainable Development Scenario, three-times as much as in the Stated Policies Scenario (22 TWh) in 2030. To meet this demand in 2030, 150 gigawatts (GW) of cumulative installed charging power capacity will be needed in the Sustainable Development Scenario and around 35 GW in the Stated Policies Scenario.

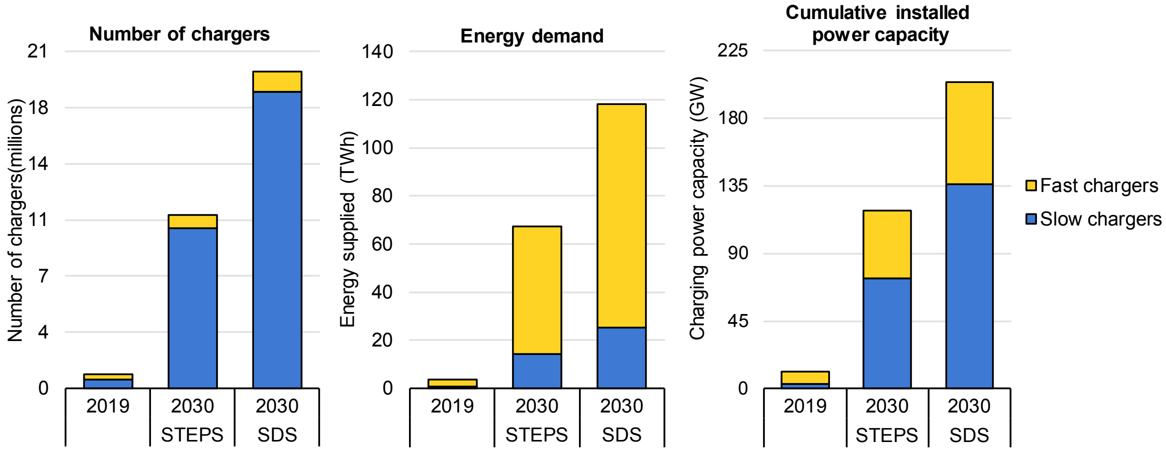
Publicly accessible chargers

Understanding the role and value of publicly accessible charging infrastructure is context driven. Publicly accessible charging infrastructure is often perceived as complementary to private charging (home or workplace) to alleviate concerns about range anxiety and to facilitate long distance travel. However, publicly accessible charging could substitute private charging as the primary charging destination in dense urban areas where multi-unit/apartment complex dwelling is more prevalent, home charging access is scarce and workplace charging is restrictive, or for fleets such as taxis and ride-hailing services (e.g. large charging hubs such as already exist in China).

Figure 3.4 shows the number of publicly accessible LDV chargers installed, their energy demand and the installed power capacity in 2030 in the two scenarios in this outlook.

In the Stated Policies Scenario, the number of publicly accessible slow and fast chargers increases from 870 000 today to almost 11 million in 2030. Publicly accessible chargers reach cumulative power capacity of 120 TW and provide almost 70 TWh of energy, roughly one-fifth of the electricity consumed by private chargers in the Stated Policies Scenario. Slow chargers are more than 90% of the total publicly accessible charger installations (10 million), account for 60% of cumulative installed charging power capacity and consume 20% of total energy.

Figure 3.4 Number of publicly accessible LDV chargers, associated energy demand and cumulative installed charging power capacity in 2019 and by scenario in 2030



Note: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario.
Source: IEA analysis based on Mobility Model (IEA, 2020).

The number of publicly accessible chargers in 2030 is 11 million in the Stated Policies Scenario and almost twice that in the Sustainable Development Scenario. Fast chargers represent 8% of the total installations yet consume 80% of total energy in both scenarios.

In the Sustainable Development Scenario, the number of publicly accessible chargers and associated installed charging power capacity and electricity consumption are projected to almost double relative to the Stated Policies Scenario. The 20 million publicly accessible slow chargers provide 120 TWh of energy with an installed capacity of 200 TW. Nearly 1.2 million fast chargers provide more than 90 TWh of energy with installed capacity of around 70 TW.

Impact of electric mobility on energy demand

The global EV stock consumed almost 80 TWh of electricity in 2019 (around 40% more than in 2018). The bulk of this consumption was to power the large electric two-wheeler fleet in circulation, particularly in China. The growth of the EV fleet envisioned in both scenarios results in increased electricity consumption in all major world regions.

In 2030, in the Stated Policies Scenario, the global electricity demand from EVs (including two/three-wheelers) increases about sixfold from 2019 levels to 550 TWh. It rises nearly eleven-fold relative to 2019, to almost 1 000 TWh in the Sustainable Development Scenario. While today EVs account for a small fraction of global total final electricity consumption (less than 0.5%), the picture is likely to change in the future. Table 3.2 shows that by 2030 EVs in the assessed countries/regions will account for at least 1% of total final electricity consumption in the Stated Policies Scenario and minimum 2% in the Sustainable Development Scenario.

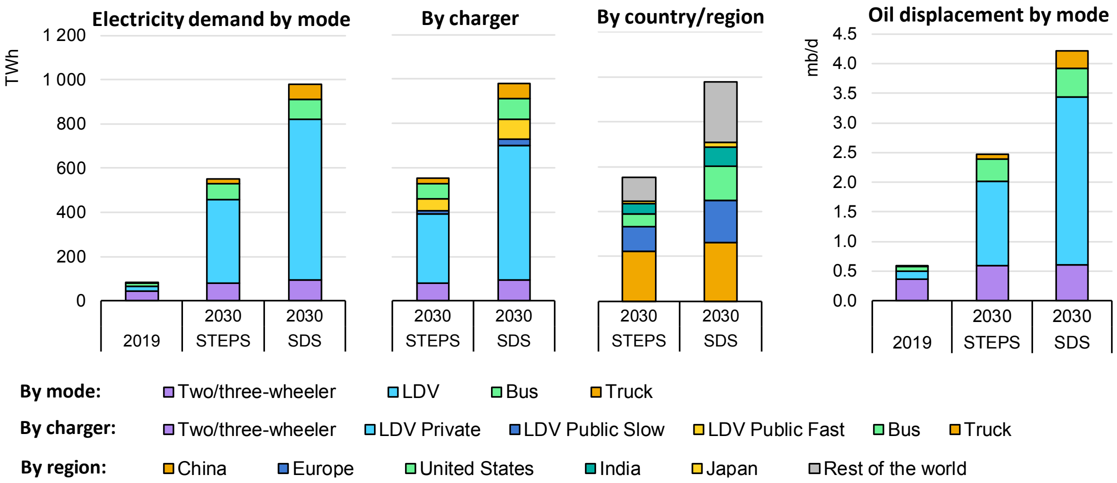
Table 3.2 Share of electricity consumption attributable to EVs by region and scenario, 2030

Country/region	2019	Stated Policies Scenario, 2030	Sustainable Development Scenario, 2030
China	1.2%	3%	3%
Europe	0.2%	4%	6%
India	0.0%	2%	3%
Japan	0.0%	1%	2%
United States	0.1%	1%	4%

Sources: Electricity demand from EVs was evaluated with the Mobility model (IEA, 2020); total final electricity consumption from (IEA, 2020) and IEA (forthcoming).

These projections suggest that EVs are likely to play an important role for power systems in the near term. In advanced economies, the increasing demand of electricity from EVs is expected to happen in a context that sees the total electricity demand stagnating or even reducing due to energy efficiency improvements. On the other hand, in emerging economies the consumption from EVs will be embedded in a context of fast growing electricity consumption from all sectors. Understanding when EVs are charged and at what power rate is important to manage the smooth operation and security of power systems (see Chapter 5). Figure 3.5 indicates that about three-fourths of the electricity consumed by EVs in 2030 in the Stated Policies Scenario is provided by slow chargers.

Figure 3.5 Electricity demand from the EV fleet by mode, charger type, country/region and oil displacement, 2019 and 2030



Notes: mb/d = million barrels per day; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; LDV = light-duty vehicle. Electricity demand by EV mode is calculated using the following assumptions (where the range indicates the variation across countries). Fuel consumption (in kWh/km): PLDVs 0.20-0.26; LCVs 0.31-0.42; buses 1.2-1.74; minibuses 0.35-1.49; medium trucks 0.87-1.11; heavy trucks 1.46-2.08; two-wheelers 0.03-0.04. Annual mileage (in km): PLDVs 8 000-18 000 km; LCVs 11 000-31 000; buses and minibuses 15 000-45 000; medium and heavy trucks 22 000-91 000; two-wheelers 4 000-7 600. Charging losses are 5% and the share of electric driving for PHEV is 70% of the annual mileage.

Source: IEA analysis developed with the Mobility Model (IEA, 2020).

Global electricity demand from EVs grows from 80 TWh in 2019 to 550 TWh in 2030 in the Stated Policies Scenario, when oil displacement reaches 2.5 mb/d. In both scenarios, most electricity is drawn from slow chargers.

Stated Policies Scenario

In the Stated Policies Scenario, EVs are projected to consume about 550 TWh of electricity in 2030, with LDVs accounting for almost 70% of the total EV power demand, followed by two/three-wheelers, whose share in overall EV electricity consumption declines from around 60% of the total in 2019 to only 15% in 2030. Buses account for 13% and trucks for 4% of EV power demand globally in 2030.

The geographical distribution of the electricity consumed by EVs shifts somewhat from current shares, which are dominated by China. China remains the largest consumer with 220 TWh in 2030, despite that its share in global electricity demand from EVs almost halves from 80% in 2019 to around 40%. As EV electricity demand in European countries and the United States increase, they account for about 110 TWh and 60 TWh of EV electricity demand, representing around 20% and 10% of global electricity consumption from EVs, respectively.

By reducing reliance on oil products in the transport sector, EVs also contribute to energy diversification, environmental and climate goals. In 2019, EVs in operation globally avoided the consumption of almost 29 million tonnes of oil equivalent (Mtoe) (0.6 million barrels per day). In 2030, the EV fleet displaces more than 120 Mtoe (2.5 million barrels per day) of diesel and gasoline.

Sustainable Development Scenario

EVs circulating worldwide require almost 1 000 TWh of electricity in 2030 in this scenario. LDVs consume three-quarters of electricity demand by EVs, followed by two/three-wheelers (10%), buses (9%) and trucks (5%). In the Sustainable Development Scenario, the EV fleet in China remains the largest electricity consumer, despite its share falling though still accounting for more than 25% of total EV electricity demand. Europe accounts for almost one-fifth, but the gap between Europe and the United States (15%) is reduced compared with the Stated Policies Scenario, due to the rapid scale up of electric mobility envisioned for the United States in the Sustainable Development Scenario.

The global EV fleet displaces 210 Mtoe (4.2 mb/d) of gasoline and diesel in 2030 in the Sustainable Development Scenario.

Implications of electric mobility on well-to-wheel GHG emissions

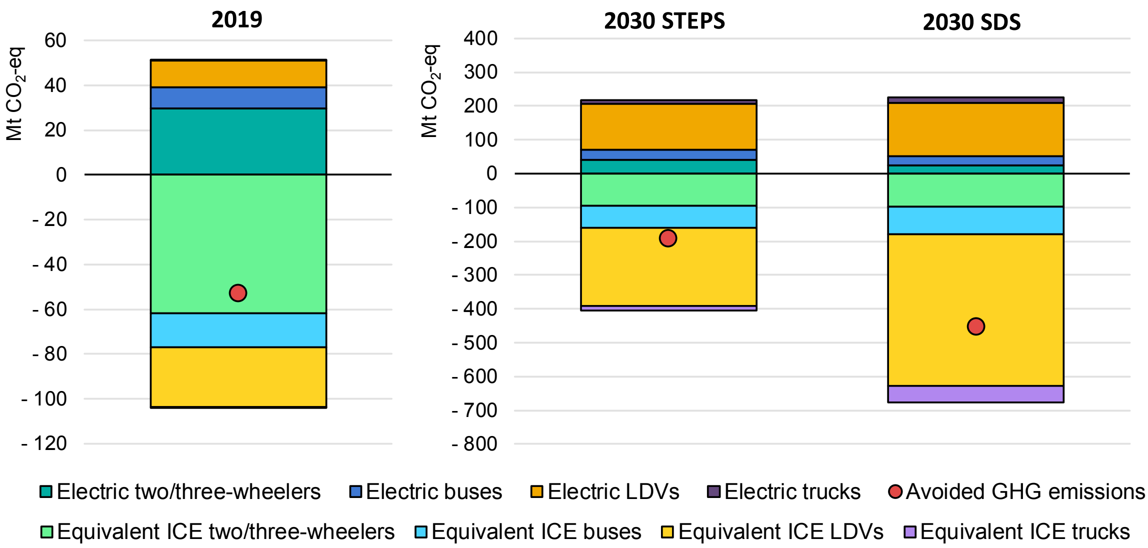
In 2019, the global EV fleet emitted 51 million tonnes of carbon dioxide equivalent (Mt CO_2-eq), about half the amount that would have been emitted from a same fleet of ICE vehicles, corresponding to 53 Mt CO_2-eq of avoided emissions (Figure 3.6).[15] Well-to-wheel (WTW)[16] emissions savings from EVs are achieved thanks to the fact that the high energy efficiency of the electric powertrain combined with the current global carbon intensity of electricity systems emit less than ICEs in most countries.[17]

To ensure that EVs can unleash their full potential to mitigate climate change, it is crucial to further reduce the CO_2 intensity of power generation. An increasing number of countries worldwide are taking actions to decarbonise electricity generation, which is set to further reduce the specific WTW emissions of EVs over

[15] The analysis was carried out with country-specific electricity mix and carbon intensities.
[16] The well-to-wheel analysis accounts for well-to-tank emissions (upstream emissions due to oil extraction and processing for ICEs, and to power generation and transmission for EVs) and tank-to-wheel emissions (tailpipe emissions). Life-cycle emissions, which take into account the emissions from vehicle manufacturing and disposal are discussed in Box 3.1, in Chapter 4 and in *Global EV Outlook 2019* (IEA, 2019b).
[17] The carbon intensity of electricity production is calculated based on the average annual carbon intensity of generation, and includes losses due to transmission and distribution, as well as in EV charging.

time. Indeed, the WTW emissions of the future EV fleet are projected to be significantly lower than those of ICEs in 2030 in both scenarios. The net emission reductions are more significant in the Sustainable Development Scenario, in which electricity generation decarbonises faster than in the Stated Policies Scenario, in line with the Paris Agreement goals (Figure 3.6).

Figure 3.6 Net and avoided well-to-wheel GHG emissions from the global EV fleet, 2019 and 2030



Notes: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; LDVs = light-duty vehicles; ICE = internal combustion engine. Positive emissions are from the global EV fleet. Negative emissions are those that would have been emitted by an equivalent ICE fleet. The red dot denotes net GHG emissions savings from EVs in comparison with an equivalent ICE fleet.

The WTW GHG emissions from the projected EV stock are determined in each scenario by multiplying the future electricity consumption from the EVs in each country by the final electricity carbon intensity at the country level, using carbon intensity values from *Energy Technology Perspectives 2020* (IEA, forthcoming) for both scenarios. The WTW CO_2-eq emissions for the equivalent ICE fleet are those that would have been emitted if the projected EV fleet were instead powered by ICE vehicles with technology shares (diesel and gasoline) and fuel economies representative of each country/region in each year. Fuel economies for ICE and EV powertrains for each mode are provided in the notes for Figure 3.5.

Sources: IEA analysis developed with the Mobility Model (IEA, 2020); carbon intensities from *Energy Technology Perspectives 2020* (IEA, forthcoming).

In 2030, EVs reduce GHG emissions by almost half compared to an equivalent ICE fleet in the Stated Policies Scenario and by two-thirds in the Sustainable Development Scenario.

In the Stated Policies Scenario, the global EV stock is projected to emit about 215 Mt CO_2-eq by 2030 on a WTW basis. If that fleet were instead powered by ICEs, GHG emissions would be almost 90% higher at around 400 Mt CO_2-eq.

In the Sustainable Development Scenario, which assumes rapid decarbonisation of power generation as described in *Energy Technologies Perspectives 2020* (IEA, forthcoming) as well as faster EV market uptake, emissions savings via road transport electrification reach 440 Mt CO_2-eq by 2030. The faster decarbonisation of electricity systems in this scenario leads to faster reductions in the specific WTW emissions of the EV fleet. Assuming the same generation mix as in the Stated Policies Scenario, emissions from the EV fleet would be about 380 Mt CO_2-eq, or two-thirds higher in 2030. This indicates that decarbonising electricity generation in line with the Sustainable Development Scenario should be pursued to significantly increase the emissions reduction potential of EVs on a WTW basis.

Box 3.2 What is the difference between well-to-wheel and life-cycle GHG emissions?

The difference between accounting for GHG emissions on a life-cycle basis versus a well-to-wheel (WTW) basis is one of scope.

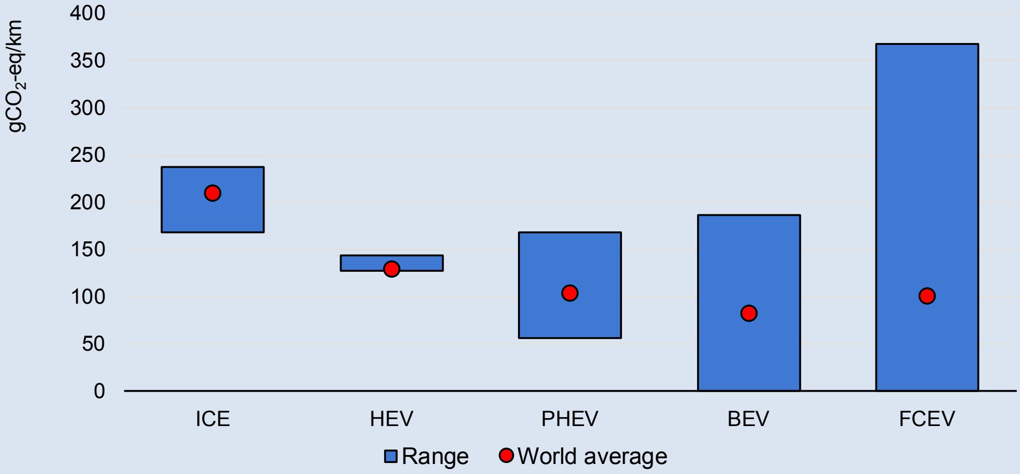
WTW emissions comprise both well-to-tank (WTT) and tank-to-wheel (TTW) emissions. In the case of oil, WTT, or upstream emissions, include those incurred from oil extraction, refining and distribution. For biofuels, they include the emissions that come from growing the biofuels feedstock, transforming it into a biofuel and transporting it to the fuel pump (and account for other co-products made in the process). For electricity, they comprise the emissions incurred in generating the electricity, including line losses, as well as in charging the vehicle. In the case of hydrogen, WTT emissions are incurred by producing, transporting and dispensing the hydrogen to the vehicle.

TTW (“tailpipe”) emissions come from the leakage of hydrocarbons in vehicle tanks and from fuel combustion. Therefore TTW emissions are zero for electric and fuel cell electric cars.

The scope of accounting for life-cycle emissions is broader than WTW emissions. Life-cycle assessment takes into account that emissions also come from sourcing, altering and incorporating materials into the final product (i.e. the car, its engine and drivetrain, or battery and/or fuel cell), as well as from the end-of-life (i.e. disposal, reuse and/or recycling).

On a WTW basis, in 2018 a medium-size battery electric car that is representative of global average energy intensity had the lowest specific WTW GHG emissions (i.e. on a per kilometre basis) among the powertrains evaluated, at around 95 grammes of CO_2-eq per kilometre (g CO_2-eq/km). The average battery electric car emits about 60% less CO_2-eq per kilometre than gasoline ICE vehicles and 40% less than conventional hybrid cars. However, due to the large variability in the carbon intensity of electricity generation in electricity systems and across countries, the GHG mitigation potential of BEVs can vary considerably, depending on the power system that serves charging demand. BEVs have nearly zero WTW GHG emissions in Norway and Iceland reflecting their low-carbon power supply, while they may have even higher specific emissions than gasoline internal combustion engines in similar size segments in countries that still rely primarily on coal as a source for electricity generation.

Well-to-wheel GHG emissions for cars by powertrain, 2018



Notes: ICE = internal combustion engine; HEV = hybrid electric vehicle; PHEV = plug-in electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle.

The range indicates the variability of WTW GHG emissions for each powertrain at the country level. For ICE vehicles, HEVs and PHEVs, the range is determined considering the minimum and maximum fuel-economy values across countries covered by the Global Fuel Economy Initiative (GFEI) (for more on the GFEI, see IEA, 2019c). PHEVs are assumed to drive 60% of their annual mileage on electric drivetrain and 40% on gasoline engine. For PHEVs and BEVs, the 2018 carbon intensities of electricity generation at country level are obtained from *Energy Technology Perspectives 2020* (IEA, forthcoming): the minimum and maximum correspond to a vehicle charging in Iceland (0.1 g CO_2-eq/kWh) and South Africa (1 002 gCO_2-eq/kWh). Note that both LCA and WTW accounting of GHG emissions measure not only CO_2 emissions, but also GHG pollutants and typically normalise these to a global warming potential of 100 years (GWP_{100}), to report on a CO_2-equivalent basis. For FCEVs, the minimum is calculated considering production of hydrogen from dedicated renewables, the maximum corresponds to hydrogen production from electrolysis considering electrolysis in China (the country with the most FCEVs in operation and with the highest carbon intensity of electricity generation) and the world average is based on steam methane reforming (8.8 kg CO_2-eq/kg hydrogen).

Sources: IEA analysis developed with the Mobility Model (IEA, 2020), using data from IEA (2019c).

Implications for automotive batteries

Trends in EV battery size

The demand for batteries used for automotive applications is expected to grow in the period to 2030 in both the Stated Policies and in the Sustainable Development scenarios. Increasing sales volume of electric PLDVs is the main driver as is the increasing size of the required batteries and electrification of other modes such as buses and trucks.

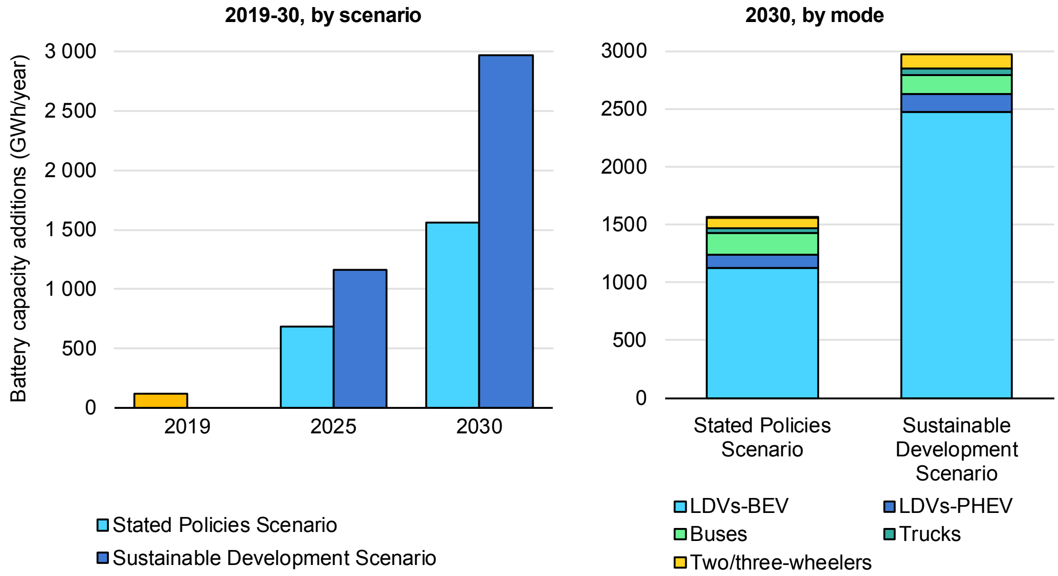
In 2019, the average battery size used in BEVs increased by 14% relative to 2018, in line with previous years. Average battery sizes for new BEVs range from 48 kWh to 67 kWh for cars (EV-Volumes, 2020). For PHEVs, the average battery size has been roughly constant over the past five years at around 11 kWh, equivalent to an electric range of around 50-60 km. There are two reasons for the increased battery size of BEVs over the past year: the change in the incentive structure in China that favours long-range vehicles, and the availability of the Tesla Model 3, which proved popular among EV consumers and is equipped with an above average battery capacity. The trend of increasing battery capacity is expected to continue, with BEVs reaching an average driving range of 350-400 km by 2030, which corresponds to battery sizes of 70-80 kWh.

Automotive battery capacity demand

In the Stated Policies Scenario, the global EV battery capacity (for all transport modes combined) is estimated to increase from around 170 gigawatt-hours (GWh) per year today to 1.5 TWh per year in 2030. In the Sustainable Development Scenario, demand of 3 TWh is projected, driven by increased electrification, particularly heavy-duty vehicles, and a higher share of BEVs in EV sales (Figure 3.7). Despite ambitious electrification in the Sustainable Development Scenario, modes other than cars would account for only 11% of overall battery demand in 2030. This highlights the centrality of electric cars in the battery market over the next decade. An important variable in this projection is the share of BEVs and PHEVs in overall EV sales.[18]

[18] For a sensitivity analysis on relative BEV/PHEV shares on projected battery capacity additions, refer to *Global EV Outlook 2019* (IEA, 2019b).

Figure 3.7 Annual global battery capacity additions from EV sales, 2019-30



Notes: For cars, battery capacity ranges increase to 70-80 kWh in 2030 for BEVs and to 10-15 kWh for PHEVs. For LCVs, battery capacity increases to 80-100 kWh in 2030 BEVs and to 15-17 kWh for PHEVs. The higher values are applied mainly in North America and the Middle East. Buses are assumed to use batteries of 250 kWh; two-wheelers use batteries of 3-4 kWh. Battery packs are assumed to have capacities of 150 kW for medium trucks and 350 kWh for heavy trucks.

Battery demand reaches 1.5 TWh per year in the Stated Policies Scenario and over 3 TWh per year in the Sustainable Development Scenario, driven by battery electric cars in both scenarios.

Demand for battery materials

Increased numbers of EVs and wider driving ranges will push up demand for batteries and thus on the key materials needed to make them. The nature of the material demand will vary according to the development of battery chemistry.[19] Given the evolving nature of lithium-ion technology, the chemical composition of batteries has been rapidly changing and is expected to continue to evolve at least over the coming decade. In the first-half of the 2010s, batteries with higher energy density used

[19] Battery cells are currently composed of a graphite anode, liquid electrolyte and a cathode. The cathode is a characterising element of batteries. There are three main families of cathode chemistry: ferrophosphate (FePO4), nickel manganese cobalt oxide (NMC) and nickel cobalt aluminium oxide (NCA). In the case of NMC, further differentiations characterise the ratios of nickel, manganese and cobalt in the cathode, leading to the use of acronyms such as NMC 111, NMC 532, NMC 622 and NMC 811, where the numerical component represents the various ratios. The FePO4 is only used by OEMs in China in lithium iron phosphate batteries (LFP) for cars. It is being phased out due to its low energy density. A numerical notation indicating different material ratios is sometimes also used for NCA. For example, the assessment of the expected battery technology commercialisation timeline included in *Global EV Outlook 2018* included a differentiation between N0.8C0.15A0.05 and N0.9C0.05A0.05 (IEA, 2018b).

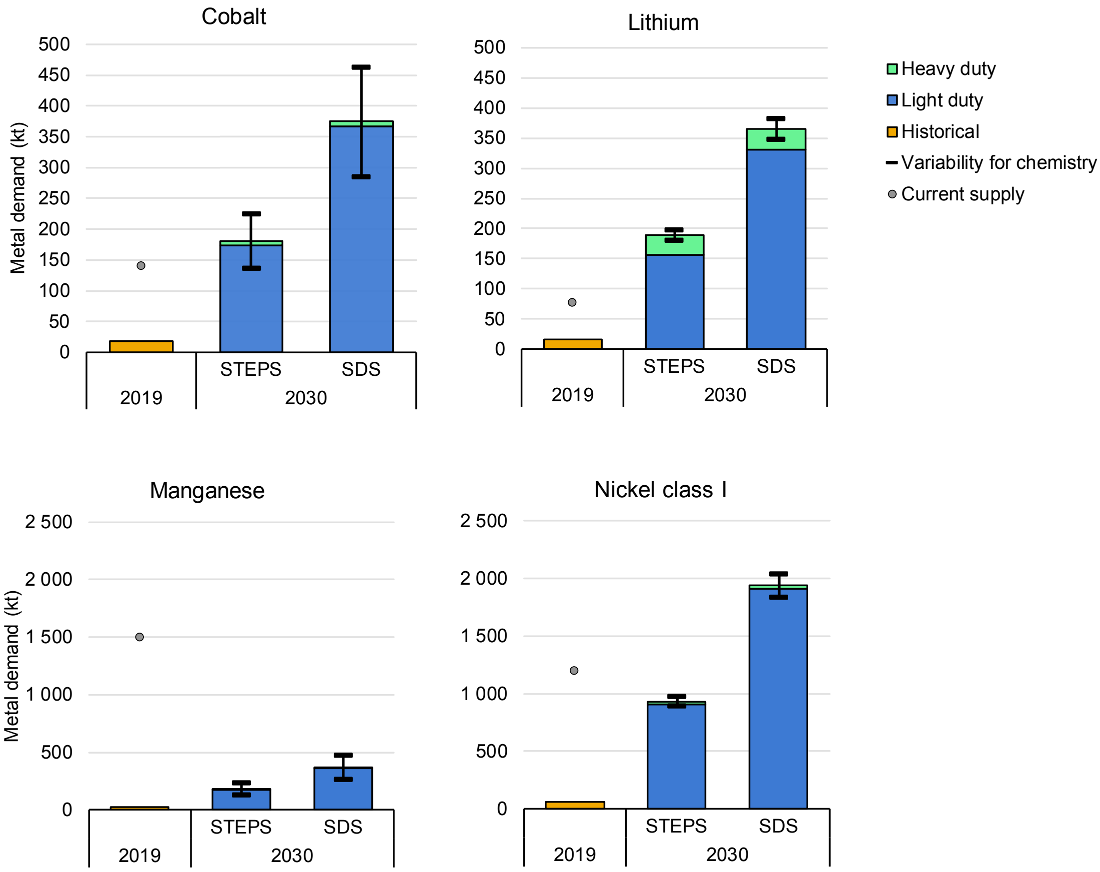
cathodes with high cobalt content (nickel cobalt aluminium oxide [NCA] and nickel manganese cobalt oxide [NMC] 111), while more modest performances were obtained with lithium iron phosphate (LFP) cathodes. Since then, the trend has been to increase energy density and to reduce the reliance on cobalt due to its price volatility and risky supply chain. Both drivers led to the use of content. In 2019, it is estimated that 48% of new batteries for electric cars use cathodes with at least 50% nickel content, meaning that both high cobalt content and LFP batteries have decreased their market share.[20] This trend is expected to continue over the coming decade, despite large uncertainties on the speed of adoption and the widespread use of high nickel content battery chemistry. In terms of anode chemistry, pure graphite anodes account for the vast majority of current supply, but silicon doped chemistries, which enable higher energy densities, are beginning to be used and are likely to increase their market share in the future. The uncertainty in cathode chemistry is reflected in the material demand projections associated with the two scenarios.

According to our estimates, the material demand for the batteries of the EVs sold in 2019 was about 19 kilotonnes (kt) for cobalt, 17 kt for lithium, 22 kt for manganese and 65 kt for nickel (Figure 3.8). For battery needs in the Stated Policies Scenario, cobalt demand expands to about 180 kt/year in 2030, lithium to around 185 kt/year, manganese to 177 kt/year and class I nickel (> 99% nickel content) to 925 kt/year. In the Sustainable Development Scenario, higher EV uptake leads to 2030 material demand values more than twice as high as the Stated Policies Scenario. The choice of the cathode chemistry significantly affects the demand for metals, particularly on cobalt which varies by plus or minus 22%.[21] By 2030, heavy-duty EV applications have a sizeable impact only on demand for lithium (16% of demand) among the materials analysed, because they are expected to be mostly equipped with lower energy density LFP cathodes for the next decade.

[20] This includes NCM 532, NMC 622, NMC 811 and advanced NCA formulations.

[21] See Figure 3.8 notes for details on the cathode composition assumptions that lead to this variability.

Figure 3.8 Annual demand for materials for batteries from EV deployment, 2019-30



Notes: kt = kilotonnes; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario. Future demand for materials for battery manufacturing relative to the scenario projections is based on the global battery capacity shown in Figure 3.7 and the following assumptions of the shares for cathode chemistries in LDVs. For the low cobalt case: 10% NCA, 10% NMC 622 and 80% NMC 811. For the high cobalt case: 11% NCA and 76% NMC 622, 13% NMC 811. The central value is an average of these two cases. The share of cathode chemistries for heavy-duty vehicles is assumed to be 95% LFP and 5% NMC 622 in the low cobalt case, while 80% LFP and 20% NMC 622 in the high cobalt case. The share of metals in the battery for the types of chemistry analysed is indicated in Table 6.1 in the *Global EV Outlook 2018* (IEA, 2018a). The current supply of nickel refers to class I nickel.

Demand for materials to make batteries for electric vehicles will increase exponentially in the period to 2030; cobalt is the most uncertain, reflecting the diversity of battery chemistries.

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Chapter 4. Batteries: An essential technology to electrify road transport

Battery technology and performance

Recent cost and technology developments

The cost of batteries for electric vehicles (EVs) is falling markedly. Industry reports show that sales-weighted battery pack prices continued to fall in 2019, reaching an average price of USD 156 per kilowatt-hour (kWh), down from more than USD 1 100/kWh in 2010 (BNEF, 2019). Not all original equipment manufacturers (OEMs) purchase at this price though, as there is a wide range of prices in the market. The lowest prices generally are enjoyed by OEMs that place very large battery orders for pure battery electric vehicles (BEVs) with long ranges and therefore need large battery packs optimised for energy storage. Considerably higher prices than the average are to be expected for either low volume manufacturers or for smaller battery packs designed for plug-in hybrid vehicles (PHEVs).[1]

The average battery pack size across all electric light-duty vehicles sold (including BEVs and PHEVs) continues an upwards trend; it is now 44 kWh, up from 37 kWh in 2018, and BEVs in most countries are in the 50-70 kWh range. This increase is driven by two trends: BEV models with longer ranges are becoming available and are increasingly in demand; and the share of BEVs compared to PHEVs is rising. For BEVs, smaller battery packs tend to be favoured in Asian countries, while larger ones dominate the North American and European markets.

There are no reliable publicly available sources to track the average energy density of battery packs: tracking the market deployment of different cathode chemistries is a good proxy. The most common cathode chemistry used in EVs is nickel manganese cobalt (NMC). The energy density of cells with NMC cathodes increases with increasing nickel content. Cells that use lithium iron phosphate (LFP) cathodes

[1] Battery packs for PHEVs are smaller and have higher power requirements, both of which correlate with higher battery costs in terms of USD/kWh (IEA, 2018).

(mostly used in the People's Republic of China [hereafter, "China"] and for heavy-duty applications) have lower energy density than NMC cells. On these grounds, there are reasons to believe that density is also continuing on an upward trend. We estimate that in 2019, 16% of EVs used NMC 622[2] or above, compared to 7% in 2018. Similarly, the share of LFP decreased from 9.1% in 2018 to 4.6% in 2019. The drop in LFP batteries in EVs can be explained by the structure of the latest incentive scheme in China, which favours higher density batteries. Current high-density EV cells can have energy densities in the range of 240-300 Watt-hours per kilogramme (Wh/kg), which equate to pack-level densities of 130-200 Wh/kg.

Outlook for battery technology developments

Technology trends over the next decade

While lithium-ion technology has made tremendous progress over the past decade in terms of energy density, costs and cycle life, there is still room for improvement. Research is being conducted to improve all three key components of lithium-ion (Li-ion) battery cells: cathodes, anodes and electrolytes. A roadmap of these developments is presented in *Global EV Outlook 2018* (IEA, 2018). In addition, recent developments in battery design and thermal management aim primarily to cut the costs of the pack and module components. Two examples are the Contemporary Amperex Technology Co. Limited's (CATL) cell-to-pack technology and the Build Your Dreams (BYD) "Blade Battery" that aim to remove the intermediary module components, thus reducing pack costs and increasing energy density by up to 20% (CATL, 2019; BYD, 2020). Meanwhile, the durability of NMC cells is continuing to increase. Laboratory tests show that the cycle and calendar life of new cell designs could be up to ten times higher than current technology, which may eventually have value in grid balancing as well as electromobility applications (Harlow, 2019).

The next generation of Li-ion battery technology, set to enter the market in the coming five to ten years, is likely to have low nickel content and use either nickel cobalt aluminium oxide (NCA) (with less than 10% nickel) or nickel manganese cobalt (NMC) 811 cathodes. On the anode side, ever increasing silicon content will be tolerated thanks to improved binding agents and electrolytes. Such developments

[2] Batteries with nickel manganese cobalt (NMC) cathode chemistries can have varying ratios of these constituent metals. An NMC 111 battery has all three in equal shares; an NMC 622 has 60% nickel, 20% manganese and 20% cobalt, and an NMC 811 cathode is made up of 80% nickel, 10% manganese and 10% cobalt. Cathode chemistries with lower cobalt content are capable of achieving higher energy densities at lower costs (as cobalt is the most expensive material to source and refine).

should enable cell-level energy densities of up to 325 Wh/kg (ANL, 2020). If these developments are combined with improved packaging technology, pack-level

densities could reach 275 Wh/kg. These values approach the upper performance bounds of Li-ion technology; any further substantial improvement would require a shift in technology.

However, some electric vehicles might not necessarily be designed for the highest possible energy density. This might be the case for urban buses or urban delivery vehicles where volumetric constraints are less stringent, or to lower the initial purchase prices of electric cars in markets where affordability is more important than long ranges. For these applications, the LFP cathode technology is very well suited due to the wide availability of its precursor materials (including the fact that it uses no cobalt) and its long cycle life. The recent announcement of some Tesla vehicles for the Chinese market to partner with CATL and adopt LFP cathodes and advanced pack designs goes in this direction (Reuters, 2020).

Upcoming technologies – a glimpse beyond 2030

For the next decade, the Li-ion battery is likely to dominate the EV market for three reasons. First, this technology is well established, meaning that there is now considerable experience in its large-scale manufacture and solid understanding of its long-term durability characteristics. Second, the very large investments in Li-ion manufacturing and supply chains that have been made to date constitute a barrier to entry for alternative technologies. Third, alternative technologies are still at a range of lower technology readiness levels (TRLs); none have yet been used in real-life conditions in commercial vehicle applications.[3]

Even after a new technology reaches a level of technological maturity making it potentially available, there will be a considerable delay before it will begin to penetrate the market. This is because extensive testing under real conditions is necessary, and even if and when testing demonstrates substantial improvements along key metrics (e.g. cost, energy density, durability, safety), new production

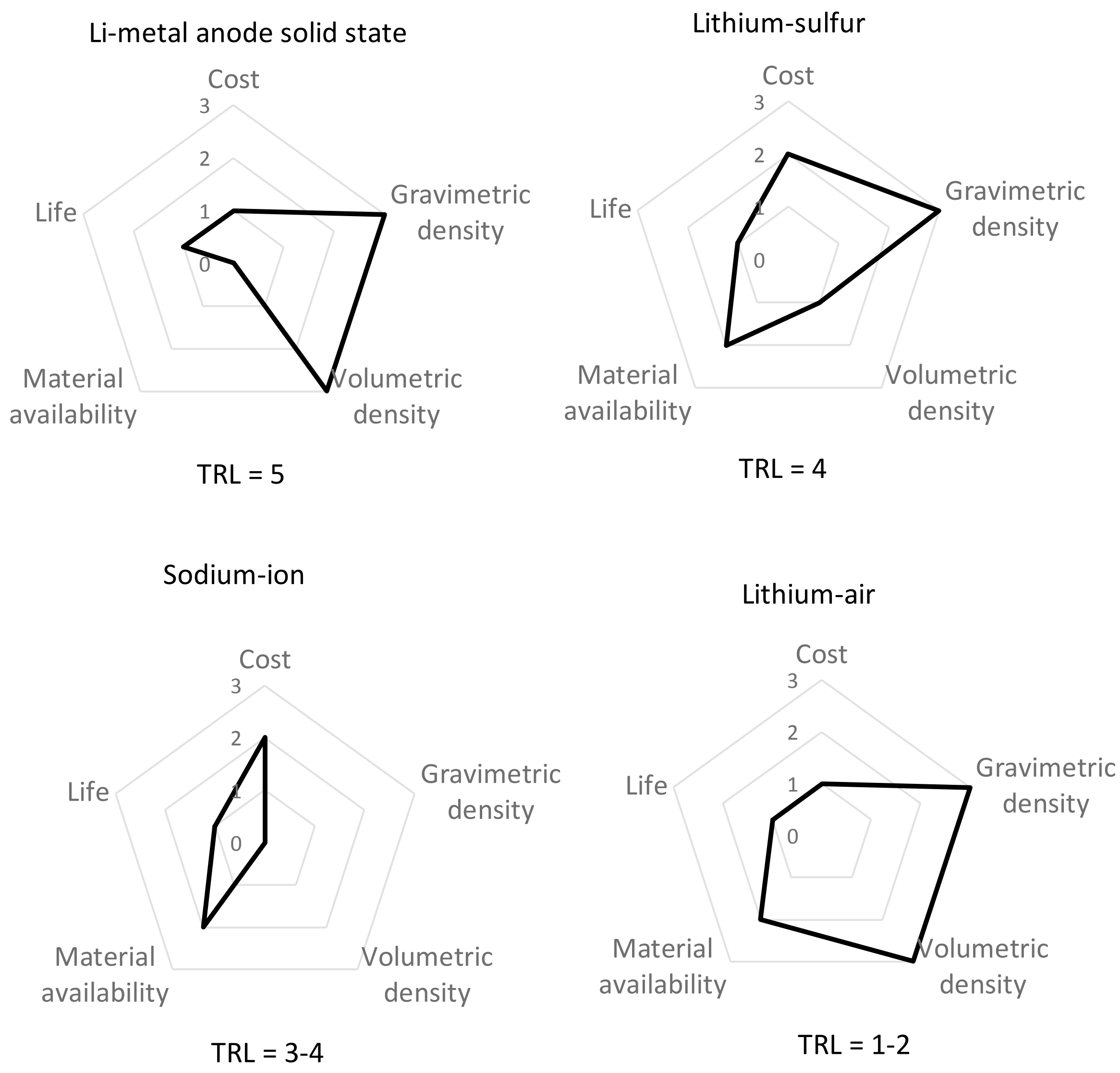
[3] The technology readiness level (TRL) scale is used to rate the status of technologies according to their status in the progression from research, development and deployment to commercialisation. Adapted by the IEA, the scale goes from the concept stage (TRL 1) to large scale demonstrations, and extends beyond the conventional TRL limit to include various stages of commercialisation (up to TRL 11: proof of commercial stability). For more information, see www.iea.org/reports/innovation-gaps.

capacity will have to be installed. Alternative chemistries that do not require substantial retooling of existing factories therefore are better placed to rapidly substitute Li-ion batteries.

For the period after 2030, there are a number of potential technologies that might be able to push the boundaries beyond the performance limits imposed by Li-ion battery technology. Figure 4.1 shows the key benefits, trade-offs and technology readiness of some of the key chemistries for future battery technology. These technologies are discussed in more detail in *Energy Technology Perspectives 2020* [IEA, forthcoming]. The most promising near-term chemistry among these advanced concepts is the lithium-metal solid state battery. This technology has been prototyped by various companies and research groups, but it remains to be proven in operation. Recent developments of this technology show that cycle life – the technology's main challenge – is improving.[4] Samsung researchers have developed a prototype with a volumetric density of over 900 Watt-hours per litre (Wh/L) (and an estimated gravimetric density of 400 Wh/kg) that is able to retain 89% of its charge after 1 000 cycles (Lee et al., 2020). Sion Power, a start-up, claims that their product (420 Wh/kg) can retain 75% of its charge after 800 cycles (Sion Power, 2020).

[4] Number of charging and discharging cycles that a battery can undergo before losing a specified share of its rated capacity. Typically, Li-ion batteries are expected to retain about 80% of their rated capacity after 500 - 1 000 charging cycles. Some batteries can retain 70% of capacity for 3 700 cycles (Harlow, 2019).

Figure 4.1 Relative advantages of post lithium-ion battery technologies



Notes: 0 = worse than Li-ion battery; 1 = comparable to Li-ion; 2 = improvement compared to Li-ion; 3 = major improvement relative to Li-ion. TRL = technology readiness level (defined on the IEA's innovation gaps site: www.iea.org/reports/innovation-gaps). More details are presented in *Energy Technology Perspectives 2020* (IEA, forthcoming). The relative advantages of each technology are estimated based on available literature on theoretical potential, working principles, ability to manufacture and materials used.

Battery technologies under development offer potential performance advantages.

Life cycle of automotive lithium-ion batteries

The determinant of the extent to which electric vehicles can support climate goals is greenhouse gas (GHG) emissions over their life-cycle. Chapter 4 of the *Global EV*

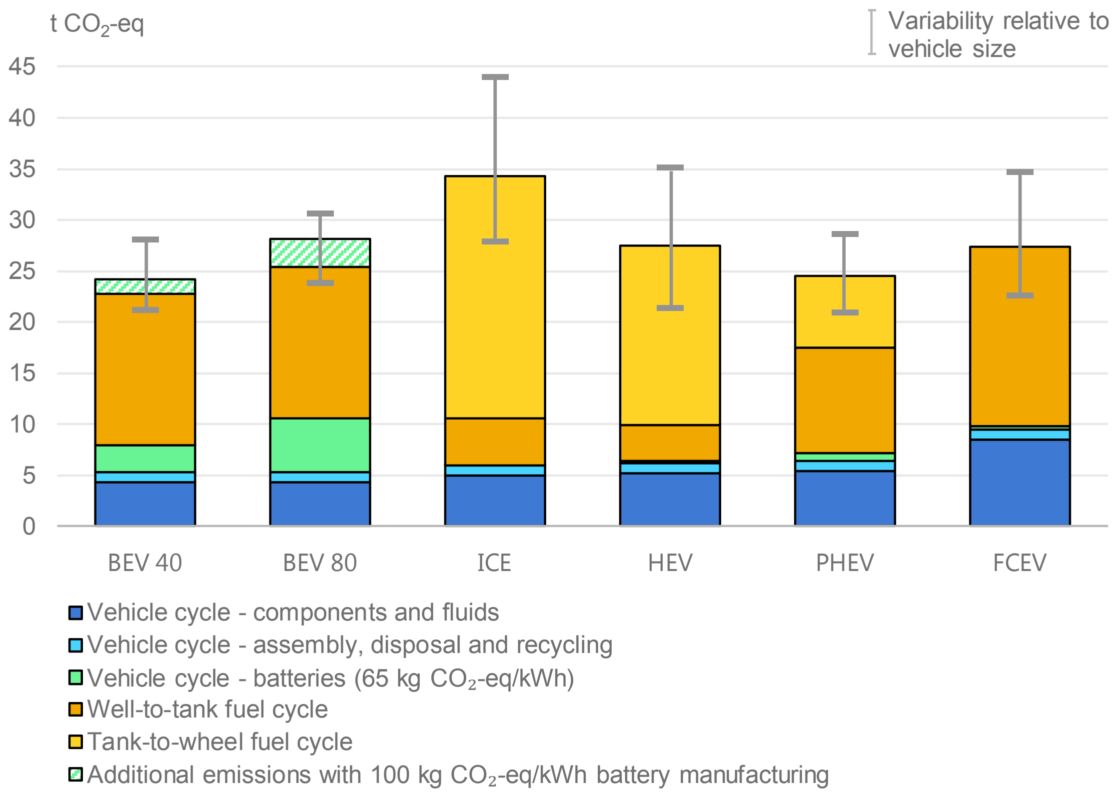
Outlook 2019 (IEA, 2019a) discusses the life-cycle GHG emissions of EVs relative to other powertrains, including the influence of factors such as vehicle mileage, size and power.[5] It highlights the influence of the carbon intensity of the electricity system to the GHG intensity in the use phase of an EV over its lifetime. The key messages from that analysis include:

- Today the use phase is the largest contributor to life-cycle GHG emissions of all powertrains.
- With a GHG intensity of electricity generation equal to the global average (518 grammes of carbon dioxide per kilowatt-hour [gCO_2/kWh] in 2018), BEVs, hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCEVs) have similar lifetime GHG emissions, and their emissions are lower than those of an average internal combustion engine (ICE) vehicle.
- Increasing the range of a BEV reduces its relative benefits compared to ICE vehicles or FCEVs.
- As the electricity used to charge EVs decarbonises in major EV markets, the benefits of lower life-cycle GHG emissions of electric cars amplify relative to other powertrains.

A BEV battery, depending on its size and assuming a typical range of emissions from battery manufacturing and the global average carbon intensity of electricity in the use phase, accounts for 10-30% of the total life-cycle emissions of the BEV (Figure 4.2).When fuelled by zero-carbon electricity during the use phase, BEVs could become three-four times less CO_2-intensive per kilometre (km) driven, and PHEVs could become two-three times less CO_2-intensive than conventional gasoline cars. In this context, the relative emissions of Li-ion battery production and disposal will remain minor in comparison to the total emissions of an ICE vehicle, and will gain in importance compared to other life-cycle stages and components of an EV. This section builds upon the analysis carried out in the *Global EV Outlook 2019* to focus on impacts from vehicle manufacturing and disposal, identifying opportunities for improved sustainability throughout the battery value chain, including end-of-life pathways (IEA, 2019a).

[5] The powertrains considered were globally representative: mid-size versions of an ICE car, a hybrid car, a plug-in hybrid electric car with 60% of its lifetime mileage driven on electricity and 40% on gasoline, a BEV with a 200 km or a 400 km range, and a fuel cell electric vehicle with a hydrogen supply primarily sourced from steam methane reforming of natural gas. The CO_2 intensity of the electricity used to power the electric powertrains was based on the global average in 2018. (Results and further information are available in *Global EV Outlook 2019*, Chapter 4, and in particular in Figure 4.2 [IEA, 2019a]). The findings using similar methodology and assumptions are replicated in Figure 4.2 in this section.

Figure 4.2 Comparative life-cycle GHG emissions of an average mid-size car by powertrain, 2018



Notes: t CO_2-eq = tonne of carbon-dioxide equivalent.

This figure provides updated battery life-cycle emissions ranges from the life-cycle GHG emissions of a global average mid-size car by powertrain in *Global EV Outlook 2019* (Figure 4.2) (IEA, 2019a). It shows the effect of a BEV battery associated with the lower bound GHG intensity of current battery manufacturing (representative of European Union based manufacturing) (green area) and the upper bound GHG intensity of current battery manufacturing (representative of China based manufacturing) (hashed green area; additional to green area), based on research from Kelly et al. (2019).

All ICE powertrains are assumed to be powered by gasoline, including the HEV and PHEV categories.

Vehicle assumptions: vehicle power 110 kW, BEV battery size 40 kWh (BEV 40) or 80 kWh (BEV 80); PHEV battery size 10.5 kWh; battery chemistry NMC 111; annual mileage 15 000 km; vehicle lifetime ten years. (Assumptions applicable to all powertrains unless otherwise stated).

Fuel-economy assumptions Worldwide Harmonised Light Vehicles Test Procedure (WLTP) values: ICE - 6.8 litres of gasoline equivalent per 100 kilometres (Lge/100 km); HEV - 5.1 Lge/100 km; BEV- 19.0 kWh/100 km (2.1 Lge/100 km);FCEV 3.7 Lge/100 km. PHEV is a combination of ICE and BEV fuel economies with 40% total mileage driven on gasoline and 60% on electricity (this utility factor is in line with WLTP provisions). The fuel economy of BEVs and PHEVs (for the electric powertrain) includes a 5% penalty for charging losses.

Power supply GHG intensity in the fuel cycle is 518 gCO_2-eq/kWh. This is representative of the 2018 global average and includes transmission and distribution system losses.

The hydrogen production pathway considered here is steam methane reforming from natural gas (well-to-wheel emissions intensity of 3.2 kg CO_2-eq/Lge), which is representative of the majority of current hydrogen production.

The ranges suggested by the sensitivity bars represent the case of small cars (lower bound) and large cars (upper bound)

Sources: IEA analysis based on ANL (2018); (Kelly et al., 2019); IEA (2019a); IEA (2019b).

On a global average, BEVs provide life-cycle GHG emissions benefits relative to ICE vehicles. Decarbonising fuel used in a vehicle is the biggest potential area for life-cycle emissions reduction for all powertrains.

Introduction to Lithium-ion battery life-cycle impacts and GHG emissions reduction potential

The key components that contribute to the life-cycle GHG emissions of a battery for an electric car include:[6]

- Materials: Mining and refining processes, especially for aluminium, and synthesis of active materials such as nickel, cobalt and graphite.
- Battery manufacturing: Climate control during cell assembly, which takes place in a "dry room" which maintains ultra-low humidity (<1% relative humidity) and other tightly controlled conditions to minimise contamination risks and to ensure safety.

In addition, at the end-of-life, battery recycling processes require energy and therefore cause GHG emissions. These are partly compensated by the fact that recycling enables materials recovery, thereby offsetting the impacts (including GHG emissions) of raw material mining and processing.

Each life-cycle phase, including recycling, presents opportunities to further reduce the overall impact of BEVs compared to ICE vehicles by using low-carbon energy sources and achieving economies of scale.

Materials

The key drivers of GHG emissions from the raw materials phase are aluminium (which is used in the vehicle body and several battery components) and lithium-ion (Li-ion) battery electrode materials, most notably cobalt, nickel, and natural and artificial graphite. Supply chains of such materials are characterised by a high degree of international trade, and their extraction, processing and refining, to achieve suitable grades for battery manufacturing, is energy intensive.[7]

The footprint of raw material production can be reduced primarily by using low-carbon energy sources for production and refining where possible or by using recovered or recycled materials. For example, emissions from current aluminium production for the battery alone vary from roughly 10 to 25 kilogrammes of carbon-dioxide equivalent per kilowatt-hour (kg CO_2-eq/ kWh) of battery, depending on the electricity grid mix where the battery is produced (Kelly et al., 2019), which can represent up to a quarter of GHG emissions from battery manufacturing. Recycled

[6] For more information on the main GHG-emitting processes in sourcing battery materials and manufacturing, see Box 4.1 in Global *EV Outlook 2019* (IEA, 2019a).

[7] For example, lithium and cobalt are primarily mined in Australia and South America (lithium), and the Democratic Republic of the Congo (cobalt), and mostly refined in China. For more information, see *Global EV Outlook 2019*, in particular Box 4.1 and 5.3 (IEA, 2019a).

aluminium production requires approximately one-twentieth of the energy inputs of primary production and sourcing recycled materials could significantly reduce the emissions associated with battery aluminium (Liu et al., 2012). Optimisation of manufacturing to promote resource efficiency can also decrease material intensity and the GHG emissions of the battery.[8]

Battery manufacturing

Raw materials need to be combined into the key battery components, namely cathode, anode, separator and electrolyte, which make up the battery cells. Individual cells are then assembled, components such as the battery management system (BMS) added and thermal controls are assembled in the casing to form the battery pack. In addition to production and refining of materials, a key contributor to GHG emissions during battery manufacturing is the energy required during cell assembly, which must take place in a dry room with extreme temperature and humidity controls.

Manufacturing facility throughput

The GHG emission intensity of cell assembly is mitigated if assembly occurs in a high throughput facility, which increases energy efficiency on per kWh of battery produced basis. Thanks to growing battery demand and large-scale battery manufacturing, the increase in throughput at existing cell manufacturing facilities has already contributed to a decrease in the life-cycle emissions from cell production (Kelly et al., 2019).

GHG intensity of energy sources used in manufacturing

The carbon footprint of manufacturing can be further reduced by using low-carbon energy sources during cell assembly. Using the case of a representative Chinese battery, Kelly et al. (2019) identified that over 80% of the emissions during cell assembly come from natural gas used to supply heat, mostly for the dry room and electrode drying.[9] The authors found that if all energy inputs to cell assembly were produced from renewable electricity, the battery's GHG footprint could be reduced

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[8] While the mining and refining of lithium typically has a lower GHG footprint than that of other transition metals, there are significant environmental impacts when using surface evaporation ponds for the pre-concentration of lithium containing brines. The conversion of aqueous lithium to lithium carbonate or lithium hydroxide products also requires large inputs of chemical reagents and generates considerable wastes (Liu et al., 2019).

[9] Electricity and heat are distinct forms of energy, though both can be measured in kWh. Heat has traditionally been produced directly by burning natural gas or coal, but can also be generated by electric resistance heating or heat pump technology, which is more efficient than resistance heating.

by 29%. Replacing natural gas-based heat processes with electricity makes sense only if the combined GHG emissions from power generation and efficiency of electricity-to-heat conversion result in a lower level of GHG emissions per kWh of heat generated. Furthermore, producing all the heat from electricity requires that facilities be equipped with different infrastructure and heat pump technology than natural gas-based facilities. Another solution to significantly lower GHG emissions from battery manufacturing is to incorporate renewable heat sources such as biomethane, assuming availability at a competitive price. Using low-carbon electricity in aluminium manufacturing, an electricity-intensive process, further reduces the carbon footprint of the battery pack.

End-of-life

Strategies for managing used EV batteries

Developing an effective waste management strategy for EV batteries is crucial, as they rely on a short list of finite critical materials with few substitutes. Batteries are often discussed in the framework of the waste hierarchy: reducing first, followed by reusing, recycling, recovering energy, and treatment and disposal (European Commission, 2008). Also known as a cascading approach, this is a guiding philosophy used by policy makers for the sustainable management of many types of solid waste.

When they are retired from an electric vehicle, batteries may either be reused in stationary storage applications, or sent to recycling facilities to recover constituent materials.

Strategies for managing used EV batteries

Value-retention processes can extend product lives through reuse, repair, refurbishment or remanufacturing. Value-retention has been shown to significantly reduce material demand and emissions in other sectors (IRP, 2018).

In the case of EV batteries, "reuse" can refer to refurbishing modules for use in another EV, as well as to repurposing or "second-life" where modules are reconfigured to be used as stationary storage. The intuitive benefit of repurposing is that it extends the battery's usable life, maximising the economic value and reducing the per kWh life-cycle impact (Engel et al., 2019; Richa et al., 2017). However, sceptics point out that EV batteries by design are not optimised for stationary storage applications. Furthermore, repurposing the battery delays it from entering the recycling loop, preventing the recovery of critical materials, and inhibiting the development of a recycling industry that requires higher volumes of battery waste to profitably operate at scale. Therefore there is disagreement as to whether the waste hierarchy is appropriate in the case of EV batteries.

Strategies for managing used EV batteries

Regardless of whether batteries are reused for stationary storage, they will eventually need to be recycled or disposed of. Understanding the opportunities and barriers related to recycling is critical to reduce the environmental impacts associated with mining and refining of primary resources, as well as avoiding the improper disposal of batteries.

Studies suggest that the potential environmental benefits of recycling will depend on both the recycling technology used and the material composition of battery cathodes (Dunn et al., 2015; Ciez and Whitacre, 2019; Richa et al., 2017). Energy inputs and direct combustion of fuels and/or battery constituents during the recycling process result in GHG emissions. The benefit from a GHG perspective depends on the balance between emissions from recycling to recover key materials suitable for new battery manufacturing, and emissions that would otherwise be associated with the primary extraction and processing of raw materials. Emissions from recycling can generally be reduced by recovering materials in usable forms, using low-carbon heat sources where possible and improving unit energy efficiency, as for any industrial process. (Details about battery reuse and recycling pathways are discussed in the Recycling lithium-ion batteries section.) The next sections describe the current status and potential for various end-of-life pathways, focussing on reuse and recycling.

Potential for battery second-life

In an electric vehicle, battery degradation will reduce the range the vehicle can travel on a single charge. Three primary factors cause normal battery degradation:

- Temperature: Exposure to extreme temperatures accelerates battery degradation, resulting in a shorter lifetime. This impact is more prominent in hot rather than cold climates (Neubauer et al., 2015). Sensitivity to heat may be mitigated by equipping the batteries with a thermal management system (i.e. cooling). Early BEVs were not usually equipped with thermal management, which is one of the reasons newer vehicles have longer battery life.
- Charging/discharging pattern: Repeatedly utilising the entire capacity of a battery (i.e. high depth of discharge) and rapidly charging and discharging (i.e. high C-rate) are likely to reduce battery performance.
- Time: Performance will degrade over time due to passive chemical processes and ambient conditions, a process referred to as calendar degradation.

Barring a collision or mechanical defect, batteries are typically assumed to reach end-of-life when they retain 80% of their initial capacity. However, the standard 80%

criterion has changed recently, as EV models on the road today have increasingly longer ranges than their predecessors. Consequently, higher losses in range may be acceptable to drivers, particularly if the vehicle is used as a second car or for short trips. As a result, remaining battery capacity at end-of-life is likely to vary based on individual behaviour and preferences. Similarly, each battery's lifespan will vary based on driving patterns and consumer preferences, but is expected to be between 8-15 years depending on the make and model.[10]

In most cases, key components of the battery systems (e.g. modules) are still functional when retired. Particularly when the vehicle is retired due to a collision or mechanical defect, the modules and cells can be refurbished and reused directly in another EV. Tesla Motors and Nissan have pursued refurbishing strategies and offer refurbished battery packs as replacements for warranty issues and in pre-owned vehicles (Ambrose and Kendall, 2016). Toyota also plans to reuse batteries as service parts in addition to non-automobile applications (Toyota Motor Corporation, 2019).

Retired Li-ion batteries that retain 70-80% of their initial capacity can be reused in less demanding stationary storage applications, providing grid services such as peak shaving and/or balancing the intermittency of some renewable-based generating sources, e.g. wind and solar.[11] Repurposing an EV battery as stationary storage is estimated to extend its lifetime by 5-15 years, depending on its initial state of health[12] and the characteristics of the second-life application[13] (Jie Tong et al., 2013; Neubauer, et al., 2015, Hossain et al., 2019). However, it should be noted that robust data is scarce due to the relative newness of the application of this technology.[14]

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[10] For example, Tesla provides an eight-year warranty on the battery and drive unit for all models, with minimum 70% retention of battery capacity over the warranty period (Tesla, 2020). However, in a survey of Tesla Model 3 drivers, Bloomberg found that charging capacity declined less than 1% for every 10 000 miles of driving, suggesting that the actual lifetime could be much longer for many drivers (Randall et al., 2019).

[11] Automotive batteries used in testing and development are another potential source of second-life storage. For example, Audi is operating a 1.9 MWh energy storage project at the EUREF-Campus in Berlin using discarded Audi e-tron test vehicle batteries (https://euref.de/en/euref-campus_en/).

[12] State of health is a complex metric that reflects the ability of the battery to deliver the specified performance and takes into account its capacity, internal resistance, voltage and self-discharge. However, most commonly it is defined as the capacity at the time of the measurement as a proportion of the starting capacity (Prasad and Rahn, 2013).

[13] The 15-year lifespan estimate represents a battery providing a network deferral service, meaning it is placed at a node of interest on the electrical grid where peak demand is expected to exceed infrastructure capacity in coming years. In this scenario the battery is assumed to operate at 50% depth of discharge per day for four months per year.

[14] Researchers rely on modelling and simulated data. There are currently no published studies tracking the performance of reused battery systems over a significant period or in real-world applications (Melin, 2019).

Challenges to second-life applications

Dynamic battery technology and cost environment

A key barrier to the second-life battery industry is their ability to compete with new battery storage given the rapidly falling costs and improving performance of new systems. Li-ion battery costs have decreased by over 85% since 2010, significantly faster than suggested by peer-reviewed articles at the start of the decade (Nykvist and Nilsson, 2015). Second-life batteries will start becoming available at scale around 2030, at which point new battery prices are likely to drop to USD 100/kWh or below.

Multi-steps refurbishing process

To be used as stationary storage, retired batteries must undergo several processes that are costly and time intensive. The first step is an initial dismantling and testing process to determine the remaining state of health of battery modules, as it will vary for each retired system. The modules (or packs) must then be fully discharged, reconfigured to meet the energy demands of their new application, equipped with a battery management and cooling system, and re-packaged. It is estimated that the cost of repurposing a used vehicle battery via the steps described could amount to USD 25-49/kWh, or about half of the repurposed battery selling price (Neubauer, 2015). The cost can be reduced when facilities are operated at high throughput, and/or information about the state of the battery modules is readily accessible to the entity undertaking the repurposing.[15]

Technical information transfer

Repurposing is complicated by the evolving nature of the battery industry, as the capacity, chemistry and design of used cells change on a yearly basis. The chemistry is often unlabelled and may be unknown to a third-party refurbisher, which makes testing and reassembly difficult and more expensive (Engel et al., 2019; Jiao and Evans, 2016). The unknown status of used batteries regarding their storage condition and remaining capacity can also exacerbate the safety issues associated with handling electrical and chemical devices (Hossain et al., 2019). Safety precautions such as wearing personal protective equipment and conducting testing in a controlled environment are necessary to mitigate the risk of fire and to contain chemical fumes. Workplace safety has been identified as an area requiring further research for both reuse and recycling (Melin, 2019).

[15] This is also true for recycling.

Other challenges

Additional barriers to second-life include a lack of transparency regarding state of health data from proprietary battery management systems, and transportation challenges as EV batteries are classified as hazardous waste in many countries. This leads to high transportation costs and difficulties navigating cross-border regulatory differences (Shi et al., 2019).

Box 4.1 Second-life battery industry dynamics

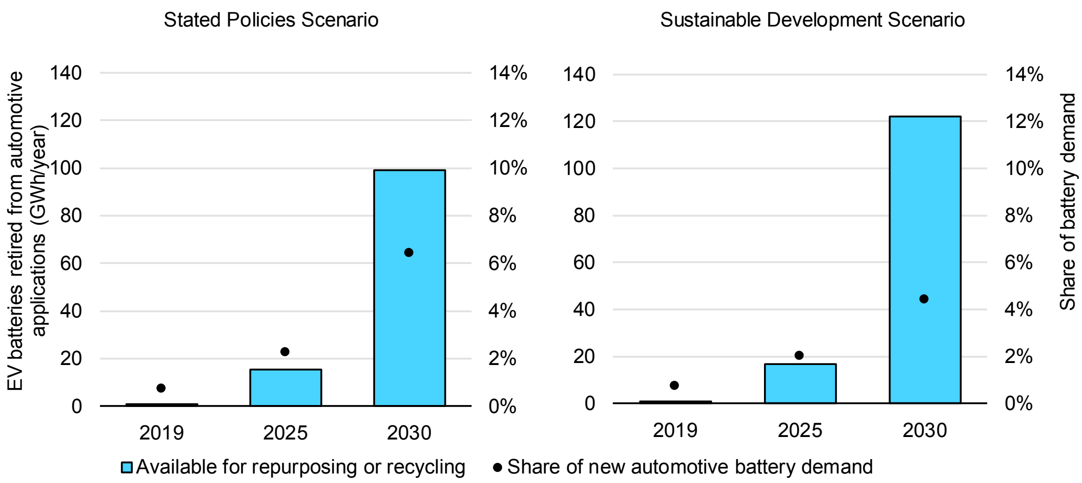
Creating a successful business model around second-life batteries is a complex challenge. Although the sustainability benefits may seem obvious, competing with new battery systems is no simple task. New batteries are considered to be more reliable and are generally produced by well established companies. Furthermore, most energy storage developers require a ten-year warranty for battery systems, considering that they may be paired with solar photovoltaic systems that are expected to last at least 20 years. Guaranteeing reliability for risk-averse customers essentially requires the backing of an OEM or other large entity, which may indicate that second-life ventures will be operated either by automakers directly or in partnership with them. Examples include 4R Energy Corporation, a repurposing venture launched by Nissan, or Renault's Advanced Battery Storage initiative. This approach also avoids concerns about transferring liability, since the OEM retains ownership and responsibility for the battery.

Nonetheless, there are opportunities for entrepreneurship and innovation within the second-life space. Most automakers lack the expertise to repurpose and develop storage systems themselves, creating demand for specialised third parties. An example is Relectrify, a company based in Melbourne, Australia, that specialises in BMS software and inverters designed specifically for second-life batteries, rather than providing the entire system.

Market prospects

From a high-level perspective, the market potential of repurposed battery storage depends on the supply of retired batteries from EVs and demand for stationary storage applications. In the Stated Policies Scenario, 100 gigawatt-hours (GWh) of spent EV batteries are estimated to become available worldwide by 2030: this is equivalent to the production volume of batteries of LDVs in 2019. In 2030, spent batteries account for 6.5% of the projected battery demand that year in the Stated Policies Scenario. The long lag-time between manufacture and end-of-life for EV batteries, mean that in the Sustainable Development Scenario, the availability of spent EV batteries is only marginally higher, at 120 GWh. However, due to its higher demand for batteries, these would account for 4.3% of expected new demand in 2030 (Figure 4.3). In both scenarios, most spent batteries in 2030 will come from LDVs.

Figure 4.3 Automotive battery capacity available for repurposing or recycling, 2019-30



Notes: Batteries for LDVs are assumed to have the same lifetime as the vehicle, while for heavy-duty vehicles, an average of
1.5 batteries per vehicle lifetime is assumed. Vehicle lifetimes vary according to region and are taken from the IEA Mobility Model (IEA, 2020). LDVs have lifetimes of roughly 15 years, HDVs around 20 years and two-wheelers about 8 years. Vehicle lifetimes are assumed to follow a normal distribution around the average lifetime.

Spent battery availability in 2030 is projected to be comparable to current production volumes.

Applications

Second-life batteries used in storage applications can provide various services for electricity grid operators, electric utilities, and commercial or residential customers. Today most pilot projects are used for peak shaving, frequency regulation and optimising energy from variable renewable energy sources. Key examples of these applications are described in Table 4.1. The largest economic benefit is provided when battery systems provide stacked services; for example, a battery whose primary purpose is to reduce demand charges for a commercial customer could also be used, in parallel, to provide resource adequacy for a utility, and frequency regulation and energy arbitrage for the system operator (Fitzgerald et al., 2015). This way the economic value from providing various services accumulates and is maximised.

A key challenge for battery storage (new or used) is how to capture each of these value streams, which will depend on the structure of the local, national and regional electricity market; the lack of a formal capacity market for resource adequacy could reduce the value proposition for energy storage. In a sense, the market dynamics are similar in dynamic charging or vehicle-to-grid (V2G) applications where batteries on board EVs directly provide similar services to electricity systems.[16] A key distinction is that second-life batteries are stationary and fully dedicated to providing electricity to the grid when needed. The comparative advantage of V2G is that it avoids the costly repurposing stage, but battery availability to provide the service is not guaranteed, as automotive batteries primary purpose is to provide mobility services (see Chapter 5).

Table 4.1 Examples of storage projects using second-life EV batteries

Service	Lead entities	System description	Size
Peak shaving	University of California Davis Micro Grid; RePurpose Energy, California Energy Commission; Nissan.	System built from used Nissan Leaf packs charges from a photovoltaic array, then discharges on a constant cycle from 16h00-20h00.	287 kWh
Increased consumption of onsite renewables	City of Kempten pilot; Energy Local Storage Advanced System; Allgäuer Überlandwerk GmbH (regional utility).	Excess energy produced by onsite solar is stored in repurposed Renault Kangoo batteries, then discharged when demand is higher than supply.	95 kWh
Frequency regulation	City of Lunen pilot; Daimler Mobility House.	In collaboration with the local utility, 1 920 used modules are assembled at a retired coal plant to supply balancing power to the grid.	9.8 MWh
Telecom tower (backup)	China Tower'; BYD; Guoxuan High Tech; YinLong New Energy.	China Tower plans to replace lead-acid with used EV batteries to provide backup power for telecom towers (they operate close to 2 million across China).	30 kWh per tower; 54 GWh potential

Sources: Mobility House (2018), Jiao (2018), UC Davis RMI Winery Microgrid Project (n.d.), ELSA (n.d.).

[16] Chapter 5 includes additional details as does the section Implications of electric mobility for power systems in *Global EV Outlook 2019* (IEA, 2019a).

Another potential application is pairing second-life batteries with renewable energy systems to increase energy access in remote areas (The Engineer, 2019; Nedjalkov, 2019). Key parameters that will determine the success of this application include the total cost of the repurposed battery, import/export requirements for battery waste, and the capacity of the local transportation system to handle and transport heavy battery modules (Falk et al., 2020). Provided that it is technically and economically feasible, using batteries for this purpose could provide significant environmental and socioeconomic benefits; Casals et al. (2019) estimated that replacing electricity produced by a diesel generator with a renewable second-life storage system would reduce GHG emissions by 32%, on top of the local air quality and socioeconomic benefits that would be realised.

Recycling lithium-ion batteries

The development of an effective recycling industry is key to the sustainability of Li-ion batteries, and by extension electric vehicles. By recovering critical materials, a robust recycling system would reduce demand for raw materials, reduce GHG emissions and negative local impacts from mining and refining. Furthermore, domestic recycling enables countries to reduce their reliance on imports for critical materials.

So far, economic viability and market incentives for recycling have been limited because of generally low raw material prices and small volumes of spent EV batteries to date. However, as the growing market for EVs puts further pressure on primary resources, raw material prices could increase, and/or prices may become more volatile. Thus, materials recovered through recycling would become more competitive. The economic and strategic value of essential inputs, such as lithium and cobalt, may become the driving forces of recycling in the long term. One of the three scientists that developed Li-ion batteries and recently won the Nobel Prize in Chemistry, Akira Yoshino, emphasised the importance of recycling in meeting future material demand (Suga, 2019).

Technologies for material recovery

Before undergoing a recycling process, battery packs must first be discharged, then dismantled to at least the module level (Northvolt, 2019). From this point, the modules are subjected to mechanical pre-treatment or a pyrometallurgical process, which must be followed by a hydrometallurgical process to recover critical materials in usable form.

- Mechanical pre-treatment primarily consists of shredding and sorting out plastic fluff, metal-enriched liquid and metal solids.[17] After sorting, most copper, aluminium and steel casings are recovered. The remaining material resembles a black powder containing nickel, cobalt, lithium and manganese. This "black mass" may undergo secondary treatment, which involves applying heat, separating the cathode from the aluminium collector foil with a chemical solvent, and then recovery of the cathode materials through hydrometallurgy (Northvolt, 2019).
- Pyrometallurgical recycling processes use high temperature smelting (~1 500 degrees Celsius) to produce a concentrated alloy containing cobalt, nickel and copper. These metals can then be extracted using a hydrometallurgical process. The lithium and manganese end up in a slag that can be directly used in the construction industry or processed further to recover lithium (Dunn et al., 2015: Umicore, n.d.).
- Hydrometallurgical recycling methods are centred on leaching, removal of impurities and separation. Leaching may be followed by solvent extraction and/or chemical precipitation to recover lithium, nickel and cobalt.

Box 4.2 Direct cathode recycling

A nascent set of processes in battery recycling is known as direct cathode recycling, which is currently under development by the ReCell Center at the Argonne National Laboratory in the United States (ReCell Center, n.d.). Direct recycling resynthesizes cathode materials through various chemical processes, yielding a cathode powder with similar if not identical properties to the new cathode pristine material. The defining feature is that cathode materials are recovered in a suitable condition to be used as direct inputs in battery production without breaking them down into individual material elements.

The benefit of recovering usable cathode material is that it preserves the embedded energy and economic investment by avoiding the need to resynthesize cathode materials (e.g. lithium, nickel, cobalt, or manganese) into a cathode compound. Once synthesised, the cathode is nearly twice as valuable as the sum of its constituent metals (Ciez and Whitacre, 2019). However, the recovered cathodes can only be input directly into the manufacturing of the same battery type, a significant limitation given the rapidly

[17] Pre-treatment is necessary to reduce hazards, remove cases and packaging materials, and to concentrate the fraction of valuable materials (Zhang et al., 2018). A key challenge in pre-treatment is the release of potentially hazardous and toxic gases during crushing due to high temperatures and force (Terborg, 2012). Wet crushing, crushing under inert atmosphere, and/or at low temperatures have been investigated as methods to minimise hazards.

developing battery chemistry landscape. However, a method to convert recycled cathode materials to more current formulations (e.g. using NMC 111 as a feedstock to produce NMC 622), while still in the laboratory research phase, is under development (ReCell Advanced Battery Recycling Center, 2019).

Table 4.2 Examples of current lithium-ion battery recycling facilities

Company	TRL level	Country	Technology	Capacity (tonnes)
Akkuser Oy	Commercial	Finland	Mechanical	1 000
Fortum	Commercial	Finland	Mechanical, thermal treatment and hydro	
Umicore	Commercial	Belgium	Pyro and Hydro	7 000
Lithion	Commercial	Canada	Mechanical	2 500
Li-cycle	Pilot	Canada	Mechanical	7 500
Retriev Technologies	Pilot	United States	Mechanical	4 500
Accurec	Commercial	Germany	Mechanical and thermal Treatment	2 500
Valdi	Commercial	France	Mechanical and hydro	20 000[18]
GEM High-Tech	Commercial	China	Mechanical and hydro	10 000
Brunp	Commercial	China	Mechanical and hydro	25 000 - 30 000
JX Nippon Mining and Metals	Commercial	Japan	Pyro and hydro	5 000
NorthVolt	Pilot	Sweden	Mechanical and hydro	

Sources: Pinegar and Smith (2019); Eduljee et al. (2020).

[18] Capacity includes all recycling at facility, not only capacity dedicated to lithium-ion batteries.

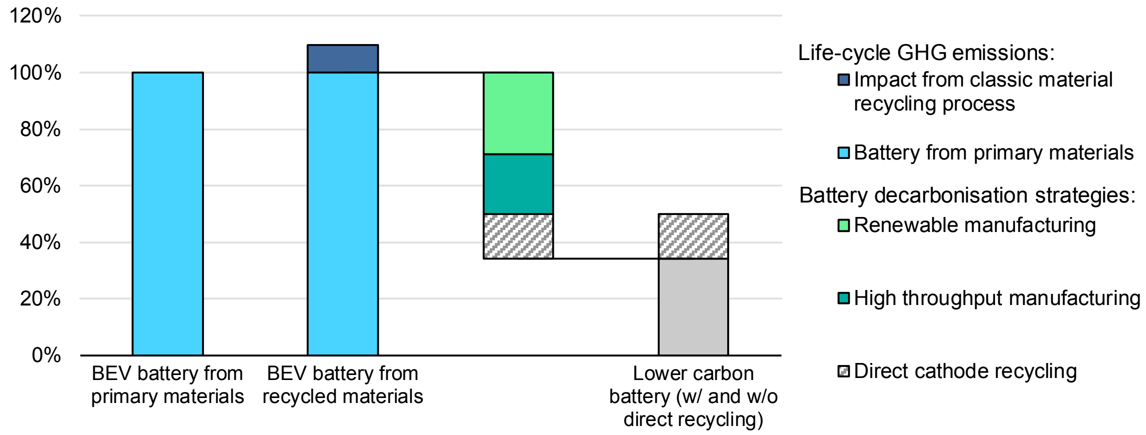
Environmental and economic trade-offs

Environmental

Like any industrial process, battery recycling is associated with its own environmental impacts. Pyrometallurgy-based pathways emit GHGs due to the high temperatures required and the need to treat toxic flue gases, both of which require significant energy inputs. However, heat released by combusting battery components (electrolyte, plastics and metals) during smelting can be recovered and used in hydrometallurgic treatment (Umicore n.d.). Mechanical-based pathways use energy for sorting, crushing and heat treatment, and must also control gas and particulate matter emissions. Hydrometallurgical recycling has fewer operational impacts at the facility but is associated with impacts from leaching chemicals through the supply chain (Hendrickson et al., 2015). Like battery manufacturing, the GHG impact of recycling can be reduced by operating facilities at high throughput and using low-carbon sources of heat and electricity.

Estimates of recycling's GHG benefits vary. Ciez and Whitacre (2019) found that only direct cathode recycling could potentially provide a significant GHG benefit with regards to primary material use as it spares the energy needed to break down all cathode components individually. By contrast, Sanfélix et al. (2019) estimated that shredding-based hydrometallurgic recycling would reduce the overall battery's impact by 11.3 gCO_2-eq/km travelled (roughly one-quarter of the total impact), assuming the recovered metals displace raw metal demand in a different industry (i.e. open-loop). Such discrepancies are likely due to differing assumptions about waste collection, recycling process efficiencies and the fate of recycled material (open-loop versus closed-loop recycling), and distinct methods of allocating credit for displaced raw material demand (Nordelöf et al., 2019). Given this ambiguity, a policy driver for battery recycling may be the independence from global raw material supply chains, rather than a significant reduction of the current battery GHG footprint.

Figure 4.4 Opportunities to lower life-cycle GHG emissions of batteries



Notes: The battery system contributes 10-30% of per km vehicle life-cycle GHG emissions (Figure 4.2), about 60% of which is attributable to materials and the remainder to manufacturing. Renewable manufacturing assumes 100% use of renewables-based electricity for cell production and assembly, resulting in a 29% reduction in overall emissions (Kelly et al., 2019). High throughput manufacturing assumes a decrease in cell assembly energy inputs from ~70 kWh/kWh of cell throughput to 35 kWh/kWh (Peters, 2017). These values have been observed in state-of-the-art or announced battery manufacturing facilities. Direct cathode recovery assumes full crediting of recovered materials as displacement of primary production of cathode materials. Classic recycling represents additional emissions associated with a battery produced from secondary materials processed with current industrial pyrometallurgical or hydrometallurgical processes (Ciez and Whitacre, 2019).

Low-carbon energy and higher plant yield are key opportunities to reduce life-cycle GHG emissions from EV batteries, though mainstream recycling technologies have a limited impact.

Box 4.3 Non-GHG impact indicators

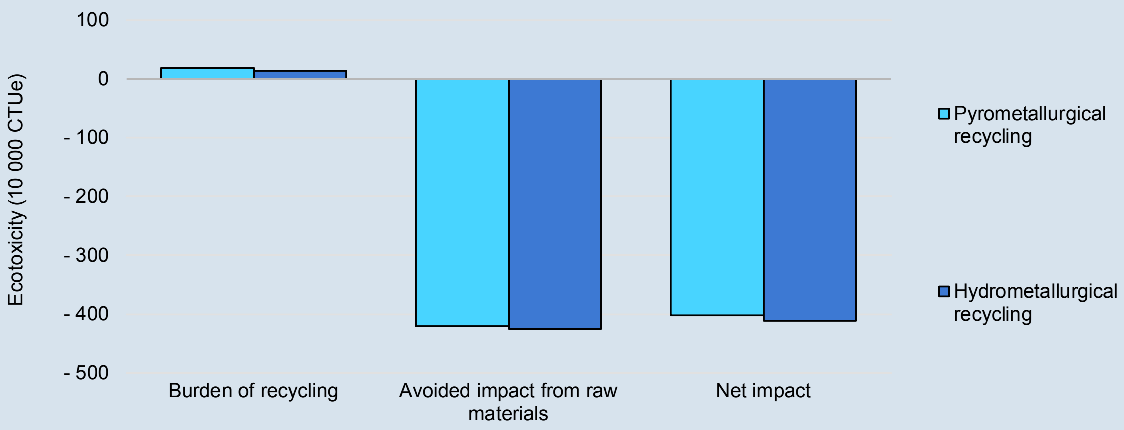
This report focusses on GHG emissions over the life-cycle of EV batteries. Nonetheless other impacts are also important, such as ecotoxicity, acidification, and water and land use. For Li-ion battery cathode materials, key non-GHG impacts include: sulfur oxide (SOx) emissions; biodiversity loss from nickel refining; toxicity of cobalt mining for local ecosystems; land and water use required for lithium recovery. Furthermore, local economic benefits of raw material mining and refining must to be balanced with potential adverse social effects on local communities.[19]

[19] Supply chain impacts are discussed more extensively in *Global EV Outlook 2019* (IEA, 2019a), as are global efforts to increase the supply chain transparency and reduce social and environmental impacts.

Mitigation measures exist. For example, SOx emissions are regulated in most Organisation of Economic Co-operation and Development (OECD) countries. Some nickel and cobalt refining operations capture sulfur emissions, which significantly decreases their adverse impacts (Kelly et al., 2019). The expected large-scale EV transition ahead is a unique opportunity for governments and industry to anticipate the risks associated with material supply chains and to develop adequate mitigation strategies and practices.[20]

Taking the non-GHG impacts into consideration reinforces the benefits of recycling (Dunn et al., 2015). The energy required for recycling means a percentage of the GHGs from material production are displaced by using recycled materials in battery production, whereas it avoids negative local impacts.

Net benefits of recycling on ecotoxicity



Notes: CTUe = comparative toxic units. Ecotoxicity is an indicator of the potential for chemicals emitted into the environment to affect the surrounding ecosystem, as recommended by the UNEP Life Cycle Initiative (Rosenbaum et al., 2008).

Source: Adapted from Richa et al. (2017).

Economic

In addition to GHG impacts, recycling pathways should be assessed based on the quality and quantity of recovered materials, as well as economic cost. Commercially available recycling processes mainly focus on recovering cobalt and nickel, in addition to the more easily recycled elements (aluminium, copper and steel). They

[20] Global efforts to promote transparent and sustainable supply chains of raw battery materials were discussed in the *Global EV Outlook 2019*, section Supply and value chain sustainability of battery materials (IEA, 2019a).

may also recover lithium-containing materials, but further processing is needed to get them to a usable form (Dunn et al. 2015). To truly close the loop and reuse the recovered materials in new cathodes, the constituent material must be refined to a sufficiently high quality then resynthesized into the cathode compound. Alternatively, the recovered metals may be used to make different products with less exigent input requirements. There is currently a knowledge gap regarding remanufacturing techniques and the quality of resynthesized cathode materials as the technology has yet to be commercialised (Melin, 2019).

Most studies assessing material recovery rates for recycling processes estimate efficiency values between 80-100%; however, these are on a laboratory scale, and represent a technical potential rather than economic reality (Melin, 2019). In particular, lithium is rarely recovered in practice as it requires an extra processing step and has a lower commodity price, around USD 8/kg, compared to USD 30/kg for cobalt (LME, 2020a, LME 2020b).

Functional recycling is only profitable if the cost of recycling is lower than the market value of the recovered materials, meaning that the economic viability varies depending on cathode chemistry, with cobalt content being a key factor. Owing to its high cost and media reports of human rights abuses at mining sites, battery producers have made efforts to reduce cobalt content, creating a trend towards chemistries like NMC 622, NCA and NMC 811 (Li and Lu, 2020). The result is that as battery producers have successfully reduced the cost and impact of the cathode by reducing cobalt content, they have also reduced the value of the battery at its end-of-life. This represents a key trade-off; the cheaper materials are less harmful to local environments and less energy intensive to produce, but their use in battery cells may lower the likelihood that the batteries will be recycled (Harper et al., 2019; Dunn et al., 2015).

Costs are expected to decrease in the future once a larger volume of batteries are retired and facilities start operating at scale, and could be further reduced with increased transparency about battery design (Gaines, 2014). Specific cost estimates for industrial recycling are not publicly available. If commodity prices are relatively low, policies such as extended producer responsibility or subsidies will likely be required to motivate recycling in the short term. Second-life batteries can create environmental and economic value, especially when paired with renewable energy systems. However, repurposing the battery in a new location may also complicate battery collection schemes and delay the recovery of critical materials. There is no clear answer, as we still have much to learn about the costs, benefits and performance of both pathways.

Policies for battery end-of-life

There is no global policy governing the reuse or recycling of Li-ion batteries at their end-of-life. Policy mandating the end-of-life treatment can mitigate environmental, social and safety issues, as well as provide certainty to the market to stabilise the supply chain of critical materials. The most significant markets of Li-ion batteries will be China, European Union and United States, as they are expected to concentrate the bulk of the electric car stock in the coming years. These three regions have different regulatory approaches to address battery end-of-life. The European Union and China have placed responsibility on the OEM. The United States has not implemented a federal policy, although several states have begun to act independently (Saidani et al., 2019).

Global policies to manage waste batteries

Policy is challenged with enforcing the recycling and recovery of critical materials that are currently uneconomical, and are likely to become more difficult given continuing efforts to reduce the share of cobalt in cathode chemistries. Due to low recycling requirements, a lack of enforcement and bans on landfilling without further specifications of recycling or reuse, there have been low recycling and recovery rates (Winslow, Laux and Townsend, 2018). Varieties of chemistries and designs, along with the lack of labelling and transparent information on the battery use, have inhibited the uptake of remanufacturing and recycling. This has resulted in increased end-of-life costs and has not yet been adequately addressed by policy (Element Energy, 2019).

Recent developments highlight the increased focus and concern for end-of-life impacts of batteries due to the uptake of EVs. At the international scale, the Global Battery Alliance was founded in 2017 as a collaboration of 70 public and private organisations with the goal to establish a sustainable battery value chain, from sourcing, to repurposing and recycling (Box 4.5) (World Economic Forum, 2020).

Box 4.4 Guiding principles and a "battery passport" for a sustainable battery value chain by 2030

The Global Battery Alliance's report, "A Vision for a Sustainable Battery Value Chain in 2030" highlights the economic, environmental and energy access opportunities that could emerge from a transition to a more sustainable battery value chain (GBA, 2019). These include life-cycle cost reductions in battery supply chains (estimated at 23%), which could result in 10 million jobs, and generate USD 150 billion in economic value in 2030. Sustainable battery supply and end-of-life strategies further present opportunities for substantial emission reductions in transport and power (estimated to contribute "30% of the reductions needed in the transport and power sectors to stay on track to achieving the 2 degree Celsius Paris Agreement target," according to the Global Battery Alliance (GBA) [2019]), all while playing a part in increasing electricity access.

Realising these opportunities will require spurring rapid and sustainable growth in battery value chains over the coming decade. To this end, the Global Battery Alliance agreed in January 2020 on ten guiding principles to foster the creation of a sustainable battery value chain by 2030. Forty-two organisations – including automotive, mining, chemicals and energy companies with a combined revenue of approximately a trillion dollars – have agreed on these principles across the three impact areas.

Ten principles for a sustainable battery value chain by 2030

10 GBA principles for a sustainable battery value chain

Impact area	No.	Principle
Establish a circular battery value chain as a major driver to achieve the Paris Agreement	1	Maximizing the productivity of batteries in their first life
	2	Enabling a productive and safe second life use
	3	Ensuring the circular recovery of battery materials
Establish a low-carbon economy in the value chain, create new jobs and additional economic value	4	Disclosing and progressively decreasing greenhouse gas emissions
	5	Prioritizing energy efficiency measures and substantially increase the use of renewable energy as a source of power and heat when available
	6	Fostering battery-enabled renewable energy integration and access with a focus on developing countries
	7	Supporting high quality job creation and skills development
Safeguard human rights and economic development consistent with the UN Sustainable Development Goals	8	Immediately and urgently eliminating child and forced labour, strengthening communities and respecting the human rights of those employed by the value chain
	9	Fostering protection of public health and the environment, minimizing and remediating the impact from pollution in the value chain
	10	Supporting responsible trade and anti-corruption practices, local value creation and economic diversification

Source: Global Battery Alliance, 2019.

The Global Battery Alliance further proposes a "battery passport" as a means to provide reliable, accessible and trusted data to businesses, governments and civil society organisations across the value chain. The battery passport is a digital representation of a battery based on a comprehensive definition of all environmental, social, governance and life-cycle requirements that are relevant to improving the sustainability of batteries. For efficiency and compliance reasons this definition of requirements will be initially based on, but not limited to, already existing relevant standards, laws and regulations. The battery passport will be enabled by a digital platform and each battery passport will be a digital twin of its physical battery.

The battery passport will be delivered in three phases in consultation with stakeholders across the value chain. The finalised Battery Passport 2.0 with full functionality and covering the entire battery life-cycle, is targeted for development by 2022.

In the United States, the California Assembly Bill 2832 requires the formation of a Lithium-Ion Car Battery Recycling Advisory Group to advise the legislature on EV Li-ion battery recycling policy (Public Resources Code, 2018). As of 2019, the mandate in China requiring producer responsibility went into effect, holding producers responsible for the recycling, as well as the reverse logistics involved in taking back the Li-ion batteries (Pagliaro and Meneguzzo, 2019). The European Union is currently reviewing the Battery Directive to adapt to the increase in EVs through identifying improvements and assessing the relevance, effectiveness, efficiency, coherence, and added value of the policy (European Commission, 2018). These developments, along with private sector innovation, will push forward battery end-of-life solutions.

European Union

The 2006 European Union Battery Directive has been the most influential piece of legislation, restricting the disposal and mandating extended producer responsibility (EPR), under which producers are responsible for the costs, collection and recycling of batteries when they become waste (Green, 2017). EVs are also regulated under the End-of-Life Vehicle Directive that requires a vehicle reuse and recovery rate of 95%, a target that is consistently met. The intent of these policies is to force consideration of the entire life-cycle in the design phase and to optimise resource recovery, therefore reducing waste from the outset.

A revision of the EU Battery Directive (2006/66/EC) is expected in the second half of 2020. In 2019 the European Union reviewed the Battery Directive which was originally developed for nickel-cadmium and lead-acid batteries. The Directive specifies that batteries other than those mentioned have a recycling requirement of 50% by weight (European Commission, 2006). Conclusions are:

- The Directive does not sufficiently incorporate recent technological developments. New technology such as Li-ion batteries and evolving chemistries need to be addressed in the end-of-life policy.
- The recycling target of 50% by weight does not adequately incentivise the recycling of critical materials that are a minority of the weight; instead, the bulk materials such as aluminium are recycled.

Extended producer responsibility obligations, especially as it pertains to the reuse of batteries, are not clear. The second-life battery industry is hindered by an unclear legal framework and absence of specific provisions on the transfer of responsibility from producers to the remanufacturer. Currently, the producer is responsible for battery disposal or recycling, regardless of the second or third lives. Provisions for second-life need to be modified to enable and encourage Li-ion battery reuse.

Announced in 2019, the European Green Deal puts strong emphasis on establishing a clean and circular economy, in addition to singling out sustainable and smart mobility (European Commission, 2019). It further highlights the job-intensive nature of the logistics and industrial facilities needed to realise domestic recycling.

China

China is the biggest player due to its global relevance in Li-ion battery production, accounting for 50% of global EV battery manufacturing capacity and about half of global production, and increasing EV demand within the country. In 2018, the government adopted an interim framework called "The Interim Measures for the Management of Recycling and Utilisation of Power Batteries of New Energy Vehicles". This measure implements the EPR of Li-ion batteries; encourages standardisation of the design and production and implements a traceability system.

Producers are responsible for labelling and the creation of recycling channels that include battery collection (Xu, 2017). The recycling is typically outsourced which has spurred the offtake of EV Li-ion battery recycling companies including Taisen Recycling, Zhejiang Huayou Cobalt, Brunp, Jinqiao Group, Jiangxi Ganfeng Lithium and GEM (Pagliaro and Meneguzzo, 2019).

The Ministry of Industry and Information Technology has released a guide for collecting and storing Li-ion batteries, along with a draft mandate on the testing of batteries that will be used in a second-life application (Avicenne Energy, 2019).

Japan

The government's long-term strategy makes explicit references to a co-operative approach across industrial stakeholders, for example, rules on Li-ion battery recycling have been established so that vehicles can be properly handled when dismantled (NEDO, 2018).

United States

The United States does not have a federal level Li-ion battery recycling regime. Relevant regulatory frameworks mostly operate at the state level. The Federal Mercury-Containing and Rechargeable Battery Management Act (Battery Act) of 1996 does not cover Li-ion batteries but mandates states to manage the proper disposal of batteries containing mercury, cadmium, lead or a determined hazardous material. The law gives authority to the administration to regulate other battery types if they are "toxic and may cause substantial harm to human health and the environment if discarded into the solid waste stream for land disposal or incineration".[21] Despite the malleability of this section, Li-ion batteries are not considered hazardous at a federal level under the Resource Conservation and Recovery Act, which regulates hazardous solid waste (Neuhaus, 2018).

California, New York State and Minnesota are the only states to have banned landfill disposal of Li-ion batteries, although the bans are rarely enforced (Gaines, Richa and Spangenberger, 2018). California has classified Li-ion batteries as hazardous waste because of cobalt levels exceeding the metal toxicity levels and other health and safety concerns including flammability (California EPA, 2019). Based on this classification, and the acknowledgement of the importance of a circular economy, the California Assembly Bill No. 2832 mandates the Secretary for Environmental Protection to assemble a Lithium-Ion Car Battery Recycling Advisory Group to advise policies for the end-of-life reuse and recycle of the Li-ion batteries. The goal of the legislation is to develop policy that ensures as close to 100% of Li-ion batteries in the state are reused or recycled in a safe and cost-efficient manner at the end-of-life (Public Resources Code, 2018). This advisory group will deliver its proposals in 2022.

The US Department of Energy recently created the ReCell Center, a consortium of labs dedicated to developing safe and cost effective battery recycling. Under ReCell, national labs, academics and industry will collaborate to develop an innovative approach towards a closed-loop battery industry. Unlike in the European Union and China, extended producer responsibility is not currently at the centre of the US strategy with the focus instead on the development of market-based solutions to encourage sustainable end-of-life battery management (ANL, 2019).

India

India does not have a Li-ion battery end-of-life policy, although the government announced in October 2019 that policy including extended producer responsibility and a subsidy scheme for recyclers is under development. In 2011, the E-waste Management and Handling Rules were updated to include Li-ion batteries and are based on the EPR principles, but do not include recycling and safe disposal requirements (JMK, 2019). The extended producer responsibility principles are

[21] Section 103.d.

difficult to effectively implement with a flow of illegal e-waste into the country and should be a cautionary tale for the future of EV end-of-life and affiliated policy (Awasthi, 2017).

South America

Today, no country in South America has Li-ion battery end-of-life legislation, and the overall battery recycling policy is sparse. Brazil was the first to regulate disposal and treatment of batteries containing lead, cadmium and mercury. They implemented extended producer responsibility with the requirement that consumers return the batteries to the place of the purchase; this policy does not cover Li-ion batteries (Espinosa, 2004).

Table 4.3 Lithium-ion batteries end-of-life policies, 2019

Region	Policy	Year	Description	Developed for Li-ion batteries[22]
European Union	Battery Directive	2006	Extended producer responsibility. Requires 50% recycling of Li-ion batteries by weight.	No
China	Interim Measures for the Management of Recycling and Utilisation of Power Batteries of New Energy Vehicles	2018	Extended producer responsibility. Implements labelling, a traceability system and encourages standardisation of the design and production.	Yes
China	Guide for Collecting and Storing Li-ion batteries	2019	Ministry of Industry and Information Technology has released a guide for collecting and storing Li-ion batteries, along with a draft mandate on the testing of batteries that will be used in second-life applications.	Yes
California	California Assembly Bill No. 2832	2018	Establishment of a Lithium-Ion Car Battery Recycling Advisory Group to advise policies for the end-of-life to achieve as close to 100% of reuse and recycling as possible.	Yes

[22] The column specifies whether the policy was developed specifically for Li-ion batteries based on the expansion of EVs, or whether it was developed for another purpose and Li-ion batteries fall within the category.

Region	Policy	Year	Description	Developed for Li-ion batteries[22]
United States	New York State Rechargeable Battery Recycling Act. Minnesota Rechargeable Batteries and Products Statute. New Jersey statutes: sale of certain batteries dependent on battery management plan	2010; 1991; 1991	Extended producer responsibility. Ban on the disposal in landfills.	New York: Yes Minnesota: Yes New Jersey: No

Revision of mandated/recommended recycling rates

To establish a circular economy, key performance indicators (KPIs) for recycling policy should focus on material recovered and recycled content used in the manufacturing of batteries, not only the collection and recycling rates. The EU Battery Directive recycling rate requirement of 50% by weight is an example of a KPI that does not encourage high critical material recovery. Requiring collection without a recycling requirement (as in the case of India) bears the risk of leading to the stockpiling of Li-ion batteries without significant recycling. Recycling rates have a wide range of definitions that complicate comparisons between regions, but they typically represent the portion of materials recycled from the waste produced. Recovery rates indicate the efficiency of the recycling process by calculating the rate of materials recovered from the recycling process (Hotta et al., 2016).

Box 4.5 Lessons learned from recycling in parallel industries

The end-of-life management of electronics, automobile parts and lead-acid batteries provide lessons and cautionary tales to the development of battery waste policy.

Electronic Waste

E-waste dumping from economically rich to poor countries is a continuing issue that results in landfill disposal, artisanal picking and rarely in recycling. Both India and China have a history of international e-waste imports, shifting the burden of waste away from the waste-producing country. This has decreased since the ratification of the Basel Convention, which prohibits such imports, but continues to be an issue due to illegal smuggling (Awasthi, 2017). Informal recycling techniques include burning and dissolution in strong acid, which is hazardous to the workers and surrounding communities (Robinson, 2009).

Automobile parts

The automotive industry has been successful at achieving high recycling rates through reusable parts such as catalytic converters, as well as shredding of the hulk for recovery of aluminium, copper and zinc (Ferrão, 2006). Recycling of cars has been further enabled through design for recycling (Coulter et al., 1998). The European Union, Korea, Japan, China and Chinese Taipei have recycling legislation, while recycling in the United States, Canada and Australia are based on market mechanisms and controlling the use of substances through environmental protection regulations (Sakai et al., 2013). The design of vehicles enables systematic dismantling and resale of parts through online inventory databases aiding in the reuse and extended life of automobiles (Staudinger, Keoleian and Flynn, 2001).

Lead-acid batteries

Lead-acid batteries have some of the highest recycling rates in the world due to regulation covering the toxicity of lead, favourable economics and a simple chemistry to recycle. The US recycling rate from 2014 to 2018 is reported at 99%, mainly driven by the fee returns and reverse logistics network (Battery Council International, 2019). While this rate is encouraging, lead-acid battery recycling has resulted in occupational and surrounding community exposure to lead toxicity (World Health Organization, 2017). Although lead-acid batteries and Li-ion batteries are not the same when it comes to recycling, many of the lessons learned can be applied to the maturing Li-ion battery recycling market.

Key lessons

Based on these observations, it will be particularly important for policy makers to ensure that:

- Recycling and processing take place in jurisdictions with environmental controls.
- Li-ion batteries are traceable from the point of retirement to final recycling and/or waste disposal.
- Li-ion battery waste is not exported to poor countries resulting in hazardous disposal or recycling.

Design for recycling

Policy based on a technology's full life-cycle impact can help avoid unintended consequences, leakage and double counting (Kendall, Ambrose and Maroney, 2019). For OEMs, considering life-cycle impacts informs the practice of EcoDesign and

Design for Recycling (DfR) (Luttropp and Lagerstedt, 2006). DfR is the inclusion of end-of-life management to the product design phase through identifying key product phases and characteristics that could enhance the viability of safe and economical second-life battery application and recycling. Without anticipation of the end-of-life in the design process, extra measures are required for disassembly that substantially increase costs and decrease safety, creating an uneconomical process with high barriers to entry (Kampker, 2016). These design interests can conflict with more profit-maximising characteristics, and without regulation or an economic incentive, trade-offs will likely lean towards benefiting the initial use (Hatcher, Ijomah and Windmill, 2011). The European Union ecodesign preparatory study for batteries also finds regulating the supply chain and design requirements is essential in creating a sustainable battery industry (Fraunhofer and Viegand Maagøe, 2019).

Characteristics that benefit battery end-of-life include modularity, standardised interfaces (housing) and design for disassembly (Kampker, 2016). The aim is to enhance the ease and safety of disassembly, cleaning, testing and reassembly. Li-ion batteries already excel in modularity – the cells are fit into a battery module, which then fits into a battery pack. This modularity allows battery cells to be easily identified, removed and replaced. Inefficiencies include difficulty in disassembly due to the use of non-reversible adhesives such as gluing and welding. The use of removable brackets, such as bolts, significantly decreases cost and enhances worker safety (Reuters, 2011). Labelling materials and market standardisation simplify the disassembly process and further decrease cost for both recycling and repurposing, although the negative impacts of standardisation include the potential stifling of battery development and innovation due to restrictions (Shaik, 2013). China's 2017 interim measure mandates labelling and encourages standardisation to enhance the efficiency of the end-of-life processes.

Policy makers must recognise that difficult trade-offs may exist between promoting innovation in battery technologies and encouraging DfR. Extended producer responsibility is expected to encourage DfR by holding the OEM responsible for batteries throughout the life-cycle. The fact that established frameworks such as the EU Battery Directive do not result in DfR may be attributable to specific challenges of end-of-life management of Li-ion batteries (such as disassembly), for which existing policy frameworks were not designed. As such, designing policy around the characteristics of the product will encourage OEMs to balance battery performance and ease of recycling.

Key messages and policy recommendations

Key messages

The rapid evolution of li-ion battery designs and chemistries for electromobility, together with the diversity of EV batteries, make it difficult to design and scale up recycling processes and technologies. Nevertheless, focusing on the battery supply chain, including end-of-life, will become increasingly important over the coming decade, as electromobility penetrates the mass market. A few salient points emerge:

- As power systems decarbonise, the relative impact of vehicle and battery manufacturing on the overall EV life-cycle GHG emissions will grow. The carbon intensity of the battery life-cycle can be reduced by using low-carbon energy inputs to processes for production, recycling or recovery of raw materials and for cell assembly, as well as by increasing the throughput of cell making processes.
- Before recycling, Li-ion batteries can be reused as stationary storage systems. Whether they will be used in such applications will depend on the economics of doing so and on policies for battery end-of-life. Extending their useful lifetime reduces the life-cycle GHG emissions, environmental impact, and cost on a per kWh basis. But such reuse also presents a trade-off with the benefits of recovering and recycling valuable cathode materials that can re-enter the supply of batteries for electric mobility.
- Battery recycling can reduce environmental, social and economic risks along critical materials supply chains. It is estimated that current mainstream recycling processes have a limited impact on an EV battery greenhouse gas footprint. This footprint can be reduced via recycling facilities scale-up, energy efficiency measures, low-carbon energy sources and innovative and simplified processes that Design for Recycling can facilitate. Recycling can also ensure the domestic availability of valuable and strategic materials.
- Many national or regional policies for waste management and recycling were put in place before an EV market existed and are thus not adapted to deal with Li-ion batteries.
- China has recently produced extensive new legislation and guidelines for the end-of-life of Li-ion batteries and the recycling industry is growing in the country. The European Union and California in the United States are reassessing their legislation and more extensive policy is under development.

Policy recommendations

As the number of li-ion batteries produced, and the mass of their critical material constituents in the rolling stock of EVs increases, a few lessons emerging from the above analysis may help to frame the role of battery supply chains in ensuring that electromobility realises its full sustainability potential:

- Develop metrics and traceability mechanisms that enable the quantification of the carbon embedded in battery manufacturing and implement incentives or regulations that favour low-carbon batteries on the market.
- In light of EV market expansion, assess and revise current battery waste management mechanisms. Clear guidance on collection, recovery and recycling rates targeting those materials classified as critical are of particular importance. Lessons learned from recycling legislation targeting consumer electronics and automotive parts should be taken into account to inform Li-ion battery policy making and implementation. While regulations that explicitly mandate design for recycling (DfR) may risk stifling innovation in Li-ion batteries, clear regulations on extended producer responsibility can ensure that DfR is incorporated into automotive design.
- Encourage second-life use of Li-ion batteries in viable technical and economic cases, such as to support the deployment of renewables-based electricity generation. Involve stakeholders in the battery value chain in the development of openly accessible devices that are capable of tracking and reporting battery cell state of health to facilitate reuse.
- As the economic value of recycling is uncertain, it will be important to reduce these uncertainties while minimising the additional costs imposed by developing and implementing waste management and recycling policies that safeguard the environment and security of supply. Financial models (e.g. deposit, subsidy, leasing) that incorporate the cost differential between recycled and primary materials can motivate recycling.
- Incentivise or mandate the use of a transparent value chain accountability system (such as the Battery Passport concept explored by the Global Battery Alliance) and involve stakeholders in the battery value chain to ensure traceability of the battery from the point of retirement to reuse and/or recycling. In particular, make information about batteries accessible to recyclers and repurposers (including labelling battery chemistry on battery packs and modules).
- Countries where high numbers of EVs are in circulation can implement supply and disposal measures which lessen the environmental and social burdens placed on materials- and battery- producing and recycling regions outside of their jurisdictions..

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Chapter 5. Integrating electric vehicles with power systems

Overview

Balancing electricity demand and supply will become an increasing challenge to ensure the smooth integration of variable renewables-based energy generation and the electrification of multiple end-use sectors. The uptake of electric vehicles in the Sustainable Development Scenario,[1] in which EVs account for around 4% of global annual electricity demand by 2030 (up from 0.3% today), bring implications and opportunities for power systems (IEA, 2019). They could play a much more active role than in the Stated Policies Scenario in which both EV electricity use, EV flexibility potential and need for flexibility services (partly due to the rise of variable renewables) are lower.

Over the coming decade, it will be increasingly important to manage EV charging patterns and to encourage charging at periods of high renewables-based electricity generation in power systems that have them in their power mix. The share of EV charging in peak demand could rise to as high as 4-10% by 2030 in the main EV markets (People's Republic of China [hereafter, "China"], European Union and United States), assuming unmanaged charging and the EV stock of the Sustainable Development Scenario. A range of ready options exist that can be tapped to influence EV charging to reduce its call at peak system demand, thereby diluting the need for upgrades to generation, transmission and distribution assets (Manríquez, 2020).[2] In particular, by 2030 at the global level, in the Sustainable Development Scenario:

[1] In this chapter, all assumptions not related to electric vehicles, including on power systems and other demand sectors, are taken from the IEA Sustainable Development Scenario presented in Energy Technology Perspectives 2020 (IEA, forthcoming).

[2] Distribution system operator perspective on the impact of EV charging is very granular spatiotemporally and many challenges are highly dependent on the local context, so analysing its impacts in a generic and global manner is a difficult undertaking. Keeping this in mind, discussion and policy guidance for mitigating the impact of EVs on distribution networks is presented at the end of this chapter.

- Promoting off-peak hour work-based charging during daytime could move on average 50 gigawatts (GW) from grid congestion periods to work hours, which could coincide with high electricity generation from solar photovoltaic (PV) or wind.
- Rather than charging EVs in the evening peak demand period, shifting charging to off-peak night hours through simple end-user programming and/or night-time tariffs. The projections indicate this could displace another 110 GW with no impact on the battery state of charge when the end-user needs the vehicle.
- In addition, about 70 GW of peak demand shaving from EVs could be realised with dynamic controlled charging in response to price signals from utilities (referred to as V1G).[3]

In addition to being able to moderate their impact on peak electricity demand by patterns of charging, EVs can facilitate the integration of variable renewables and provide flexibility services to power systems. Services to electricity grids cover various timescales, from the millisecond frequency control to long term where EVs act as a variable in adjusting supply and demand, and influence capacity planning.[4] EVs could also play an active role in providing electricity to a grid during peak periods. If just 5% of the total EV battery capacity was made available for vehicle-to-grid applications, this could supply about 600 GW of peak demand across the main EV markets[5] by 2030 with the EV deployment projected in the Sustainable Development Scenario, and potentially address a lack of variable renewable generation in peak periods.

For this potential to be realised, governments and relevant industry need to address the underlying technical and acceptability challenges by:

- Instituting static electricity pricing by period of the day (peak/off-peak periods) to incentivise off-peak charging, or dynamic electricity pricing for larger benefits, including enhanced integration of variable renewables.
- Investing in dynamic controlled charging (V1G) and vehicle-to-grid (V2G) infrastructure, alongside the adaptation of effective regulatory frameworks and promotion of aggregators.

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[3] Broadly speaking pricing includes the effect of increased renewable energy penetration and the effect of reducing transmission line congestion by mitigating peak demand under dynamic controlled charging, which manifests in the form of system level operating cost reduction which in turn lowers locational marginal prices.

[4] One of the most common flexibility services that current EV fleets participate in is ancillary services, or the control of network frequency thanks to an ultra short-term modulation of the battery charging rate. The long-term value of this market for EVs, however, is uncertain, as EV fleets expand and thus the potential revenue per vehicle is bound to shrink. More extensive discussion on the possible flexibility markets EVs could contribute to and their policy and regulatory implications, is provided in *Global EV Outlook 2019*, Chapter 5 (IEA, 2019).

[5] 600 GW represents the cumulative flexibility capacity available distributed across the United States (90 GW), China (300 GW), India (40 GW) and the European Union (160 GW).

- Developing software that allows distributed loads to participate in the electricity market, one- and bi-directional electricity flows (for V1G and V2G) and user-friendly controls to promote end-user engagement.

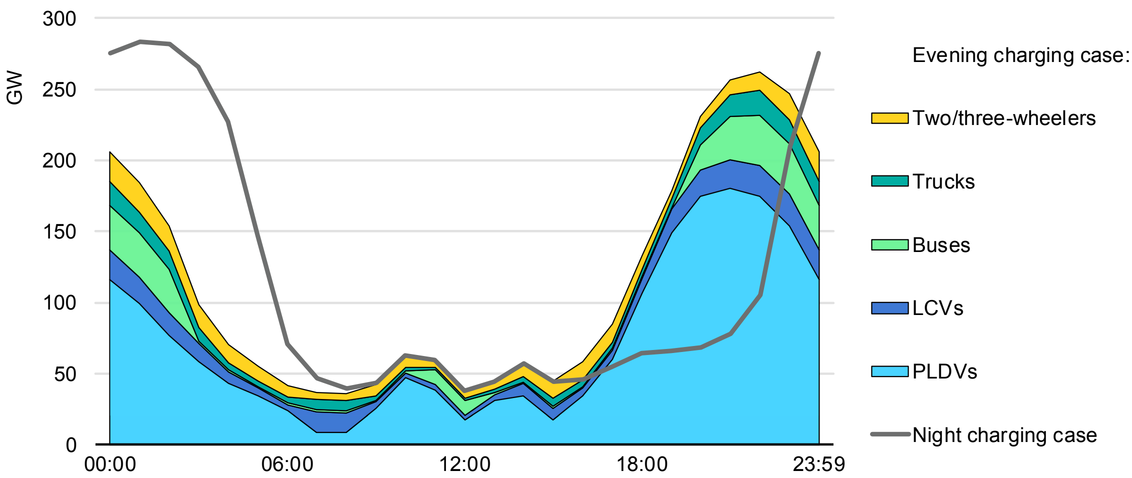
Approaches should also aim to address the local impacts of EVs on electricity distribution networks. EV charging may result in local congestion due to clustering of EV charging, especially if they are numerous (e.g. passenger cars), concentrated in a given area (e.g. fleet depots or multi-dwelling buildings), or require high power charging (e.g. some light-commercial vehicles, trucks, buses).

EV charging

EV diversity in vehicle types, use patterns and charging options

The diversity of electric vehicle types (e.g. two/three-wheelers, passenger light-duty vehicles [PLDVs], light-commercial vehicles [LCVs]) and their activity profiles (e.g. commuting, urban logistics, road freight, public transit) are the main determinants of EV charging patterns in 2030 (Figure 5.1).

Figure 5.1 Global average weekday load profiles in an evening charging case and a night charging case by vehicle type in the Sustainable Development Scenario, 2030



Note: PLDVs = passenger light-duty vehicles; LCVs = light-commercial vehicles. EV load curves are aggregated at the global level. They are not accounting for varying time zones and might not be representative of regional patterns. They are representative of an assumed typical weekday.

Electric cars make up the bulk of daily EV electricity demand; the evening charging peak could be shifted using static off-peak tariffs.

In the Sustainable Development Scenario in 2030, PLDVs account for more than 60% of the energy consumed by EVs at the global level. PLDVs are the largest contributor of all EVs to the evening or night charging peaks. When people return home from work is a key time for vehicle charging and accounts for 80-90% of PLDV charging in the United States (Wood et. al., 2017; Funke, 2019) and Europe (Mathieu, 2018; Engel et al., 2018) or potentially later during the night.[6] Most other modes, including buses, LCVs and trucks, follow suit, although work-based charging opportunities or breaks in commercial or bus activities help spread the EV load profile throughout the day. The charging pattern of two/three-wheelers is spread more evenly over the day, due to the multiplicity of functions they fulfil, the large number of small-size batteries they represent and their ease of charging (Table 5.1).

Table 5.1 Characteristics of driving and charging patterns by EV type in the main EV markets

Type	Primary use case	Daily mission profile	Variety of routes	Charging patterns
PLDVs	Mostly commuting or activities that precede or follow the commute; occasional long distance trips.	Peak on road from 6:00-9:00 and 16:00-19:00, parked at home or at workplace 95% of the time; long distance trips often during low electricity demand periods.	Low	80-90% at home in the evening or late at night; occasionally at workplace; more distributed pattern for motorway chargers.
LCVs	Urban logistics, construction, retail, delivery, renovation, maintenance and other services from individuals under contract or self-employed.	Low trip distances, high number of trips. Traffic peaks earlier than PLDVs in the morning and travel day ends later in the evening than PLDVs.	High	In the evening or at night after end of commercial activities; occasionally before start of most businesses or during daytime.
Buses	Public transportation, school buses.	Fixed routes, pre-determined schedules, short (optimised) and known dwelling times during the day.	Very low	Mostly at depot for overnight charging. 10%-30% of charging in daytime (e.g. at end of line).

[6] Studies distinguish between charging immediately in the evening (upon return from work around 18:00) and delayed evening/overnight charging (22:00 or later) using time-of-use rates segmented by time of day. The number of time-of-day rates levels can vary from simply from just day/night or peak/off-peak time pricing to several (off-peak, mid-peak, on-peak and super off-peak rates) depending on the utility, prevailing market rules and geography (BNEF, 2017).

Type	Primary use case	Daily mission profile	Variety of routes	Charging patterns
Trucks	Local distribution, freight, long-haul goods delivery.	Long trips, smaller number of trips than other modes. Traffic volume peaks between 10:00-13:00.	Medium	Mostly at depot, overnight.
Micro mobility, two/three-wheelers	Commuting, last-mile connectivity, on demand ride sourcing, shared mobility services, food delivery.	Traffic volume spreads throughout the day due to the multiplicity of vehicles and functions.	Very high	Spread relatively evenly across the day compared to other modes.

Notes: These are the charging patterns reported in recent literature and are considered reasonable in a 2030 timeframe. They also represent the main determinants of the estimated 2030 charging load profiles shown in Figure 5.1.

Sources: Figenbaum (2018); Beach (2019); McGuckin and Fucci (2018); US DOT (2018); Tao et al. (2018); Engel (2018); Pavlenko (2019); Groot et al. (2017); NHTS (2018); Wood et al. (2017); Funke (2019).

The type of day (i.e. weekday, weekend or holiday) has a strong influence on the EV load curve. Weekday travel accounts for about 75% of annual private car mileage (McGuckin and Fucci, 2018) and 75% of urban bus mileage (Miller, 2018). On the contrary, discretionary activities such as shopping or recreational purposes shape vehicle operations on weekends. The range of timing and routes of weekend EV charging load curves generally results in smoother load curves but can also lead to occasional, localised, high electricity consumption at peak travel periods (e.g. at the beginning or towards the end of a holiday or following a major sporting or entertainment event) (RTE, 2019). It might also be location-dependant, with implications for local distribution networks, such as commercial neighbourhoods with large parking facilities, malls or airports, and highway fast charging stations, which may have higher demand during weekends.

Temperature and seasonality also influence the magnitude and timing of electricity demand peaks due to their impact on occupancy rates, battery efficiency and electricity prices. Widespread adoption of teleworking could also impact vehicle use and charging patterns (Brand, 2019).

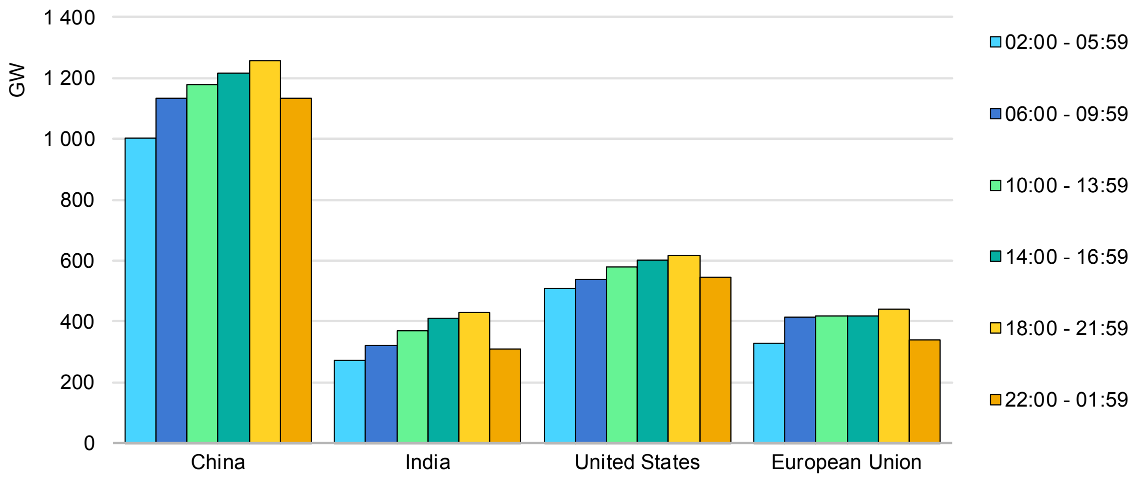
Time-of-use tariffs can significantly reduce peak demand

Co-ordinating charging windows among EVs that charge in the evening and night periods can moderate risks of grid congestion. Currently a peak in electricity use occurs between 19:00-20:00 in the winter in key EV markets such as France and Germany (ENTSOE, 2020), and in the summer in the United States, southern China and Australia (NHTS, 2017; Haustein and Nielsen, 2016), as people turn on heating and cooling systems, and home appliances.

Looking forward, a variety of factors will contribute to increasing peak electricity demand in the evening hours from sectors other than transportation, underscoring the importance of shifting EV charging to off-peak hours (Figure 5.2). These include connected devices, shifts to electric cooking and soaring space cooling demand, which will contribute as much as 30% of the peak load in places with high air conditioner ownership such as China (IEA, 2020).

In parallel, wind and solar deployment profiles suggest that variable renewable electricity generation (from offshore and onshore wind, as well as utility and buildings-integrated PV) covers only 10-20% of electricity needs from 18:00-22:00 by 2030 in the Sustainable Development Scenario, on an average weekday in these markets. Of course, this is highly geographically dependent.

Figure 5.2 Required generation capacity to meet electricity demand from loads other than EVs during days of peak demand in the Sustainable Development Scenario in selected countries/regions, 2030



Note: The hourly capacity required is averaged over the 30 days of highest electricity demand.

Shifting EV charging outside of the 18:00–22:00 period would help reduce the burden on electric generation capacity needed to meet peak demand.

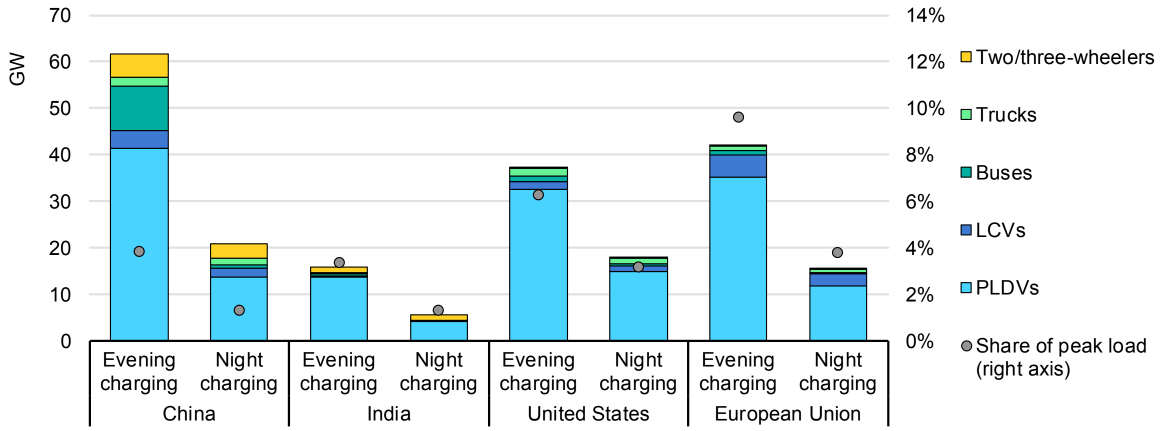
To assess the sensitivity of the main charging periods on generation capacity needs for the energy system in 2030, we consider two cases: the evening charging case and the night charging case (shown in Figure 5.1). The *evening charging case* assumes that 80% of EV charging needs are met during the 18:00-00:00 period at a global level. In the *night charging case* EV charging needs are met in the 23:00-05:00 period, which takes advantage of the fewer constraints usual to night-time transportation patterns. It assumes the expected predominance of home charging in 2030 for PLDVs and two/three-wheelers, as well as public and private charging at depots for LCVs, buses and trucks.

In the *evening charging case*, EVs add 60 GW to the peak demand in China, 50 GW in both the United States and European Union, and 20 GW in India by 2030 (Figure 5.3). At the global level, this represents the equivalent of roughly half of installed nuclear generation capacity in 2018. Around 80% of these capacity additions globally will be required for PLDV charging, although more than 20 GW will be needed for other modes in China (including buses, LCVs and two/three-wheelers).

The *night charging case* shows that around 60% of the peak load related to EVs could be avoided by shifting the charging period by a few hours. This means that off-peak tariffs have the potential to avoid the addition of 110 GW of flexible electricity generation capacity. In the night charging case, in 2030 and with the EV fleet of the Sustainable Development Scenario, the contribution of EVs to peak load falls from 4-5% to under 2% in China and India, and from 8-12% to slightly over 4% in the United States and the European Union.

The *night charging case* could be achieved by implementing effective regulatory and market frameworks to adopt differentiated time-of-use electricity tariffs for peak and off-peak periods (to be evaluated at the national or regional level based on consumption data and revised as load profiles change). The attractiveness of the incentive to encourage EV charging at night could be enhanced with larger price differentials across pricing segments, or by refining the differentiations (e.g. with more than two segments), and complemented by digital equipment to facilitate vehicle charging start at the optimised times, in co-ordination with consumers choice, to increase the effectiveness of the pricing measures. This case does not include upgrades in electric vehicle supply equipment in comparison to the evening charging case, nor controls to make EV charging responsive to real-time electricity prices.

Figure 5.3 Contribution of EVs to hourly peak demand by country/region in the evening and night charging cases in the Sustainable Development Scenario, 2030



Shifting EV charging practices to avoid peak hours could reduce the contribution of EVs to peak demand to less than 4%.

The start time of EV charging needs to be managed (e.g. through controls, differentiated tariffs at the local level) to avoid sudden high local variations of electricity demand when an off-peak tariff begins. As EV participation increases, more dynamic pricing mechanisms (e.g. more rate tiers or full real-time electricity pricing) could reduce this risk, alongside other benefits.

Advanced flexibility

Digitalisation brings additional opportunities to reduce the contribution of EVs to peak demand through controlled charging (or V1G) or via the use of batteries as distributed energy resources during peak periods (through strategic discharging using vehicle-to-grid [V2G] infrastructure).

Controlled charging aids integrating variable renewables generation and moderating new capacity needs

Unidirectional controlled charging (V1G) refers to the ability to control the time, rate and duration of EV charging to optimise it in terms of electricity system needs. It requires dispatch signals sent by a power system operator or an aggregator to the EV's on-board controls or to the electric vehicle supply equipment to manage the charging demand.

Time-of-use based strategies (where end-users would programme the time of charging in advance or automated programming mode maximising the share of electricity used during off-peak hours) could displace an average of 60% of power generation capacity needs for EV charging away from peak loads. Active control strategies could help to further optimise vehicle charging. After applying an off-peak programming strategy, the remaining load displacement potential is around 20 GW in China, the European Union and United States, and about 8 GW in India (Figure 5.3).

Controlled charging can also help integrate variable renewables-based generation since it may coincide with the times during which the vehicle is parked at the workplace (during times when solar irradiance is the highest) or at different time intervals during the night (making the most of variable wind electricity generation) (IRENA, 2019).

V1G would benefit from opening markets to new stakeholders. Aggregators could serve as an intermediary for market signals so that the existing EV communications and control capability is enough to activate V1G without dedicated investments in metering or other network element. However, boundaries around data ownership need to be drawn and market signals need to be dynamic (Zhang et al. 2020). Once in place, V1G offers a strategic opportunity for utilities to leverage the flexibility of EVs, with a net positive economic impact for power system operations and end-users. These include increased and more stable revenues from end-users participating in market services, avoided or delayed costs for generation, transmission and distribution capacity expansions and increased flexibility to help avoid curtailment of variable renewables generation (Table 5.2) (Elementenergy, 2019a).

Table 5.2 Relevant literature on the economic benefits of electric vehicle charging flexibility

Strategy	Reference	Region	Benefits
Static TOU rates	Citizens Utility Board, 2019	Illinois, US	USD 2.6 billion in 2030 (system)
Static TOU rates	MJ Bradley & Associates, 2017	Five northeast states, US	USD 0.2-1 billion (system) and USD 107-265 per PLDV owner in 2030
Static TOU rates	NYSERDA, 2019	New York State, US	USD 2.3 billion in 2030 (system)
Controlled charging (V1G)	LBNL, 2018	California, US	USD 1.45-1.75 billion (grid-storage system equivalent)
Controlled charging (V1G)	SilverSpring Networks, 2015	United States	USD 70 per kW per year in peak generation capacity cost and USD 770 per kW per year in transmission upgrade costs

Strategy	Reference	Region	Benefits
Static TOU rates	BCUC, 2019	British Columbia, Canada	USD 2 400 per EV over ten-year period (system)
Static TOU rates and real-time pricing	Kletke et al., 2018	European Union 28	13% reduction in energy system costs, or EUR 0.7 million (USD 0.8 million) in 2030
Static rates and unidirectional charging (V1G)	Jian et al., 2018	Shanghai	CNY 1 000 (USD 140) per EV in 2030, and 4.5 Mt CO_2 in 2030
Static rates	Elementenergy, 2019b	United Kingdom	GBP 180 million (USD 230 million) in 2030 (system)
Controlled charging (V1G)	Ensslen et al., 2018	France and Germany	Avoided procurement cost in 2030: EUR 0.68-0.76 billion (USD 0.77-86 billion) (or 46-51%) in France, EUR 0.44 billion (USD 0.50 billion) (or 20%) in Germany

Notes: TOU = time-of-use; V1G = unidirectional controlled charging. System benefits include avoided costs from grid upgrades (transmission, distribution and peak generation capacity expansion) and lower energy costs.

V2G can turn EVs into distributed energy resources

While the V1G strategies outlined can help to mitigate the impact of EVs on power systems and significantly facilitate the integration of variable renewables in electricity generation, deploying vehicle-to-grid (V2G) technologies could fundamentally change the dynamics by turning EVs from a consumer of electricity into a power provider, and hence part of the solution to shave peak demand. Meeting peak demand[7] in an electricity system typically requires 15-25% of generation capacity beyond capacity required to meet electricity demand for 90% of the hours of lowest demand. This accounts for about 600 GW of capacity to meet peak demand across China, European Union, United States and India combined. The projected EV energy storage capacity (i.e. the cumulative battery capacity of the EV fleet) in these regions by 2030 in the Sustainable Development Scenario amounts to 16 000 GWh. The question arises: could part of this stored energy be harnessed as mobile distributed electricity generation units to help meet peak demand?

The fraction of this cumulative battery capacity that potentially could be used for vehicle-to-grid applications is typically less than 3%. That is enough to make a strong

[7] In this case, peak demand is the average capacity required to meet demand for 1% of the hours with highest electricity demand throughout the year.

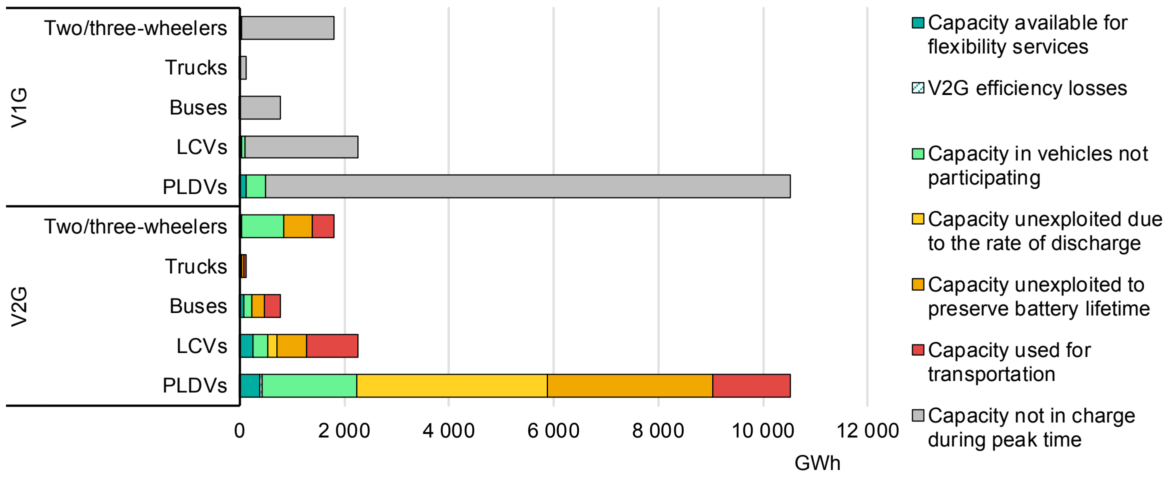
case to tap this capacity in lieu of traditional electricity storage options or installing new generation capacity to meet peak demand (Figure 5.4).

To provide power to the grid, EVs need to be parked, connected to V2G infrastructure and belong to an owner willing to actively participate. Our analysis excludes 50-60% of commercial vehicles, 80-95% of PLDVs in developing economies (other than China) and 65-85% of PLDVs in developed economies and China in 2030. In addition, no more than 5% of two/three-wheelers and buses are assumed to participate. These assumptions reflect the limited battery capacity for two/three-wheelers (which may reduce the financial reward per vehicle) as well as the lack of dedicated charging infrastructure for this mode, and the attractive revenue potential for commercial vehicle fleet owners from the high number of vehicles available, as opposed to personal electric car owners.

Other practical and technical challenges reduce V2G potential, although none constitutes an impediment:

- In many power systems peak demand occurs in the evening hours (18:00-22:00). In this period, only small shares of EV batteries are likely to be at their lowest state of charge and in need of a recharge. In fact, the PLDV battery capacity is typically four-five times larger than what is required for daily travel. In addition, part of the charging could be transferred to the day (e.g. at the workplace). Therefore, roughly 15% of PLDV battery capacity is used for transportation on average during a weekday, and a higher share of capacity for other modes.
- As there is little consensus to date on how V2G affects vehicle lifetime, the assumption here is that maximum 60-80% of the nominal rated battery capacity could actually be drawn with no premature degradation of the battery. More research and tests are needed to analyse the parameters influencing the lifetimes of batteries, including the amount of energy being drawn and recharged annually, the typical state of charge patterns over a day and the average rate of discharge.
- Depending on the maximum discharge rate of EVs, not all of the usable capacity would be discharged during the peak demand periods, as each of these periods are typically limited in time to an hour or a couple of hours. The discharging capacity of PLDVs and LCVs ranges from 3 kilowatts (kW) to 10 kW (for a total capacity of 40 kWh to 80 kWh), and rates tend to be on the higher end of this range for vehicles using home-based charging equipment. Overall, limitations due to the rate of discharge render around a quarter of total battery capacity not practical for V2G applications.
- Due to the conversion from direct to alternative current during discharging, 10% (for 8 kW chargers or more) to 20% (for 3 kW chargers) of the energy being drawn from the battery will be lost (Zecchino et al., 2019).

Figure 5.4 Available capacity for controlled charging (V1G) or vehicle-to-grid (V2G) relative to global on-board EV battery capacity in the Sustainable Development Scenario, 2030



Notes: The available capacity for flexibility services represents the share of the total global capacity that reasonably could be technically available for controlled charging and discharging. Constraints other than those singled-out in this figure, such as policy readiness or consumer behaviour, might affect this potential as well. Given the uncertainty of each influencing parameters, this figure should be read in light of the assumptions presented in the text.

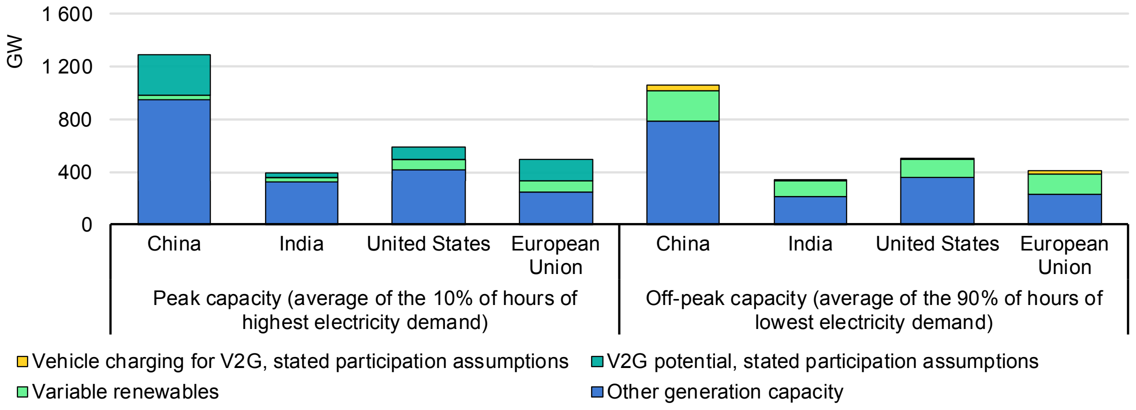
About 5% of total global EV battery capacity could be available for V2G, unlocking several hundreds of gigawatt-hours to meet peak demand.

Accounting for all limitations, around 5% of the total electric vehicle battery capacity would be available for use in V2G services. PLDVs hold the largest potential in absolute terms due to the combination of their large fleet size and the opportunity to deliver flexibility services from home. The share of total LCV battery capacity that could realistically be used for V2G is about 10%, the highest across modes. The participation rate might indeed be higher than for PLDVs due to the possibility of aggregating battery capacity across a LCV fleet, in which the batteries could also be larger. The share of electric bus capacity that could be used for V2G has potential to grow, depending on bus operations and further enhancements in the rate of discharge of V2G infrastructure.

EV battery capacity available for V2G is sufficient to meet substantial peak demand

Despite being a very small share of the total EV battery capacity by 2030, the total technically available potential for V2G in the Sustainable Development Scenario for EV deployment exceeds the additional generation capacity required to meet peak demand in almost all major EV markets (Figure 5.5). Indeed this technical potential is about 2 000 GW globally, an amount well in excess of the flexible generation capacity needed during peak periods.

Figure 5.5 V2G potential and variable renewable capacity relative to total capacity generation requirements in the Sustainable Development Scenario, 2030



Notes: Analysis represented in this figure is based on the EV deployment rates in the Sustainable Development Scenario and the assumptions of V2G capacity potential (Figure 5.4). If the technical V2G potential is untapped, additional generation capacity and/or other flexibility measures would be needed to meet demand. This graph aims to show the potential contribution of V2G to peak power capacity needs but does not show its actual contribution in the Sustainable Development Scenario.

V2G services could unlock up to 600 GW of flexible capacity distributed across the main EV markets in 2030 and moderate intermittency of variable renewables during peak demand.

Potentially, under stated EV participation assumptions to demand-side response programmes, V2G services could unlock up to nearly 600 GW of flexible capacity, split across China, European Union, United States and India. This flexible capacity could be used for:

- Compensating variability in renewable-based generation during peak periods. Indeed, while variable renewables account for 25-40% of the power being drawn during off-peak times,[8] it could fall to 5-10% during peak time, which represents a capacity loss of 400 GW across China, India, European Union and United States.
- Contributing to meet part of the additional capacity generation needs during peak demand periods, as an extra 500 GW would typically be required to provide electricity demand in such periods relative to off-peak times across the four regions considered.

In 2030, across China, India, European Union and United States, V2G could help avoid 380 terawatt-hours (TWh) of electricity generation needs during peak demand. This is nearly equivalent to the total final electricity consumed in Italy in 2018. If V2G from EVs met peak demand instead of fossil fuel-based generation, 330 million tonnes of CO_2 (Mt CO_2) emissions would be avoided globally, equivalent to total

[8] Estimates of peak time are averages on the 10% most congested hours for the grid on an annual basis. Estimates referring to off-peak times are averages on the 90% least-congested hours for the grid on an annual basis.

energy-related CO_2 emissions from Italy in 2018. To achieve these peak demand savings, and accounting for energy losses, around 470 TWh of electricity would need to be supplied to EV batteries at off-peak times, during which the carbon intensity of the electricity will be lower.

Impact on electricity distribution systems

Widespread vehicle electrification will impact all the components of an electricity system: generation, transmission and distribution networks. At a local level, EV charging can significantly increase and change the timing and magnitude of electricity loads on distribution networks and possibly impact cables, transformers and other components, as well as power quality or reliability. This is particularly critical for high power charging and in cases where many EVs are concentrated in specific locations, like clustering of residential light-duty vehicle charging or depots for commercial fleets.

Impacts of residential EV charging

Residential EV charging represents a significant increase in household electricity consumption that can require upgrades of the household electrical system. Unless properly managed, it may lead to demand that exceeds the maximum power that can be supported by distribution systems, especially for legacy infrastructure and during times of high electricity utilisation (e.g. in peak hours or on extreme days) (IEA, 2018). For example, the Norwegian Water Resources and Energy Directorate indicates that an average increase in residential load of 5 kW would overload more than 30% of distribution transformers in Norway (NVE, 2016). In Germany, its market share of more than 10% EV may be leading to bottlenecks (Jochem, Märtz and Wang, 2018).

Clustering effects[9] in EV uptake can trigger local overloading of residential distribution transformers where vehicles are typically charged, resulting in a need to accelerate distribution system upgrades (Saarenpää et al. (2013); Liu et al. (2017). This is exacerbated for higher power charging: level 2 charging (typically using a 220 to 240 Volt power source delivering maximum 19 kW) significantly increases the peak load and stress on distribution transformers compared to level 1 charging (typically using a 120 V power source delivering maximum 1.9 kW) (Muratori, 2018). Moreover, EV charging can negatively impact power quality and require upgrades or re-design of distribution networks (Khalid et al., 2019).

[9] EV adopters can be consumers with similar socio-demographics, which tend to live in the same area. Moreover, neighbour effects support the adoption of new technologies like EVs.

Controlled charging helps to minimise the impact of EV charging on residential distribution networks. However, price signals are usually offered to consumers over a large geographic region, often at the scale of an entire country, with the intent of reshaping overall system load. At the local level, multiple consumers responding to the same signal might cause "rebound peaks" that can overstress distribution systems, calling for co-ordination among consumers connected to the same distribution network (Muratori and Rizzoni, 2016). For example, direct EV charging control from an intermediate aggregator allows for active network management for shifting load between feeders in response to the effect of anticipated EV charging demand relative to local network constraints (UKPN, 2019).

Impact of commercial EV charging

Commercial and publicly accessible EV charging can involve higher power levels. This is particularly the case for direct current fast charging (DCFC), which today is typically at 50 kW per plug. Though power levels are rapidly increasing and often being installed with many charging plugs at a particular location which could lead to possible megawatt level loads, roughly equivalent to a peak load in a large hotel. Moreover, DCFC stations are often located in areas where electricity systems are less developed (e.g. along highways). Much higher power levels (up to 1 megawatt or more) might be needed for heavy truck charging, but those applications are still in an early market phase and currently most electric heavy-duty vehicles (e.g. primarily buses) are charged at depots overnight. Nevertheless, DCFC may also be directly connected to a medium-voltage grid which avoids grid congestion issues on the low voltage network on which slow chargers are usually connected.

The impacts of integrating fast EV charging with distribution systems are geographically and case specific. Distribution grid impacts and upgrades could be prevented via controlled, staggered charging systems based on the needs of commercial fleet or via distributed energy storage or other flexibility measures. Even in cases where upgrades would be required, they would not necessarily be cost prohibitive, especially for widely utilised stations. Power systems can be cost effectively upgraded to accommodate fast EV charging in many cases.

Conclusions and policy recommendations

Ready solutions exist to address the few technical challenges to accommodating EV charging at the bulk power level (i.e. generation and transmission): a number of technologies, regulatory frameworks and market incentives could be adopted to avoid having a majority of EVs charging at times of peak electricity demand. Some are easy to implement both technically and practically, with large scope for displacing EV peak demand from peak demand times from other electricity uses, such as **strategic charging infrastructure siting** (e.g. at the workplace to encourage daytime charging).

Off-peak charging, **unidirectional controlled charging** (V1G) and **vehicle-to-grid** (V2G) can unlock further flexibility potentials. These technologies can enable a smoother integration of EVs with power systems, integration of variable renewables, and, in the case of V2G, the use of EV battery capacity as an active, flexible, distributed energy resource during peak periods.

A significant opportunity for achieving system cost reductions and unlocking the potential from a fraction of the 16 000 GWh of cumulative EV battery capacity deployed by 2030 in the Sustainable Development Scenario resides in V2G. Therefore, the deployment of charging infrastructure, standards and regulatory enablers for flexibility services (especially for PLDVs, LCVs and buses) needs to be complemented by business models that compensate EV owners for providing flexibility services. Further research is also required to investigate the effect of charging and discharging cycles on battery lifetime, as the scientific community has not reached consensus on this matter.

Among various available pricing mechanisms **time-of-use rates** are widely offered by many utilities (Myers, 2019).[10] TOU pricing gives users incentive to charge EVs during off-peak hours (e.g. 23:00–05:00) and disincentives to charge during peak hours (e.g. 18:00–22:00). There can be multiple price tiers, based on the season, month, type of day (e.g. weekend or weekday) and other factors influencing hourly electricity demand. Today, the reduction in the off-peak rate relative to peak rates on a per kWh basis range from 5-40% in the United States (BNEF, 2017), to 20-65% in the United Kingdom (Zap Map, 2019), 23% in Beijing (Wan and Tong, 2019), and 35-80% in France (IEA DSM, 2017), although these tiers may not be applied to all end-users. The direct control of EV fleets by an aggregator, differentiated tariffs across various sub grids or end-users alongside other flexibility tools provide ways to mitigate a new peak induced by the tariffs.

Real-time pricing is a more advanced, dynamic pricing mechanism that adjusts electricity price based on real-time balance of demand and generation. In many countries it is applied at the wholesale market level and is not visible to individual consumers. Hence, aggregators have a key role to play to make the link between price signals and the control of EV charging without additional network investment.

[10] There are multiple categories of time-varying rates, including time-of-use, subscription rates, off-peak credits, real-time pricing, variable peak pricing, critical peak pricing and critical peak rebates.

The management of demand via aggregators may also help integrate EVs to the systems in districts less sensitive (i.e. elastic) to price incentives. Real-time pricing aims to balance electricity markets at the system level and generally does not include distribution level considerations. Therefore, pricing mechanisms to manage distribution level congestion and related business models should be envisaged by policy makers and industry stakeholders. Taking distribution network effects into account requires not only appropriate business models and price signals, but also co-ordination among multiple customers with related communication and distributed control challenges.

While the timing and speed of charging at publicly accessible stations (such as on-street or highway chargers) is less flexible (e.g. due to end-user time constraints), business models exist that provide incentives to reduce maximum peak power from public installations. For example, demand charges (a fixed monthly payment proportional to the peak power drawn over a month) are a fairly common market instruments to limit the peak power demand of commercial and industrial customers. This can also be done by modulating EV charging power[11] or leveraging behind-the-meter stationary energy storage. Stationary battery storage can be cost effective at mitigating costs associated with demand charges by up to 50% for EV direct current fast charging stations, especially for low utilisation EV charging loads (Muratori et al., 2019), or when coupled with onsite solar PV systems. Although PLDVs constitute more than 70% of global EV electricity demand in 2030 in the Sustainable Development Scenario, the contribution of other modes is likely to be significant in certain regions. In particular, buses, LCVs and two/three-wheelers could account for more than half of the contribution of EVs to the peak load in China. Hence, it is essential to target PLDVs when adapting regulations on power markets, but it is also important to analyse implications on generation, transmission and distribution of other modes. Targeted policies could aim to exploit opportunities specific to fleet vehicles such as LCVs, buses and trucks. For example, incentives for V2G might particularly be effective and attractive for publicly or privately operated fleets, as there is a higher proportion of fast charging infrastructure for these modes, and since facilitated aggregation opportunities and the larger pooled battery capacity might offer more attractive financial rewards.[12]

[11] To the extent EV drivers can afford any additional waiting time, which is unlikely on highway charging stations, for example.

[12] As many vehicle fleets already benefit from co-ordinated management on aspects other than charging.

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Annexes

Annex A

Electric vehicle stock, sales, market share and supply equipment deployment statistics

This annex presents the electric vehicle (EV) and electric vehicle supply equipment time series data for the 44 countries covered in this report.[1] These include the Electric Vehicles Initiative (EVI)[2] members, countries falling under the scope of activity of the European Alternative Fuels Observatory and countries that have reported data to the EVI.

The main data sources are submissions from EVI members, statistics and indicators available from the European Alternative Fuels Observatory (EAFO, 2020) for European countries that are not members of the EVI and data extracted from commercial databases (EV-Volumes, 2020; Marklines, 2020; ACEA, 2020; OICA, 2020; CAAM, 2020).

In the following tables, the category "others" includes Austria, Belgium, Bulgaria, Croatia, Cyprus[3], Czech Republic, Denmark, Estonia, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxemburg, Malaysia, Malta, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and Turkey.

[1] Numbers reported in this annex can differ from the data published in the *Global EV Outlook 2019* due to revisions from databases or new analysis conducted.

[2] The Electric Vehicles Initiative is a multi-government policy forum under the Clean Energy Ministerial dedicated to accelerating the introduction and adoption of electric vehicles. It is co-ordinated by the International Energy Agency. Thirteen countries currently participate in the EVI: Canada, China, Chile, Finland, France, Germany, India, Japan, Netherlands, New Zealand, Norway, Sweden and United Kingdom.

[3] 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 Turkey. The information in this document relates to the area under effective control of the Government of the Republic of Cyprus.

Note by Turkey: 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. Turkey recognises the Turkish Republic of Northern Cyprus. Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Electric car stock

Table A.1 Electric car stock (battery electric and plug-in hybrid vehicles) by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia							0.0	0.3	0.6	1.9	3.7	5.1	7.3	10.9	20.1
Brazil										0.1	0.1	0.3	0.7	1.1	3.0
Canada							0.5	2.5	5.7	10.7	17.7	29.3	45.9	90.1	141.1
Chile							0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.7
China					0.5	1.9	7.0	16.9	32.2	85.3	292.7	628.7	1207.7	2288.8	3349.1
Finland							0.1	0.2	0.5	0.9	1.6	3.3	7.2	15.5	29.4
France	0.0	0.0	0.0	0.0	0.1	0.3	3.0	9.3	18.9	31.5	54.5	84.0	118.8	165.5	226.8
Germany	0.0	0.0	0.0	0.1	0.1	0.2	1.9	5.3	12.2	24.9	48.1	72.7	109.6	177.1	258.8
India				0.4	0.5	0.9	1.3	2.8	2.9	3.4	4.4	4.8	7.0	9.1	11.2
Japan					1.1	3.5	16.1	40.6	69.5	101.7	126.4	151.2	205.3	255.1	294.0
Korea						0.1	0.3	0.8	1.4	2.7	6.0	11.0	25.7	60.6	92.4
Mexico							0.0	0.1	0.1	0.2	0.3	1.0	2.2	4.0	4.7
Netherlands				0.0	0.1	0.3	1.1	6.3	28.7	43.8	87.5	112.0	119.3	146.7	214.8
New Zealand						0.0	0.0	0.1	0.1	0.4	0.9	2.4	5.9	11.4	17.7
Norway			0.0	1.7	1.8	2.7	3.9	8.4	15.7	35.4	69.2	114.1	176.3	249.0	328.6
Portugal						0.7	0.9	1.0	1.1	1.3	2.5	4.3	8.7	17.0	29.7
South Africa									0.0	0.0	0.3	0.7	0.9	1.0	1.2
Sweden						0.0	0.2	1.1	2.7	7.3	15.9	29.3	49.7	78.6	97.0
Thailand		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.4	0.4	9.0	19.4
United Kingdom	0.2	0.5	1.0	1.2	1.4	1.7	2.9	5.6	9.3	24.1	48.5	86.4	133.7	184.0	259.2
United States	1.1	1.1	1.1	2.6	2.6	3.8	21.5	74.7	171.4	290.2	404.1	563.7	762.1	1123.4	1450.0
Others	0.54	0.54	0.54	0.62	0.67	0.98	3.40	7.75	13.24	26.49	51.01	83.37	142.26	213.49	318.96
Total	**1.91**	**2.24**	**2.70**	**6.60**	**8.89**	**17.03**	**64.32**	**183.64**	**386.32**	**692.63**	**1 235.73**	**1 988.18**	**3 136.78**	**5 111.92**	**7 167.83**

Table A.2 Battery electric car stock by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia							0.05	0.22	0.41	0.78	1.54	2.21	3.42	5.22	11.51
Brazil										0.06	0.12	0.25	0.32	0.40	0.94
Canada							0.22	0.84	2.48	5.31	9.69	14.91	23.62	46.28	78.68
Chile							0.01	0.01	0.02	0.02	0.03	0.05	0.17	0.28	0.44
China					0.48	1.57	6.32	15.96	30.57	59.40	206.12	463.12	931.12	1746.99	2581.19
Finland							0.06	0.11	0.17	0.36	0.61	0.84	1.45	2.40	4.66
France	0.01	0.01	0.01	0.01	0.12	0.30	2.93	8.60	17.38	27.94	45.21	66.97	92.95	124.01	166.81
Germany	0.02	0.02	0.02	0.09	0.10	0.25	1.65	3.86	9.18	17.52	29.60	40.92	59.09	95.15	146.46
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80	7.00	9.10	11.19
Japan					1.08	3.52	16.13	29.60	44.35	60.46	70.93	86.39	104.49	131.02	152.32
Korea						0.06	0.34	0.85	1.45	2.70	5.76	10.44	24.41	54.94	84.07
Mexico							0.00	0.09	0.10	0.15	0.24	0.50	0.73	0.93	1.20
Netherlands				0.01	0.15	0.27	1.12	1.91	4.16	6.83	9.37	13.11	21.12	44.98	107.54
New Zealand				0.00	0.00	0.01	0.03	0.05	0.08	0.19	0.49	1.65	4.58	8.94	13.28
Norway			0.01	1.69	1.78	2.68	3.91	8.03	15.01	33.10	58.88	83.10	116.13	162.27	222.62
Portugal						0.72	0.91	0.96	1.10	1.29	1.97	2.78	4.67	9.10	15.98
South Africa									0.03	0.05	0.17	0.27	0.33	0.40	0.56
Sweden						0.00	0.18	0.45	0.88	2.12	5.08	8.03	12.39	19.54	30.34
Thailand		0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.19	0.89
United Kingdom	0.22	0.55	1.00	1.22	1.40	1.65	2.87	4.57	7.25	14.06	20.95	31.46	45.01	60.75	99.26
United States	1.12	1.12	1.12	2.58	2.58	3.77	13.52	28.17	75.86	139.28	210.33	297.06	401.55	640.37	882.28
Others	0.54	0.54	0.54	0.62	0.67	0.96	3.31	6.66	11.39	22.74	38.37	53.41	76.78	111.07	178.67
Total	**1.91**	**2.24**	**2.70**	**6.61**	**8.89**	**16.65**	**54.88**	**113.71**	**224.84**	**397.76**	**719.86**	**1182.32**	**1931.40**	**3274.34**	**4790.87**

Table A.3 Plug-in hybrid electric car stock by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia								0.08	0.18	1.13	2.15	2.85	3.92	5.72	8.60
Brazil											0.03	0.08	0.36	0.71	2.08
Canada							0.30	1.70	3.18	5.42	8.00	14.36	22.33	43.82	62.38
Chile										0.01	0.04	0.05	0.06	0.13	0.21
China						0.34	0.66	0.92	1.65	25.92	86.58	165.58	276.58	541.80	767.90
Finland								0.13	0.30	0.57	0.97	2.44	5.72	13.10	24.70
France							0.10	0.70	1.53	3.60	9.28	17.03	25.82	41.47	60.02
Germany							0.24	1.40	3.02	7.41	18.52	31.81	50.47	81.92	112.35
India															0.01
Japan							0.02	10.98	25.11	41.28	55.47	64.86	100.86	124.08	141.68
Korea											0.25	0.58	1.25	5.62	8.35
Mexico											0.01	0.53	1.50	3.08	3.53
Netherlands					0.00	0.00	0.02	4.35	24.51	36.94	78.16	98.90	98.22	101.75	107.27
New Zealand							0.00	0.01	0.01	0.22	0.42	0.76	1.30	2.48	4.42
Norway						0.00	0.00	0.34	0.66	2.34	10.28	30.95	60.18	86.73	106.02
Portugal									0.04	0.05	0.49	1.52	4.02	7.92	13.72
South Africa										0.00	0.13	0.40	0.53	0.61	0.68
Sweden								0.66	1.78	5.21	10.83	21.29	37.28	59.09	66.61
Thailand										0.06	0.32	0.32	0.32	8.84	18.48
United Kingdom						0.02	0.03	1.02	2.09	10.02	27.55	54.96	88.66	123.28	159.91
United States							7.98	46.57	95.58	150.94	193.77	266.65	360.51	483.00	567.74
Others						0.02	0.09	1.09	1.85	3.76	12.64	29.95	65.49	102.42	140.28
Total						**0.39**	**9.43**	**69.93**	**161.48**	**294.87**	**515.87**	**805.86**	**1205.37**	**1837.57**	**2376.95**

New electric car sales

Table A.4 New electric car sales (BEV and PHEV) by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia							0.05	0.25	0.29	1.32	1.77	1.37	2.28	3.61	9.16
Brazil								0.09	0.17	0.06	0.09	0.17	0.32	0.42	1.91
Canada							0.52	2.02	3.12	5.07	6.96	11.58	16.68	44.15	50.96
Chile							0.01	0.01	0.01	0.02	0.04	0.03	0.13	0.18	0.30
China					0.48	1.43	5.07	9.90	15.34	73.17	207.38	336.00	579.00	1081.09	1060.30
Finland							0.03	0.18	0.22	0.44	0.69	1.43	3.06	5.71	7.88
France	0.01	0.01	0.01	0.00	0.01	0.19	2.73	6.26	9.62	12.64	22.95	29.51	37.60	46.70	61.35
Germany	0.02			0.07	0.02	0.14	1.65	3.37	6.93	12.74	23.19	24.61	54.56	67.50	108.63
India			0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00	1.20	2.10	2.09
Japan					1.08	2.44	12.62	24.44	28.88	32.29	24.65	24.69	54.10	49.75	38.90
Korea						0.06	0.27	0.51	0.60	1.26	3.30	5.02	14.64	34.90	31.86
Mexico							0.00	0.09	0.01	0.05	0.10	0.78	1.20	1.79	0.72
Netherlands				0.01	0.03	0.12	0.88	5.12	22.42	15.09	43.77	22.67	10.32	27.97	67.52
New Zealand				0.00	0.00	0.01	0.02	0.03	0.04	0.32	0.49	1.50	3.47	5.54	6.88
Norway			0.01	1.68	0.08	0.91	1.23	4.46	8.21	21.45	33.73	44.89	62.31	72.69	79.64
Portugal						0.72	0.19	0.05	0.18	0.20	1.12	1.84	4.39	8.34	12.68
South Africa									0.03	0.02	0.24	0.38	0.20	0.15	0.23
Sweden						0.00	0.18	0.93	1.55	4.67	8.59	13.42	20.35	28.96	40.70
Thailand						0.00	0.01	0.01	0.01	0.07	0.04	0.04	0.16	8.63	10.32
United Kingdom	0.22	0.32	0.45	0.22	0.18	0.28	1.22	2.69	3.75	14.74	29.34	37.91	47.25	50.36	75.14
United States	1.12			1.47		1.19	17.73	53.24	96.70	118.78	113.87	159.62	198.35	361.32	326.64
Others	0.53			0.08	0.05	0.30	2.42	4.33	5.69	13.43	23.85	31.20	60.93	78.30	107.86
Total	**1.89**	**0.34**	**0.84**	**3.69**	**2.28**	**8.24**	**48.24**	**118.16**	**204.16**	**328.80**	**546.59**	**750.64**	**1172.51**	**1980.14**	**2101.68**

Table A.5 New battery electric car sales by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia							0.05	0.17	0.19	0.37	0.76	0.67	1.21	1.80	6.28
Brazil								0.07	0.13	0.06	0.06	0.13	0.03	0.07	0.54
Canada							0.22	0.62	1.64	2.83	4.38	5.22	8.71	22.66	32.40
Chile							0.01	0.01	0.01	0.00	0.01	0.02	0.12	0.11	0.16
China					0.48	1.09	4.75	9.64	14.61	48.91	146.72	257.00	468.00	815.87	834.2
Finland							0.03	0.05	0.05	0.18	0.24	0.22	0.50	0.78	1.90
France	0.01	0.01	0.01	0.00	0.01	0.19	2.63	5.66	8.78	10.57	17.27	21.76	25.98	31.06	42.80
Germany	0.02			0.07	0.02	0.14	1.40	2.21	5.31	8.35	12.08	11.32	25.07	36.06	63.28
India			0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00	1.20	2.10	2.08
Japan					1.08	2.44	12.61	13.47	14.76	16.11	10.47	15.30	18.10	26.53	21.30
Korea						0.06	0.27	0.51	0.60	1.26	3.05	4.69	13.97	30.53	29.13
Mexico							0.00	0.09	0.01	0.05	0.09	0.25	0.23	0.20	0.27
Netherlands				0.01	0.03	0.12	0.86	0.79	2.25	2.66	2.54	4.05	9.19	24.43	62.00
New Zealand				0.00	0.00	0.01	0.01	0.02	0.03	0.11	0.30	1.16	2.94	4.36	5.28
Norway			0.01	1.68	0.08	0.91	1.23	4.12	7.88	19.77	25.78	24.22	33.08	46.14	60.35
Portugal						0.72	0.19	0.05	0.14	0.19	0.67	0.81	1.89	4.43	6.88
South Africa									0.03	0.01	0.12	0.10	0.07	0.07	0.16
Sweden						0.00	0.18	0.27	0.43	1.24	2.96	2.95	4.36	7.15	15.80
Thailand						0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.03	0.11	0.69
United Kingdom	0.22	0.32	0.45	0.22	0.18	0.26	1.21	1.71	2.68	6.81	10.10	10.51	13.55	15.74	38.51
United States	1.12			1.47		1.19	9.75	14.65	47.69	63.42	71.04	86.73	104.49	238.82	241.91
Others	0.53			0.08	0.05	0.28	2.35	3.33	4.93	11.52	14.99	15.63	23.77	34.38	67.52
Total	**1.89**	**0.34**	**0.84**	**3.69**	**2.28**	**7.86**	**39.19**	**57.64**	**112.58**	**195.43**	**324.1**	**464.75**	**756.49**	**1 343.4**	**1 533.42**

Table A.6 New plug-in hybrid electric car sales by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia								0.08	0.10	0.95	1.01	0.70	1.08	1.80	2.88
Brazil								0.02	0.03		0.03	0.05	0.29	0.35	1.37
Canada							0.30	1.40	1.48	2.24	2.58	6.36	7.97	21.49	18.56
Chile										0.01	0.02	0.01	0.02	0.07	0.14
China						0.34	0.32	0.26	0.73	24.27	60.66	79.00	111.00	265.22	226.11
Finland								0.13	0.17	0.26	0.44	1.21	2.55	4.93	5.98
France							0.10	0.60	0.83	2.07	5.68	7.75	11.61	15.65	18.55
Germany							0.24	1.16	1.62	4.39	11.11	13.29	29.50	31.44	45.35
India															0.01
Japan							0.02	10.97	14.12	16.18	14.19	9.39	36.00	23.22	17.60
Korea											0.25	0.33	0.67	4.37	2.73
Mexico											0.01	0.52	0.97	1.58	0.45
Netherlands					0.00		0.02	4.33	20.16	12.43	41.23	18.62	1.13	3.54	5.52
New Zealand							0.00	0.01	0.01	0.21	0.20	0.34	0.54	1.19	1.60
Norway						0.00	0.00	0.33	0.32	1.68	7.95	20.67	29.23	26.55	19.30
Portugal									0.04	0.01	0.44	1.03	2.50	3.91	5.80
South Africa										0.00	0.12	0.28	0.13	0.08	0.07
Sweden								0.66	1.12	3.43	5.63	10.46	15.99	21.81	24.91
Thailand										0.06	0.02	0.04	0.14	8.52	9.63
United Kingdom						0.02	0.01	0.99	1.07	7.93	19.24	27.40	33.70	34.62	36.63
United States							7.98	38.59	49.01	55.36	42.83	72.89	93.86	122.49	84.73
Others						0.02	0.07	1.00	0.76	1.91	8.86	15.56	37.15	43.92	40.34
Total						**0.38**	**9.05**	**60.52**	**91.58**	**133.37**	**222.49**	**285.89**	**416.02**	**636.74**	**568.26**

Market share of electric cars

Table A.7 Market share of electric cars (BEV and PHEV) by country, 2005-19 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia										0.1%	0.2%	0.1%	0.2%	0.4%	1.1%
Brazil												0.0%	0.0%	0.0%	0.1%
Canada								0.1%	0.2%	0.3%	0.4%	0.7%	1.0%	2.6%	3.0%
Chile															0.1%
China								0.1%	0.1%	0.4%	1.0%	1.4%	2.3%	4.6%	4.9%
Finland								0.1%	0.2%	0.4%	0.6%	1.2%	2.5%	4.7%	6.9%
France							0.1%	0.3%	0.5%	0.7%	1.2%	1.4%	1.8%	2.2%	2.8%
Germany							0.0%	0.1%	0.2%	0.4%	0.7%	0.7%	1.6%	2.0%	3.0%
India							0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%
Japan						0.1%	0.3%	0.5%	0.6%	0.7%	0.6%	0.6%	1.2%	1.1%	0.9%
Korea										0.1%	0.2%	0.3%	0.9%	2.3%	2.1%
Mexico								0.0%			0.0%	0.0%	0.1%	0.1%	0.1%
Netherlands							0.2%	1.0%	5.4%	3.9%	9.7%	5.9%	2.5%	6.3%	15.1%
New Zealand										0.1%	0.2%	0.6%	1.2%	2.1%	2.8%
Norway				1.5%	0.1%	0.7%	0.9%	3.2%	5.7%	14.5%	21.1%	26.6%	33.6%	49.1%	55.9%
Portugal						0.3%	0.1%	0.1%	0.2%	0.1%	0.6%	0.8%	1.9%	3.7%	5.7%
South Africa									0.0%		0.0%	0.1%	0.1%	0.0%	0.1%
Sweden							0.1%	0.3%	0.5%	1.4%	2.4%	3.4%	5.2%	7.0%	11.4%
Thailand														0.9%	1.7%
United Kingdom							0.1%	0.1%	0.1%	0.6%	1.1%	1.4%	1.8%	1.9%	2.8%
United States							0.2%	0.4%	0.7%	0.8%	0.7%	1.0%	1.3%	2.3%	2.1%
Others								0.1%	0.1%	0.3%	0.5%	0.6%	0.8%	1.0%	1.5%

Table A.8 Market share of battery electric cars by country, 2005-19 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia											0.1%	0.1%	0.1%	0.2%	0.8%
Brazil												0.0%	0.0%	0.0%	0.0%
Canada									0.1%	0.2%	0.3%	0.3%	0.5%	1.3%	1.9%
Chile															0.1%
China								0.1%	0.1%	0.2%	0.7%	1.0%	1.9%	3.4%	3.9%
Finland										0.2%	0.2%	0.2%	0.4%	0.6%	1.7%
France							0.1%	0.3%	0.5%	0.6%	0.9%	1.1%	1.2%	1.5%	1.9%
Germany							0.0%	0.1%	0.2%	0.3%	0.4%	0.3%	0.7%	1.1%	1.8%
India							0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%
Japan						0.1%	0.3%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.6%	0.5%
Korea										0.1%	0.2%	0.3%	0.9%	2.0%	1.9%
Mexico							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Netherlands							0.2%	0.2%	0.5%	0.7%	0.6%	1.1%	2.2%	5.5%	13.9%
New Zealand											0.1%	0.5%	1.0%	1.7%	2.2%
Norway				1.5%	0.1%	0.7%	0.9%	3.0%	5.4%	13.3%	16.1%	14.4%	17.8%	31.2%	42.4%
Portugal						0.3%	0.1%	0.1%	0.1%	0.1%	0.3%	0.4%	0.8%	1.9%	3.1%
South Africa									0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sweden							0.1%	0.1%	0.1%	0.4%	0.8%	0.7%	1.1%	1.7%	4.4%
Thailand														0.0%	0.1%
United Kingdom							0.1%	0.1%	0.1%	0.3%	0.4%	0.4%	0.5%	0.6%	1.5%
United States							0.1%	0.1%	0.3%	0.4%	0.4%	0.5%	0.7%	1.5%	1.5%
Others								0.1%	0.1%	0.2%	0.2%	0.2%	0.3%	0.5%	1.0%

Table A.9 Market share of plug-in hybrid electric cars by country, 2005-19 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia										0.1%	0.1%	0.1%	0.1%	0.2%	0.4%
Brazil												0.0%	0.0%	0.0%	0.1%
Canada								0.1%	0.1%	0.2%	0.2%	0.4%	0.5%	1.3%	1.1%
Chile															0.1%
China										0.1%	0.3%	0.3%	0.4%	1.1%	1.1%
Finland								0.1%	0.2%	0.2%	0.4%	1.0%	2.1%	4.1%	5.2%
France										0.1%	0.3%	0.4%	0.5%	0.7%	0.8%
Germany									0.1%	0.1%	0.3%	0.4%	0.9%	0.9%	1.3%
India															0.0%
Japan								0.2%	0.3%	0.3%	0.3%	0.2%	0.8%	0.5%	0.4%
Korea														0.3%	0.2%
Mexico													0.1%	0.1%	0.0%
Netherlands								0.9%	4.8%	3.2%	9.2%	4.9%	0.3%	0.8%	1.2%
New Zealand										0.1%	0.1%	0.1%	0.2%	0.5%	0.7%
Norway								0.2%	0.2%	1.1%	5.0%	12.3%	15.8%	17.9%	13.6%
Portugal									0.0%	0.0%	0.2%	0.4%	1.1%	1.7%	2.6%
South Africa												0.1%	0.0%	0.0%	0.0%
Sweden								0.2%	0.4%	1.1%	1.6%	2.7%	4.1%	5.3%	7.0%
Thailand														0.9%	1.6%
United Kingdom										0.3%	0.7%	1.0%	1.3%	1.3%	1.4%
United States							0.1%	0.3%	0.4%	0.4%	0.3%	0.4%	0.6%	0.8%	0.5%
Others							0.0%	0.0%	0.0%	0.1%	0.3%	0.4%	0.5%	0.5%	0.5%

Electric light-commercial vehicles (LCV)

Table A.10 Electric LCV stock (BEV and PHEV) by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia															
Brazil															
Canada											0.01	0.01	0.01	0.01	0.01
Chile										0.01	0.04	0.05	0.07	0.09	0.15
China						0.40	0.70	1.20	1.80	2.50	14.98	53.38	120.60	204.80	247.46
Finland													0.21	0.26	0.35
France	0.26	0.26	0.26	0.73	0.73	1.52	3.20	6.84	11.96	16.44	21.37	26.93	33.24	41.34	49.34
Germany	0.02	0.02	0.02	0.05	0.05	0.22	0.50	1.45	2.05	2.76	3.78	6.22	11.40	16.70	21.89
India															
Japan							0.85	3.34	5.40	6.45	7.27	7.60	7.92	8.20	8.72
Korea											0.02	0.03	0.03	0.03	0.03
Mexico															
Netherlands					0.05	0.09	0.16	0.49	0.67	1.26	1.46	1.63	2.21	3.20	4.50
New Zealand															0.78
Norway							0.00	0.01	0.01	0.56	1.27	1.97	2.92	4.81	6.72
Portugal													0.08	0.33	0.54
South Africa															
Sweden							0.01	0.28	0.50	0.78	1.11	1.15	1.23	3.71	3.95
Thailand		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
United Kingdom	0.10	0.25	0.46	0.66	0.84	1.08	1.35	1.78	2.10	2.92	4.70	5.83	6.45	7.63	10.95
United States						0.01	0.19	1.01	2.08	3.56	5.21	5.21	5.21	5.21	5.21
Others	0.26	0.26	0.26	0.61	0.61	0.83	1.01	1.90	2.79	4.01	5.78	7.97	9.94	13.29	17.37
Total	**0.63**	**0.79**	**1.00**	**2.06**	**2.28**	**4.15**	**7.96**	**18.31**	**29.36**	**41.26**	**66.99**	**117.97**	**201.51**	**309.59**	**377.97**

Table A.11 New electric LCV sales (BEV and PHEV) by country, 2005-19 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia															
Brazil															
Canada											0.01				
Chile							0.01	0.01	0.01	0.02	0.04	0.03	0.13		
China					0.27	0.12	0.33	0.52	0.55	0.72	12.46	38.40	67.22	84.21	42.65
Finland													1.00	1.67	0.06
France	0.26					0.80	1.68	3.65	5.11	4.49	4.93	5.56	6.31	8.10	8.00
Germany	0.02			0.03		0.17	0.28	0.95	0.60	0.72	1.02	2.45	4.47	5.29	5.19
India															
Japan							0.85	2.49	2.07	1.05	0.83	0.32	0.33	0.28	0.52
Korea											0.02	0.01			
Mexico															
Netherlands						0.04	0.07	0.34	0.18	0.59	0.20	0.17	0.51	1.01	1.30
New Zealand															0.07
Norway							0.00	0.00		0.56	0.71	0.70	0.94	1.89	1.91
Portugal							0.01	0.02	0.03	0.02	0.06	0.04	0.19	0.25	0.21
South Africa															
Sweden							0.01	0.28	0.21	0.28	0.33	0.05	0.20	2.47	1.38
Thailand															0.00
United Kingdom	0.10	0.16	0.20	0.21	0.18	0.24	0.27	0.44	0.32	0.82	1.04	1.13	0.99	1.18	3.32
United States						0.01	0.18	0.82	1.08	1.48	1.65				
Others	0.26			0.35		0.22	0.20	1.22	1.11	1.65	2.45	3.20	3.52	3.90	5.10
Total	**0.63**	**0.16**	**0.20**	**0.59**	**0.44**	**1.59**	**3.88**	**10.72**	**11.24**	**12.38**	**25.73**	**52.07**	**85.80**	**110.26**	**69.71**

Table A.12 Market share of electric LCVs (BEV and PHEV) by country, 2005-19 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia															
Brazil															
Canada											0.0%				
Chile							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%		
China					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	2.1%	3.6%	3.5%	2.2%
Finland													6.4%	10.8%	0.4%
France						0.2%	0.4%	1.0%	1.4%	1.2%	1.3%	1.3%	1.4%	1.8%	1.7%
Germany							0.1%	0.4%	0.3%	0.3%	0.4%	0.9%	1.6%	1.9%	1.8%
India															
Japan							0.1%	0.4%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.1%
Korea											0.0%	0.0%			
Mexico															
Netherlands						0.1%	0.1%	0.6%	0.3%	1.1%	0.4%	0.2%	0.7%	1.3%	1.7%
New Zealand															0.1%
Norway							0.0%	0.0%		1.9%	2.1%	2.0%	2.7%	5.3%	5.1%
Portugal							0.0%	0.1%	0.1%	0.1%	0.2%	0.1%	0.5%	0.6%	0.5%
South Africa															
Sweden							0.0%	0.7%	0.6%	0.7%	0.7%	0.1%	0.4%	4.4%	2.4%
Thailand															0.0%
United Kingdom						0.1%	0.1%	0.2%	0.1%	0.3%	0.3%	0.3%	0.3%	0.3%	0.9%
United States						0.0%	0.0%	0.1%	0.2%	0.2%	0.2%				
Others						0.0%	0.0%	0.2%	0.2%	0.3%	0.3%	0.4%	0.4%	0.7%	0.9%

Electric vehicle supply equipment stock

Table A.13 Publicly accessible chargers (slow and fast) by country, 2005-19 (number of chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia													476	727	1 930
Brazil														459	913
Canada								724	1 179	2 321	3 424	4 035	5 841	7 940	8 951
Chile							2	10	13	18	27	27	42	70	192
China										30 000	58 758	141 254	213 903	275 000	515 908
Finland									267	383	836	847	847	2 275	3 451
France								809	1 802	1 814	10 445	19 618	21 184	24 132	29 701
Germany								1 518	2 447	2 722	5 058	23 901	24 014	25 724	37 063
India												25	247	352	1 827
Japan						312	801	1 381	1 794	11 511	22 091	24 321	28 762	29 971	30 394
Korea							62	177	292	388	786	1 566	4 014	7 093	9 187
Mexico													1 502	2 706	2 706
Netherlands						400	400	2 803	5 791	11 981	18 008	32 524	33 282	36 671	50 153
New Zealand													104	293	369
Norway						2 800	3 123	3 746	4 607	5 293	5 513	7 541	9 209	12 371	9 436
Portugal							1 078	1 127	1 175	1 195	1 260	1 295	1 605	1 786	3 091
South Africa													124	239	246
Sweden								505	2 000	2 130	2 502	3 474	6 912	7 000	9 440
Thailand													96	96	817
United Kingdom							1 503	2 840	5 691	7 706	9 240	13 260	15 241	17 424	27 094
United States			333	339	373	482	3 903	11 695	14 990	20 115	31 674	38 168	43 037	54 500	77 358
Others							1 306	4 145	5 980	8 207	14 199	20 812	24 029	30 854	41 891
Total			**333**	**339**	**373**	**3 994**	**12 178**	**31 480**	**48 028**	**105 784**	**183 821**	**332 668**	**434 471**	**537 682**	**862 118**

Table A.14 Publicly accessible slow chargers by country, 2005-19 (number of chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia													436	666	1 679
Brazil														454	908
Canada								722	1 172	2 266	3 361	3 900	5 168	7 100	7 976
Chile							1	6	8	13	22	22	35	61	154
China										21 000	46 657	86 365	130 508	163 667	301 238
Finland									250	357	706	706	706	2 050	3 113
France								800	1 700	1 700	9 865	18 620	20 153	22 736	27 661
Germany								1 500	2 400	2 606	4 587	22 213	22 213	23 112	34 203
India													222	327	1 736
Japan										8 640	16 120	17 260	21 507	22 287	22 536
Korea							29	59	115	151	449	1 075	3 081	5 394	6 514
Mexico													1 486	2 677	2 677
Netherlands						400	400	2 782	5 770	11 860	17 786	32 120	32 875	35 852	49 324
New Zealand														89	131
Norway						2 800	3 105	3 688	4 511	5 185	5 185	7 040	8 292	11 145	5 466
Portugal							1 072	1 120	1 158	1 178	1 238	1 254	1 452	1 602	2 732
South Africa													87	158	113
Sweden								500	1 000	1 065	1 251	1 737	3 456	6 050	8 279
Thailand													88	88	748
United Kingdom							1 503	2 804	5 435	7 182	8 174	11 497	13 062	14 732	22 359
United States			333	339	373	482	3 903	11 695	14 990	20 115	28 150	35 089	39 601	50 258	64 265
Others							1 299	3 940	5 419	7 533	12 518	18 617	21 164	25 906	34 504
Total			**333**	**339**	**373**	**3 682**	**11 312**	**29 616**	**43 928**	**90 851**	**156 069**	**257 515**	**325 592**	**396 410**	**598 317**

Table A.15 Publicly accessible fast chargers by country, 2005-19 (number of chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia													40	61	251
Brazil														5	5
Canada								2	7	55	63	135	673	840	975
Chile							1	4	5	5	5	5	7	9	38
China										9 000	12 101	54 889	83 395	111 333	214 670
Finland									17	26	130	141	141	225	338
France								9	102	114	580	998	1 031	1 396	2 040
Germany								18	47	116	471	1 688	1 801	2 612	2 860
India												25	25	25	91
Japan						312	801	1 381	1 794	2 871	5 971	7 061	7 255	7 684	7 858
Korea							33	118	177	237	337	491	933	1 699	2 673
Mexico													16	29	29
Netherlands								21	21	121	222	404	407	819	829
New Zealand													104	204	238
Norway							18	58	96	108	328	501	917	1 226	3 970
Portugal							6	7	17	17	22	41	153	184	359
South Africa													37	81	133
Sweden								5	1 000	1 065	1 251	1 737	3 456	950	1 161
Thailand													8	8	69
United Kingdom								36	256	524	1 066	1 763	2 179	2 692	4 735
United States											3 524	3 079	3 436	4 242	13 093
Others							7	205	561	674	1 681	2 195	2 865	4 948	7 387
Total						**312**	**866**	**1 864**	**4 100**	**14 933**	**27 752**	**75 153**	**108 879**	**141 272**	**263 802**

References: Annex A

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Annex B.1.

Transport regulations and targets supporting passenger light-duty electric vehicle deployment

Country/ region	Key policy measures and targets*	Year announced	Source
Asia			
China (EV30@30 signatory)[a]	Proposal for tightened fuel-economy standard: 4 L/100 km by 2025 (New European Driving Cycle).	2019	Government of China (2019)
	Target of 5 million EV by 2020 (including 4.6 million PLDV).	2012	Government of China (2012)
	New electric vehicle (NEV)[b] mandate: 12% NEV credit sales in passenger cars by 2020.[c]	2016	Government of China (2018)
	By 2025, around 25% NEV (PHEV, BEV and FCEV) sales.	2019	MIIT (2019)
India (EV30@30 signatory)	CO_2 emissions standard of 113 gCO_2/km in 2022.	2015	Ministry of Power (2015)
	Target of 30% EV sales by 2030 across all modes.	2018	Government of India (2018)
Indonesia	2 200 EVs in PLDV by 2025.	2019	Market Research Indonesia (2019)
Japan (EV30@30 signatory)	Fuel-economy target of 19.7% reduction in specific fuel consumption by 2020 relative to 2009 and an additional 23.8% between 2020 and 2030.	2011 and 2019	ECCJ (2011), Government of Japan (2019a)
	2030 corporate average fuel economy standards: 25.4 km/L (+ 32% compared to 2016).	2019	Nippon (2019)
	CO_2 from transport to be reduced by 25% by 2030 (compared to 2015).	2018	METI (2018)
	Long-term goal (by the end of 2050) to reduce 80% of GHG emissions per vehicle produced by Japanese automakers.	2018	Government of Japan (2018)
	Target of 20-30% BEV and PHEV sales in PLDV by 2030, in addition to 30-40% HEV and 3% FCEV.	2018	Government of Japan (2018)
	By 2050, 100% sales of HEV, PHEV, BEV and FCEV.	2018	Government of Japan (2018)

Country/ region	Key policy measures and targets*	Year announced	Source
Korea	Targets of 430 000 BEV and 67 000 FCEV on the road by 2022.	2019	Government of Korea (2019)
	By 2030, 33% of new cars to be BEV or FCEV.	2019	Electrive (2019)
	Target of 80 000 FCEV taxis in 2040.	2019	Yonhap News Agency (2019)
Malaysia	Target of 100 000 electric PLDV stock in 2030.	2017	Government of Malaysia (2017)
Pakistan	By 2030, 30% of PLDV sales to be EV. By 2040, 90% of PLDV sales to be EV.	2019	ICCT (2020)
Sri Lanka	Replace all state-owned vehicles with BEV or HEV by 2025.	2017	Straits Times (2017)
	Private owners have until 2040 to replace their fossil fuel burning vehicles (including two/three-wheelers).	2017	Straits Times (2017)
Thailand	Target of 1.2 million EVs by 2036.	2016	Harman (2018)
Europe[d]			
European Union	From 2020: - EU average vehicle fleet emission target for new cars is 95 gCO_2/km. - Allocation of a specific emissions target for each manufacturer (EU wide) vehicle fleet.	2019	European Union (2019a)
	Emission standards for gCO_2/km of LDV, requiring 15% reduction between 2021 and 2025 and 37.5% reduction for cars and 31% for vans between 2021 and 2030.	2019	European Union (2019b)
	Revision of the Clean Vehicles Directive on public procurement, including minimum requirements of 17.6% in 2025 and 38.5% in 2030.	2019	European Parliament (2019)
	Target of 90% reduction in transport GHG emissions by 2050.	2019	European Green Deal (2019)
	Based on CO_2 targets, projection of 13 million zero- and low-emission vehicles by 2025.	2019	European Green Deal (2019)
Denmark	Target of 1 million electrified vehicles PLDV stock by 2030.	2018	Government of Denmark (2018a)
	2030: No sales of new diesel and petrol cars. 2035: Every new car to be ZEV.	2018	Government of Denmark (2018b)
Finland (EV30@30 signatory)	Target of 250 000 EV (BEV, PHEV, FCEV) stock in PLDV by 2030.	2017	Government of Finland (2017)

Country/ region	Key policy measures and targets*	Year announced	Source
France (EV30@30 signatory)	Multiply by five the sales of BEV in 2022 relative to 2017.	2018	Government of France (2018)
	Reach a fleet of 1 million BEV and PHEV in 2022.	2018	Government of France (2018)
	by 2023: - for PLDV: target of 500 000 PHEV and 660 000 BEV (including FCEV) - for LCV: target of 170 000 BEV, PHEV, FCEV.	2020	Government of France (2020)
	by 2028: - for PLDV: target of 1.8 million PHEV and 3 million BEV (including FCEV) - for LCV: target of 500 000 BEV, PHEV, FCEV.	2020	Government of France (2020)
	2040: No sales of new cars and vans using fossil fuels.	2019	Government of France (2019)
Germany	Target of 7-10 million EVs (BEV and FCEV) by 2030.	2019	Climate Action Programme 2030 (2019)
	All passenger vehicle sales to be ZEV by 2050.	2015	ZEV Alliance (2015)
Iceland	2030: Ban on new registrations of diesel and gasoline cars.	2018	Government of Iceland (2018)
Ireland	Target of 500 000 EVs in PLDV by 2030.	2018	Government of Ireland (2018)
	2030: ban on new ICE car registrations.	2020	Draft Scheme of New Climate Law (2020)
Italy	Expected stock of 6 million "electrically powered vehicles" in 2030 (including 4 million BEV).	2019	Integrated National Energy and Climate Plan (2019)
Netherlands (EV30@30 signatory)	Target to reduce national GHG emissions by 49% by 2030 relative to 1990 levels.	2019	National Climate Agreement (2019a)
	Target of 15 000 FCEVs by 2025 and 300 000 by 2030.	2019	National Climate Agreement (2019b)
	Target of 50% of taxis to be ZEVs by 2025.	2019	National Climate Agreement (2019a)
	Target of 100% ZEV sales in PLDVs by 2030.	2017	Kabinetsformatie (2017)
Norway (EV30@30 signatory)	2025: 100% ZEV sales in PLDVs and LCVs.	2016	Government of Norway (2016)
Poland	1 million EVs in PLDVs by 2025.	2016	Government of Poland (2016)
Portugal	Target of one-third of car stock to be ZEV by 2030.	2019	Mobi Summit (2019)
	2040: Proposed ICE ban.	2018	Publico (2018)

Country/ region	Key policy measures and targets*	Year announced	Source
Slovenia	Target of 17% EV stock in PLDVs by 2030.	2017	Novak (2017)
	2030: Targets of 100% EV sales in PLDV.	2017	Novak (2017)
Spain	Targets of 5 million EVs in LDVs, buses and two/three-wheelers in 2030.	2020	Government of Spain (2020)
	2040: No sales of PLDV emitting CO_2.	2020	Government of Spain (2020)
Sweden (EV30@30 signatory)	Targets of: - Reduce CO_2 emissions from transport by 70% in 2030 relative 2010 - Net zero GHG emissions by 2045.	2017	Government of Sweden (2017)
	No new petrol or diesel cars to be sold after 2030.	2019	Government of Sweden (2019)
United Kingdom (EV30@30 signatory)	Target of 50-70% EV sales in PLDVs by 2030.	2018	Government of the United Kingdom (2018)
	2035: Ban on sales of new ICE cars. HEVs and PHEVs could also be banned – ongoing consultation. (Previously planned for 2040, but currently being brought forward.)	2020	Government of the United Kingdom (2020)
North America			
Canada (EV30@30 signatory)	Annual reduction of CO_2 emissions per kilometre of 5% from 2017 to 2025 for PLDVs and 3.5% from 2017 to 2021 and 5% from 2022 to 2025 for light trucks.	2012	Government of Canada (2012)
	Targets of: - 825 000 ZEVs on the road by 2025 - 2.7 million ZEVs on the road by 2030 - 14 million ZEVs on the road by 2040.	2019	Government of Canada (2019)
	Targets of: - 10% ZEV sales in PLDVs from 2025 - 30% ZEV sales in PLDVs from 2030 - 100% ZEV sales in PLDVs from 2040.	2019	Government of Canada (2019)
	2040: 100% of sales to be ZEVs (BEV, PHEV or FCEV).	2019	Government of Canada (2019)
United States (selected states)	Targets of 3.3 million EVs in eleven states combined by 2025.[e]	2014	ZEV Program (2014)
	ZEV[f] mandate in ten states[g]: 22% ZEV credit sales in passenger cars and light-duty trucks by 2025.[h]	2016	ZEV Program (2014)
	California: 1.5 million ZEVs and 15% of effective sales by 2025, and 5 million ZEVs by 2030.	2016	State of California (2018), CARB (2016)
	All passenger vehicle sales to be ZEVs in ten states.[i]	2015	ZEV Alliance (2015)

Country/ region	Key policy measures and targets*	Year announced	Source
Other countries			
Cabo Verde	Targets of: - 100% of public authorities fleet to be EVs by 2030 - 35% of PLDV sales to be EV by 2025 - 70% of PLDV sales to be EV by 2030 - 100% of PLDV sales to be EV by 2035.	2019	Ministry of Industry, Trade and Energy (2019)
	Integral replacement of all ICE vehicles with EVs by 2050.	2019	Ministry of Industry, Trade and Energy (2019)
Colombia	Targets of: - 10% of vehicle sales to be ZEVs by 2025. - 600 000 EVs by 2030. - 100% of government fleet to be EVs by 2030.	2019	BC News (2019)
Costa Rica	Target of 37 000 EV stock in PLDVs by 2023.	2017	Government of Costa Rica (2017)
	- 25% of vehicle fleet to be electric by 2035. - 70% of taxis to be ZEV by 2035, 100% by 2050. - 100% sales of new LDVs to be ZEVs by 2050 (60% of the fleet of LDVs).	2019	Government of Costa Rica (2019)
Chile	Tenfold increase in EVs from 2017 by 2022.	2018	Government of Chile (2018)
	40% EV in PLDV by 2050.	2018	Government of Chile (2018)
Israel[1]	Targets of: - 177 000 EV stock in PLDVs by 2025. - 1.4 million EV stock in PLDVs by 2030.	2018	Government of Israel (2018)
	2030: All new vehicles to be powered by electricity or CNG.	2018	Government of Israel (2018)
South Africa	Target of 20% HEVs by 2030.	2012	Intended Nationally Determined Contribution (INDC) (2012)
New Zealand	Target of 64 000 EV stock in PLDVs by 2021.	2016	Government of New Zealand (2016)

Notes: L/100 km = litres per 100 kilometres; LDV = light-duty vehicles; PLDV = passenger light-duty vehicles; BEV = battery electric vehicles; LCV = light- commercial vehicles; HEV = hybrid electric vehicles; FCEV = fuel cell electric vehicles; ZEV = zero-emissions vehicle; ICE = internal combustion engine; gCO_2/km = grammes of carbon dioxide per kilometre; CNG = compressed natural gas.

[1] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the Organisation for Economic Co-operation and Development 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.

(a) Countries that joined the EV30@30 Campaign set a collective aspirational goal to reach 30% sales share for EVs across PLDV, LCV, buses and trucks modes by 2030 (CEM-EVI, 2018).

(b) New energy vehicle includes BEVs, PHEVs and FCEVs.

(c) The 12% NEV credit sales mandate includes multipliers depending on vehicle technology and range. Current NEV models are eligible for multipliers between 1 and 5.

(d) Several European countries also apply vehicle registration and circulation taxes differentiated on the basis of environmental performance (not included in this table).

(e) California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont and Washington.

(f) Zero-emission vehicle includes BEVs, PHEVs and FCEVs.

(g) This includes the eight states listed in note 6 plus Maine and New Jersey, which joined in 2016.

(h) The 22% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible for credits between 0.5 and 3.

(i) As part of ZEV Alliance members: California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont and Washington.

Annex B.2.

Transport regulations and targets supporting heavy-duty electric vehicle deployment

Country/ region	Key policy measures and targets	Year announced	Source
Asia			
China (EV30@30 signatory)[a]	Proposal to improve fuel economy of trucks by 15% by 2021 relative to 2015 levels.	2016	ICCT (2016)
	Target of 5 million EVs by 2020 (including 0.4 million buses and 0.2 million trucks).	2015	Government of China (2012)
India (EV30@30 signatory)	Target of 100% BEV share of purchases in urban buses by 2030.	2017	SIAM (2017)
	FAME Phase II[b] includes a purchase incentive scheme for electric buses.	2019	Government of India (2019)
Japan (EV30@30 signatory)	Fuel economy to be improved 13.4% by 2025 for heavy trucks and of 14.3% for buses relative to 2015 levels.	2019	Government of Japan (2019b)
Korea	Target of: - 40 000 FCEV buses by 2040 - 30 000 FCEV trucks by 2040.	2019	Yonhap News Agency (2019)
Malaysia	2 000 EVs in bus stock by 2030.	2018	Government of Malaysia (2017)
Pakistan	Buses: 50% of new sales to be EV by 2030 and 90% by 2040. Heavy-duty trucks: 30% of new sales to be EV by 2030 and 90% by 2040.	2019	ICCT (2020)
Europe			
European Union	CO_2 emission standards for new heavy-duty trucks to be reduced by 15% by 2025 and by 30% by 2030 (reference period: 2019/2020).	2019	Regulation (EU) 2019/1242
	Revision of the Clean Vehicles Directive including minimum requirements for urban buses (24-45% in 2025 and from 33% to 65% in 2030), and for trucks (6-10% in 2025 and 7% to 15% in 2030).	2019	European Union (2019c); European Parliament (2019)

Country/ region	Key policy measures and targets	Year announced	Source
France (EV30@30 signatory)	By 2023, target of 200 hydrogen heavy-duty vehicles (buses, MFT and HFT).	2020	Automobile Propre (2020)
	By 2028, target of 800 to 2 200 hydrogen heavy-duty vehicles (buses, MFT and HFT).	2020	Automobile Propre (2020)
Germany	Incentives for buses to switch to electric, hydrogen and biogas technologies.	2019	Climate Action Programme 2030 (2019)
Hungary	All public transport to be electric by 2029.	2019	Daily News Hungary (2019)
Ireland	Ban on sales of diesel-only buses in 2019. Target of 70% electric bus stock by 2035.	2018	Government of Ireland (2018)
Netherlands (EV30@30 signatory)	30% reduction of CO_2 emissions across the transport sector by 2030.	2019	National Climate Agreement (2019b)
	Target of 100% EV public bus share of purchases by 2025 and 100% EV public bus stock by 2030.	2016	Government of the Netherlands (2017)
	In 2025, target of 3 000 FCEV heavy-duty vehicles on the road.	2019	National Climate Agreement (2019b)
Norway (EV30@30 signatory)	Target of 100% EV share of purchases of urban buses by 2025. Target of 75% EV share of purchases of long distance buses and 50% in trucks by 2030.	2016	Government of Norway (2016)
Spain	Targets of 5 million EV in LDV, buses and two/ three-wheelers in 2030.	2020	Government of Spain (2020)
Sweden (EV30@30 signatory)	Targets of: - Reduction of CO_2 emissions from transport by 70% in 2030 relative to 2010. - Net zero GHG emissions by 2045.	2017	Government of Sweden (2017)
North America			
Canada (EV30@30 signatory)	Tighter GHG emissions standards for heavy-duty trucks from 2021 and increasing stringency up to 25% relative to 2017 in 2027.	2018	Government of Canada (2018)
United States	Fuel economy of heavy-duty trucks should be reduced by 30% by 2027 relative to 2010 levels.	2011	NHTSA (2011)
Other regions			
Cabo Verde	50% of EVs (new acquisitions) for urban transportation by 2025. 25% of heavy-duty trucks sales to be electric in 2030, 100% in 2035.	2019	Ministry of Industry, Trade and Energy (2019)

Country/ region	Key policy measures and targets	Year announced	Source
Chile	100% electric public transport sector by 2040.	2018	Electromovility Platform (2020)
Colombia	100% new public transport to be ZEV by 2035	2019	BC News (2019)
Costa Rica	Targets of: - 70% of buses to be zero emissions by 2035. - 100% of buses to be zero emissions by 2050.	2019	Government of Costa Rica (2019)

Notes: MFT = medium freight truck; HFT = heavy-freight truck. The Clean Vehicles Directive sets a minimum sale share for each European Union member state, while the range in this table is the EU range. Half of the target has to be fulfilled by zero-emissions buses (BEV and FCEV).

(a) Countries that joined the EV30@30 Campaign set a collective aspirational goal to reach 30% sales share for EV across PLDV, LCV, buses and trucks by 2030 (CEM-EVI, 2018).

(b) Faster Adoption and Manufacturing of Electric Vehicles.

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Abbreviations and acronyms

AC	alternating current
AFID	Alternative Fuels Infrastructure Directive
APBIIA	Automotive Power Battery Industry Innovation Alliance
APU	auxiliary power unit
ASEAN	Association of Southeast Asia Nations
B2C	business-to-customer
BEE	Bureau of Energy Efficiency
BEV	battery electric vehicle
BMS	battery management system
C2ES	Centre for Climate and Energy Solutions
CAD	Canadian dollar
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CCS	combined charging system
CEVS	Council for Electrified Vehicle Society
China	People’s Republic of China
CNG	compressed natural gas
CO_2	carbon dioxide
DC	direct current
DCFC	direct current fast charging
DfR	Design for Recycling
e-bike	electric-assist bicycle
e-buses	electric bus
EGTS	electric green taxi system
EPR	extended producer responsibility
ERS	electric road systems
ESCO	Energy Savings Company
e-scooter	electric scooter
EUR	Euro
EV	electric vehicle
EVI	Electric Vehicle Initiative
EVSE	electric vehicle supply equipment
FAME	Phase I of the Faster Adoption and Manufacturing of Electric Vehicles
FAME II	Phase II of the Faster Adoption and Manufacturing of Electric Vehicles
FCA	Fiat Chrysler Automobiles
FCEV	fuel cell electric vehicles
GBA	Global Battery Alliance
GBP	United Kingdom pound

GDP	gross domestic product
GHG	greenhouse gas
GVW	gross vehicle weight
HDV	heavy duty vehicle
HEV	hybrid electric vehicles
HFT	heavy freight trucks
HRS	hydrogen refuelling stations
HSL	Helsinki Region Transport
ICC	International Code Council
ICE	internal combustion engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
INR	Indian Rupees
IPCEI	Import Project of Common European Interest
ISO	International Organization for Standardization
JPY	Japanese yen
KPI	key performance indicator
KRW	Korean won
LCV	light-commercial vehicle
LEV	low-emission vehicle
LFP	iron phosphate
Li-ion	lithium-ion
LTO	and take-off cycles
MFT	medium freight truck
METI	Ministry of Economy, Trade and Industry
NCA	nickel cobalt aluminium oxide
NEMMP	National Electric Mobility Mission Plan
NEV	New Energy Vehicle
NMC	nickel manganese cobalt oxide
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
PLDV	passenger light-duty vehicle
PV	photovoltaic
RED	Red Metropolitana de Movilidad
SAFE	Safer Affordable Fuel-Efficient
SBG	Shenzhen Bus Group
SDG&E	San Diego Gas & Electric
SDS	Sustainable Development Scenario
SEK	Swedish Krona
STEPS	Stated Policies Scenario
SUV	sport utility vehicle
TCO	total cost of ownership

TRL	technology readiness levels
TRNC	Turkish Republic of Northern Cyprus
TTW	tank-to-wheel
US DOE	US Department of Energy
USD	United States Dollar
V1G	unidirectional controlled charging
V2G	vehicle-to-grid
WBTC	West Bengal Transport Corporation
WLTP	Worldwide Harmonised Light Vehicles Test Procedure
WTT	well-to-tank
WTW	well-to-wheel
ZETI	Zero-Emission Technology Inventory
ZEV	Zero Emission Vehicle

Units of measure

cc	cubic centimetres
gCO_2	grammes of carbon dioxide
gCO_2/km	grammes of carbon dioxide per kilometre
gCO_2/kWh	grammes of carbon dioxide per kilowatt hour
gCO_2-eq/pkm	grammes of carbon dioxide equivalent per passenger kilometre
Gt-CO_2	gigatonnes of carbon dioxide
GW	gigawatt
GWh	gigawatt-hours
kg CO_2-eq/kWh	kilogrammes of carbon dioxide equivalent per kilowatt-hour
kg CO_2-eq/Lge	kilogrammes of carbon dioxide equivalent per litres of gasoline equivalent
km	kilometres
km/L	kilometres per litre
kt	kilotonnes
kW	kilowatt
kWh	kilowatt-hours
kWh/100 km	kilowatt-hours per 100 kilometres
Lge	litres of gasoline equivalent
Lge/100 km	litres of gasoline equivalent per 100 kilometres
Lge/100 m	litres of gasoline equivalent per 100 metres
Mb/d	million barrels per day
Mt CO_2	million tonnes of carbon dioxide
Mtoe	million tonnes of oil equivalent
MW	megawatt
Nm^3/h	normal cublic metres per hour
pkm	passenger-kilometres
TEU	twenty-foot equivalent units
t CO_2	tonnes of carbon dioxide

t CO_2-eq	tonnes of carbon dioxide equivalent
TW	terawatt
TWh	terawatt-hours
Wh/kg	Watt-hours per kilogrammes
Wh/L	Watt-hours per litre

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