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Global EV Outlook 2019

Scaling-up the transition to electric mobility

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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. 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 features a specific analysis of the performance of electric cars and competing powertrain options in terms of greenhouse gas emissions over their life cycle. As well, it discusses key challenges in the transition to electric mobility and solutions that are well suited to address them. This includes vehicle and battery cost developments; supply and value chain sustainability of battery materials; implications of electric mobility for power systems; government revenue from taxation; and the interplay between electric, shared and automated mobility options.

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This report was collectively developed by (in alphabetical order): Till Bunsen; Pierpaolo Cazzola; Léa d'Amore; Marine Gorner; Sacha Scheffer; Renske Schuitmaker; Hugo Signollet; Jacopo Tattini and Jacob Teter. Leonardo Paoli (University of Cambridge) also provided extensive contributions.

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Highlights

- Electric mobility is expanding at a rapid pace. In 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car sales. The People's Republic of China remains the world's largest electric car market, followed by Europe and the United States. Norway is the global leader in terms of electric car market share.

- Policies play a critical role. Leading countries in electric mobility use a variety of measures such as fuel economy standards coupled with incentives for zero- and low-emissions vehicles, economic instruments that help bridge the cost gap between electric and conventional vehicles and support for the deployment of charging infrastructure. Increasingly, policy support is being extended to address the strategic importance of the battery technology value chain.

- Technology advances are delivering substantial cost cuts. Key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants. Other solutions include the redesign of vehicle manufacturing platforms using simpler and innovative design architecture, and the application of big data to right size batteries.

- Private sector response to public policy signals confirms the escalating momentum for electrification of transport. In particular, recent announcements by vehicle manufacturers are ambitious regarding intentions to electrify the car and bus markets. Battery manufacturing is also undergoing important transitions, including major investments to expand production. Utilities, charging point operators, charging hardware manufacturers and other power sector stakeholders are also boosting investment in charging infrastructure.

- These dynamic developments underpin a positive outlook for the increased deployment of electric vehicles and charging infrastructure. In 2030, in the New Policies Scenario, which includes the impact of announced policy ambitions, global electric car sales reach 23 million and the stock exceeds 130 million vehicles (excluding two/three-wheelers). In the EV30@30 Scenario, which accounts for the pledges of the EVI EV30@30 Campaign to reach 30% market share for electric vehicles (EVs) by 2030 (excluding two/three-wheelers), EV sales reach 43 million and the stock is more than 250 million. Projected EV stock in the New Policies Scenario would cut demand for oil products by 127 million tonnes of oil equivalent (Mtoe) (about 2.5 million barrels per day [mb/d]) in 2030, while with more EVs in the EV30@30 Scenario the reduced oil demand is estimated at 4.3 mb/d. Electricity demand to serve EVs is projected to reach almost 640 terawatt-hours (TWh) in 2030 in the New Policies Scenario and 1 110 TWh in the EV30@30 Scenario.

- On a well-to-wheel basis, greenhouse gas (GHG) projected emissions from EVs will continue to be lower than for conventional internal combustion engine (ICE) vehicles. In the New Policies Scenario, GHG emissions of the EV fleet reach almost 230 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq) in 2030, offsetting about 220 Mt CO_2-eq emissions. In the EV30@30 Scenario, the assumed trajectory for power grid decarbonisation is consistent with the IEA Sustainable Development Scenario and further strengthens GHG emission reductions from EVs.

- An average battery electric car and plug-in hybrid electric car using electricity characterised by the current global average carbon intensity (518 grammes of carbon-dioxide equivalent per kilowatt-hour [g CO_2-eq/kWh]) emit less GHGs than a global average ICE vehicle using gasoline over their life cycle. But the extent ultimately depends on the power mix: CO_2 emissions savings are significantly higher for electric cars used in countries where the power generation mix is dominated by low-carbon sources. In countries where the power generation mix is dominated by coal, hybrid vehicles exhibit lower emissions than EVs.

- The EV uptake and related battery production requirements imply bigger demand for new materials in the automotive sector, requiring increased attention to raw materials supply. Traceability and transparency of raw material supply chains are key instruments to help address the criticalities associated with raw material supply by fostering sustainable sourcing of minerals. The development of binding regulatory frameworks is important to ensure that international multi-stakeholder co-operation can effectively address these challenges. The battery end-of-life management – including second-life applications of automotive batteries, standards for battery waste management and environmental requirements on battery design – is also crucial to reduce the volumes of critical raw materials needed for batteries and to limit risks of shortages.

- Absent adjustments to current transport-related taxation schemes, the increasing uptake of electric vehicles has the potential to change the tax revenue base derived from vehicle and fuel taxes. Gradually increasing taxes on carbon-intensive fuels, combined with the use of location-specific distance-based charges can support the long-term transition to zero-emissions mobility while maintaining revenue from taxes on transportation.

Executive summary

Electric mobility continues to grow rapidly. In 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car registrations. The People's Republic of China (hereafter "China") remained the world's largest electric car market, followed by Europe and the United States. Norway was the global leader in terms of electric car market share (46%). The global stock of electric two-wheelers was 260 million by the end of 2018 and there were 460 000 electric buses. In freight transport, electric vehicles (EVs) were mostly deployed as light-commercial vehicles (LCVs), which reached 250 000 units in 2018, while medium electric truck sales were in the range of 1 000-2 000 in 2018. The global EV stock in 2018 was served by 5.2 million light-duty vehicle (LDV) chargers, (540 000 of which are publicly accessible), complemented by 157 000 fast chargers for buses. EVs on the road in 2018 consumed about 58 terawatt-hours (TWh) of electricity (largely attributable to two/wheelers in China) and emitted 41 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq), while saving 36 Mt CO_2-eq compared to an equivalent internal combustion engine (ICE) fleet.

Policies continue to have a major influence on the development of electric mobility. EV uptake typically starts with the establishment of a set of targets, followed by the adoption of vehicle and charging standards. An EV deployment plan often includes procurement programmes to stimulate demand for electric vehicles and to enable an initial roll-out of publicly accessible charging infrastructure. Fiscal incentives, especially important as long as EVs purchase prices are higher than for ICE vehicles, are often coupled with regulatory measures that boost the value proposition of EVs (e.g. waivers to access restrictions, lower toll or parking fees) or embedding incentives for vehicles with low tailpipe emissions (e.g. fuel economy standards) or setting zero-emissions mandates. Policies to support deployment of charging infrastructure include minimum requirements to ensure EV readiness in new or refurbished buildings and parking lots, and the roll-out of publicly accessible chargers in cities and on highway networks. Adoption of standards facilitates inter-operability of various types of charging infrastructure.

Technology developments are delivering substantial cost reductions. Advances in technology and cost cutting are expected to continue. Key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants. The dynamic development of battery technologies as well as recognition of the importance of EVs to achieve further cost reductions in the broad realm of battery storage has put the strategic relevance of large-scale battery manufacturing in the limelight of policy attention.

Other technology developments are also expected to contribute to cost reductions. These include the possibility to redesign vehicle manufacturing platforms using simpler and innovative design architecture that capitalise on the compact dimensions of electric motors, and that EVs have much fewer moving parts than ICE vehicles. As well as the use of big data to customise battery size to travel needs and avoid over sizing the batteries, which is especially relevant for heavy-duty vehicles.

The private sector is responding proactively to the policy signals and technology developments. An increasing number of original equipment manufacturers (OEMs) have declared intentions to electrify the models they offer, not only for cars, but also for other modes of road transport. Investment in battery manufacturing is growing, notably in China and Europe. Utilities, charging point operators, charging hardware manufacturers and other stakeholders in the power sector are also increasing investment in the roll-out of charging infrastructure. This takes place in an environment that is increasingly showing signs of consolidation, with several acquisitions by utilities and major energy companies.

Global EV Outlook 2019 explores the future development of electric mobility through two scenarios: the New Policies Scenario, which aims to illustrate the impact of announced policy ambitions; and the EV30@30 Scenario, which takes into account the pledges of the Electric Vehicle Initiative's EV30@30 Campaign to reach a 30% market share for EVs in all modes except two-wheelers by 2030. In the New Policies Scenario in 2030, global EV sales reach 23 million and the stock exceeds 130 million vehicles (excluding two/three-wheelers). In the EV30@30 Scenario, EV sales and stock nearly double by 2030: sales reach 43 million and the stock numbering more than 250 million. China maintains its world lead with 57% share of the EV market in 2030 (28% excluding two/three-wheelers), followed by Europe (26%) and Japan (21%). In the EV30@30 Scenario, EVs account for 70% of all vehicle sales in 2030 (42% excluding two/three-wheelers) in China. Almost half of all vehicles sold in 2030 in Europe are EVs (partly reflective of having the highest tax rates on fossil fuels). The projected share of EVs in 2030 in Japan is 37%, over 30% in Canada and the United States, 29% in India, and 22% in aggregate of all other countries. With the projected size of the global EV market (in particular cars), the expansion of battery manufacturing capacity will largely be driven by electrification in the car market. This supports increasing consensus that the electrification of cars will be a crucial driver in cutting unit costs of automotive battery packs.

The projected EV stock in the New Policies Scenario would cut demand for oil products by 127 million tonnes of oil equivalent (Mtoe) (about 2.5 million barrels per day [mb/d]) in 2030, while with more EVs the in the EV30@30 Scenario the reduced oil demand is estimated at 4.3 mb/d. Absent adjustments to current taxation schemes, this could affect governments' tax revenue base derived from vehicle and fuel taxes, which is an important source of revenue for the development and maintenance of transport infrastructure, among other goals. Opportunities exist to balance potential reductions in revenue, but their implementation will require careful attention to social acceptability of the measures. In the near term, possible solutions include adjusting the emissions thresholds (or the emissions profile) that define the extent to which vehicle registration taxes are subject to differentiated fees (or rebates), adjustments of the taxes applied to oil-based fuels and revisions of the road-use charges (e.g. tolls) applied to vehicles with different environmental performances. In the longer term, gradually increasing taxes on carbon-intensive fuels, combined with the use of location-specific distance-based approached can support the long-term transition to zero-emissions mobility while maintaining revenue from transport taxes. Location-specific distance-based charges are also well suited to manage the impacts of disruptive technologies in road transport, including those related to electrification, automation and shared mobility services.

Electricity demand from EVs in the New Policies Scenario is projected to reach almost 640 terawatt-hours (TWh) in 2030 (1 110 TWh in the EV30@30 Scenario), with LDVs as the largest electricity consumer among all EVs. Since EVs are expected to become more relevant for power systems, it is important to ensure that their uptake does not impede effective power system management. Slow chargers, which can provide flexibility services to power systems, are estimated to account for more than 60% of the total electricity consumed globally to charge EVs in both scenarios in 2030. Since buses account for the largest share of fast charging demand, concentrating these consumption patterns to low demand periods such as at night can constructively impact the load profile in a power system.

Policies and market frameworks need to ensure that electric mobility can play an active role in increasing the flexibility of power systems. By providing flexibility services, electric mobility can increase opportunities for integration of variable renewable energy resources into the generation mix, as well as reducing cost associated with the adaptation of power systems to increased EV uptake. Electricity markets should facilitate the provision of ancillary services such as grid balancing that are suitable for EV participation and allow for the participation of small loads through aggregators. To participate in demand response in the electricity market, aggregators should not face high transaction costs (including not only fees, but also other regulatory, administrative, or contractual hurdles) to be able to pool large numbers of small loads.

On a well-to-wheel basis, projected greenhouse gas (GHG) emissions from EVs by 2030 are lower at a global average than for conventional internal combustion engine (ICE) vehicles. In the New Policies Scenario, GHG emissions by the EV fleet reach roughly 230 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq) in 2030, offsetting emissions of about 220 Mt CO_{2}-eq that would have resulted from a fleet of ICE vehicles of equivalent size. In the EV30@30 Scenario, the assumed trajectory for power generation decarbonisation is consistent with the IEA Sustainable Development Scenario and further strengthens GHG emissions reductions from EVs compared with ICE vehicles.

At global level, battery electric cars (BEVs) and plug-in hybrid electric cars (PHEVs) using electricity characterised by the current global average carbon intensity of electricity generation (518 grammes of carbon-dioxide equivalent per kilowatt-hour [g CO_2-eq/kWh]) emit a similar amount of GHG as hybrid vehicles and less GHGs than a global average ICE vehicle using gasoline over their life cycle. The impact however differs strongly by country. CO_2 emissions savings are significantly higher for electric cars used in countries where the power generation mix is dominated by low-carbon sources and the average fuel consumption of ICE vehicles is high. In countries where the power generation mix is dominated by coal, very efficient ICEs, such as hybrid vehicles, exhibit lower emissions than EVs. In the future, the emissions reduction potential over the life cycle of EVs can rise further the faster electricity generation is decarbonised.

The EV uptake and related battery production requirements imply bigger demand for new materials in the automotive sector. The demand for cobalt and lithium is expected to significantly rise in 2030 in both scenarios. Cathode chemistries significantly affect the sensitivity of demand for metals, particularly cobalt. Both cobalt and lithium supplies need to scale up to enable the projected EV uptake. The scale of the changes in material demand for EV batteries also calls for increased attention to raw material supplies. The challenges associated with raw material supply relate primarily to the ramp-up of production, environmental impacts and social issues. Traceability and transparency of raw material supply chains are key instruments to help address some of these criticalities by fostering sustainable sourcing of minerals. The development of binding regulatory frameworks is important to ensure that international multi-stakeholder co-operation can effectively address these challenges. The battery end-of-life management is also crucial to reduce the dependency of the critical raw materials needed in batteries and to limit risks of shortages. Relevant policy options to address this are within the 3R framework (reduce, reuse and recycle) and specifically within the reuse and recycle components.

Findings and recommendations

Electric mobility is developing at a rapid pace

The global electric car fleet exceeded 5.1 million in 2018, up by 2 million since 2017, almost doubling the unprecedented amount of new registrations in 2017. The People's Republic of China (hereafter "China") remained the world's largest electric car market with nearly 1.1 million electric cars sold in 2018 and, with 2.3 million units, it accounted for almost half of the global electric car stock. Europe followed with 1.2 million electric cars and the United States with 1.1 million on the road by the end of 2018 and market growth of 385 000 and 361 000 electric cars from the previous year (Figure 1). Norway remained the global leader in terms of electric car market share at 46% of its new electric car sales in 2018, more than double the second-largest market share in Iceland at 17% and six-times higher than the third-highest Sweden at 8%.

Electric two/three-wheelers on the road exceeded 300 million by the end of 2018. The vast majority are in China. With sales in the tens of millions per year, the Chinese market for electric two-wheelers is hundreds of times larger than anywhere else in the world. In 2018, electric buses continued to witness dynamic developments, with more than 460 000 vehicles on the world's road, almost 100 000 more than in 2017.

In addition to conventional passenger vehicles, low-speed electric vehicles (LSEVs)[1] in 2018 were estimated at 5 million units, up almost 700 000 units from 2017. All LSEVs were located in China. Shared "free floating" electric foot scooters flourished very rapidly in 2018 and early 2019 in major cities around the world. These foot scooter schemes now operate in around 129 cities in the United States, 30 in Europe, 7 in Asia and 6 in Australia and New Zealand.

In freight transport, electric vehicles (EVs) were mostly deployed as light-commercial vehicles (LCVs), which reached 250 000 units in 2018, up 80 000 from 2017. Medium truck sales were in the range of 1 000-2 000 in 2018, mostly concentrated in China.

The global EV stock in 2018 was served by 5.2 million light-duty vehicle (LDV) chargers, (540 000 of which are publicly accessible), complemented by 157 000 fast chargers for buses.

The number of EV chargers continued to rise in 2018 to an estimated 5.2 million worldwide for light-duty vehicles (LDVs). Most are slow chargers (levels 1 and 2 at homes and workplaces), complemented by almost 540 000 publicly accessible chargers (including 150 000 fast chargers, 78% of which are in China). With the 156 000 fast chargers for buses, by the end of 2018 there were about 300 000 fast chargers installed globally.

The global EV fleet consumed an estimated 58 terawatt-hours (TWh) of electricity in 2018, similar to the total electricity demand of Switzerland in 2017. Two-wheelers continued to account for the largest share (55%) of EV energy demand, while LDVs witnessed the strongest growth of all transport modes in 2017-18. China accounted for 80% of world electricity demand for EVs in 2018. The global EV stock in 2018 emitted about 38 million tonnes of carbon-dioxide

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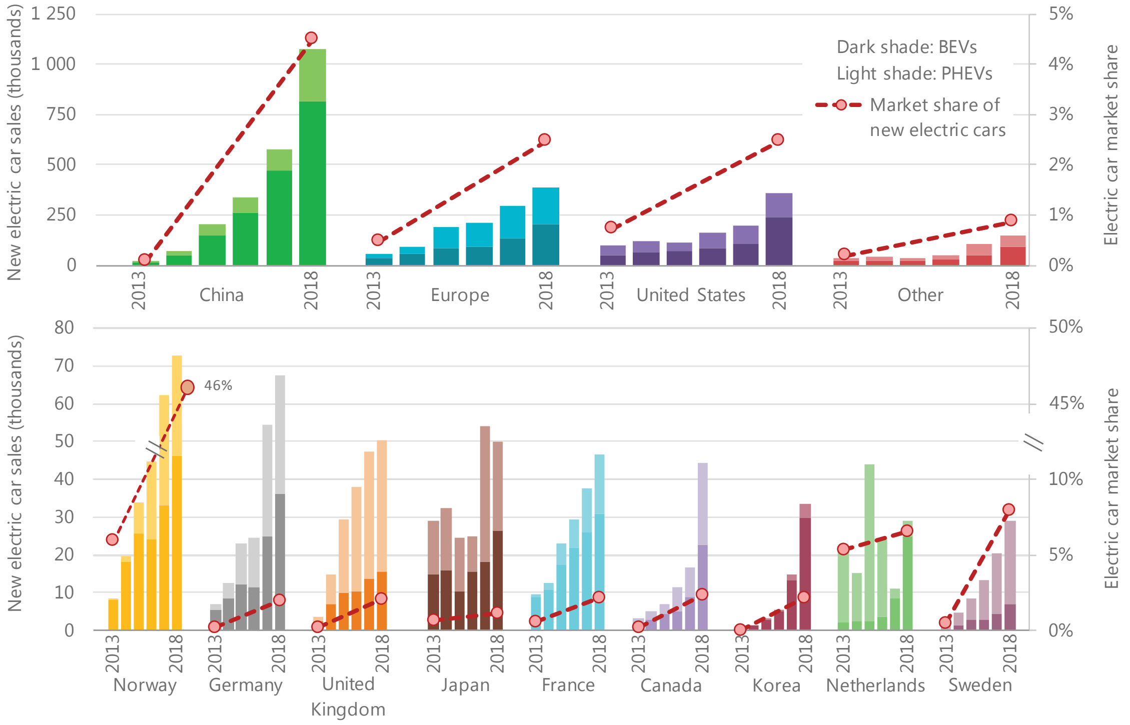
[1] LSEVs are passenger vehicles that are significantly smaller than electric cars, to the point that they are not subject to the same official approval and registration requirements as passenger cars.

equivalent (Mt CO_2-eq) on a well-to-wheel basis. This compares to 78 Mt CO_2-eq emissions that an equivalent internal combustion engine fleet would have emitted, leading to net savings from EV deployment of 40 Mt CO_2-eq in 2018.

Figure 1. Global electric car sales and market share, 2013-18



Notes: BEVs = battery electric vehicles; PHEVs = plug-in hybrid electric vehicles. Europe includes Austria, Belgium, Bulgaria, Croatia, Cyprus,[2] 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. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand.

Sources: IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019).

China has the largest number of electric car sales worldwide, followed by Europe and the United States.

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[2] 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".

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 the effective control of the Government of the Republic of Cyprus.

Policies have major influences on the development of electric mobility

Policy approaches to promote the deployment of EVs typically start with a vision statement and a set of targets. An initial step is the adoption of electric vehicle and charging standards. Procurement programmes kick-start demand and stimulate automakers to increase the availability of EVs on the market, plus provide impetus for an initial roll out of publicly accessible charging infrastructure. Another useful policy measure is to provide economic incentives, particularly to bridge the cost gap between EVs and less expensive internal combustion engine (ICE) vehicles as well as to spur the early deployment of charging infrastructure. Economic incentives are often coupled with other policy measures that increase the value proposition of EVs (such as waivers to access restrictions, lower toll or parking fees) which are often based on the better performance of EVs in terms of local air pollution. Measures that provide crucial incentives to scale up the availability of vehicles with low and zero tailpipe emissions include fuel economy standards, zero-emission vehicle mandates and the rise in the ambition of public procurement programmes. Regulatory measures related to charging infrastructure include minimum requirements to ensure "EV readiness" in new or refurbished buildings and parking lots, deployment of publicly accessible chargers in cities and on highway networks, and are complemented by requirements regarding inter-operability and minimum availability levels for publicly accessible charging infrastructure. So far only observed in Norway, when the EV and charging infrastructure deployment evolves, some policy measures may need to be adjusted as the markets and infrastructure mature. One example is how fuel and vehicle taxes are adjusted and their contribution to government revenue.

Front running countries such as those involved in the Electric Vehicles Initiative are already making progress from their initial phases of EV policy implementation (e.g. establishment of standards, public procurement and early charging roll out, economic incentives). Many of these countries have regulatory instruments in place and, to date, some advanced markets like Norway have started phasing out some aspects of their EV support policies (Table 1).

Table 1. EV-related policies in selected regions

		Canada	China	European Union	India	Japan	United States
Regulations (vehicles)	ZEV mandate	✓*	✓				✓*
	Fuel economy standards	✓	✓	✓	✓	✓	✓
Incentives (vehicles)	Fiscal incentives	✓	✓	✓	✓		✓
Targets (vehicles)		✓	✓	✓	✓	✓	✓*
Industrial policies	Subsidy	✓	✓			✓	
Regulations (chargers)	Hardware standards**	✓	✓	✓	✓	✓	✓
	Building regulations	✓*	✓*	✓	✓		✓*

		Canada	China	European Union	India	Japan	United States
Incentives (chargers)	Fiscal incentives	✓	✓	✓		✓	✓*
Targets (chargers)		✓	✓	✓	✓	✓	✓*

* Indicates that the policy is only implemented at a state/province/local level.

** Standards for chargers are a fundamental prerequisite for the development of EV supply equipment. All regions listed here have developed standards for chargers. Some (China, European Union, India) are mandating specific standards as a minimum requirement; others (Canada, Japan, United States) are not.

Notes: ZEV = zero-emissions vehicle. Check mark indicates that the policy is set at national level. Building regulations refer to an obligation to install chargers (or conduits to facilitate their future installation) in new and renovated buildings. Incentives for chargers include direct investment and purchase incentives for both public and private charging.

Key policy developments in 2018/19 include:

- In the European Union, several significant policy instruments were approved. They include fuel economy standards for cars and trucks and the Clean Vehicles Directive which provides for public procurement of electric buses. The Energy Performance Buildings Directive sets minimum requirements for charging infrastructure in new and renovated buildings. Incentives supporting the roll-out of EVs and chargers are common in many European countries.
- In China, policy developments include the restriction of investment in new ICE vehicle manufacturing plants and a proposal to tighten average fuel economy for the passenger light-duty vehicle (PLDV) fleet in 2025 (updating the 2015 limits). The use of differentiated incentives for vehicles based on their battery characteristics (e.g. zero-emissions vehicle credits and subsidies under the New Energy Vehicle mandate).
- Japan's automotive strategy through a co-operative approach across industrial stakeholders, aims to reduce 80% of greenhouse gas (GHG) emissions from vehicles produced by domestic automakers (90% for passenger vehicles) – including exported vehicles – to be achieved by 2050 with a combination of hybrid electric vehicles (HEVs), BEVs, PHEVs and fuel cell electric vehicles (FCEVs). Fuel economy standards for trucks were revised and an update of fuel economy standards for cars was announced.
- Canada outlined a vision for future EV uptake accompanied by very ambitious policies in some provinces, such as the zero-emissions vehicles (ZEVs) mandate in Quebec (similar to one in California). British Columbia announced legislation for the most stringent ZEV mandate worldwide: 30% ZEV sales by 2030 and 100% by 2040. This places Canada in a similar framework as the ten states in the United States that have implemented a ZEV mandate.
- India's announced the second phase of the "Faster Adoption and Manufacturing of Electric Vehicles in India" (FAME India) scheme. It reduces the purchase price of hybrid and electric vehicles, with a focus on vehicles used for public or shared transportation (buses, rickshaws and taxis) and private two-wheelers.
- In Korea, the scope of national subsidies for all low-carbon vehicle purchases increased from 32 000 vehicles in 2018 to 57 000 in 2019, adding to other policy instruments including public procurement, subsidies and rebates on vehicle acquisition taxes, reduced highway tolls and public parking fees). An ambition to scale up overseas sales of low-emission vehicles produced in Korea was also announced in 2018. It is accompanied by a goal to boost production capacity to more than 10% of all vehicles by 2022, and the use of financial support and loan guarantees to major industrial players.

Growing momentum on the policy front is also emerging in other countries. Key examples include Chile, which has one of the largest electric bus fleets in the world after China. Chile's aim is to electrify 100% of its public transport by 2040 and 40% of private transport by 2050. New Zealand also has high ambitions and has adopted a transition to a net-zero emissions economy by 2050. Both New Zealand and Chile joined the Electric Vehicles Initiative (EVI) in 2018.

Policies are crucial to ensure that electric mobility has positive impacts for flexibility in power systems. The use of EVs to provide flexibility services is a feature that has relevant implications to increase opportunities for the integration of variable renewable energy in the electricity generation mix and to reduce costs associated with the adaptation of the grid to increased EV uptake. This requires that power markets evolve in such a way as to include services (e.g. grid balancing) suitable for EV participation and to allow the participation of small loads for demand-side response through aggregators. The update of the European directive on common rules for the internal market in electricity, adopted in March 2019 by the European Parliament as part of the Clean Energy for All Europeans package, is an important milestone in this respect.

Technology advances are delivering substantial cost reductions for batteries

Recent technology progress for battery storage in general has been boosted by high demand for batteries in consumer electronics. Structural elements indicate not only that continued cost reductions are likely, but that they are strongly linked to developments underway in the automotive sector, i.e. changes in battery characteristics (chemistry, energy density and size of the battery packs) and the scale of manufacturing plants. It is expected that by 2025 batteries will increasingly use cathode chemistries that are less dependent on cobalt, such as NMC 811,[3] NMC 622 or NMC 532 cathodes in the NMC family or advanced NCA batteries.[4] This will lead to an increase in energy density and a decrease of battery costs, in combination with other developments (e.g. the availability of silicon-graphite chemistries for anode technology). Today most battery production is in plants that range from 3 to 8 gigawatt-hours per year (GWh/year) though three plants with over 20 GWh/year capacity are already in operation and five more are expected by 2023.

Strategic importance of the battery technology value chain is increasingly recognised

Policy support has been extended to the development of manufacturing capacity for automotive batteries. This reflects the dynamic development of battery technologies and the importance of EVs to achieve further cost reductions in battery storage for a multitude of applications. It also recognises the strategic relevance that large-scale battery manufacturing can have for industrial development (due to the relevance of its value chain in the clean energy transition).

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[3] NMC 811 is a cathode composition with 80% nickel, 10% manganese, and 10% cobalt.

[4] Lithium nickel cobalt aluminium oxide battery.

Examples of policy measures related to battery manufacturing include:

- In China, policy support aims to stimulate innovation and induce consolidation among battery manufacturers, giving preference to those that offer batteries with the best performance.
- In the European Union, the Strategic Action Plan for Batteries in Europe was adopted in May 2018. It brings together a set of measures to support national, regional and industrial efforts to build a battery value chain in Europe, embracing raw material extraction, sourcing and processing, battery materials, cell production, battery systems, as well as reuse and recycling. In combination with the leverage offered by its market size, it seeks to attract investment and establish Europe as a player in the battery industry.
- In countries with a smaller domestic market, as is the case for Japan and Korea, the policy support is to reinforce export markets.

In all regions, increasing attention is being given to solid state batteries. This is representative of the rapid pace of innovation in the automotive battery sector. In addition to optimised technical performance, innovation has a pivotal role in economic development. Strengthening capacities for innovation has played a central role in the growth dynamics of successful developing countries.

Other technology developments are contributing to cost cuts

Other developments to induce continued cost cuts include options to redesign vehicle manufacturing platforms to use simpler and innovative design architecture, taking advantage of the compact dimensions of electric motors and capitalising on the presence of much fewer moving parts in EVs than in ICE vehicles. This is in line with a recent statement from Volkswagen concerning the development of a new vehicle manufacturing platform to achieve cost parity between EV and ICE vehicles. Adapting battery sizes to travel needs (matching the range of vehicles to consumer travel habits) is also critical to reduce cost by avoiding "oversizing" of batteries in vehicles. For example, instruments allowing real-time tracking of truck positioning to facilitate rightsizing of batteries. Close co-operation between manufacturers to design purpose-built EVs are not only relevant for freight transport, but also in order to meet range, passenger capacity and cargo space requirements for vehicles used in shared passenger fleets (e.g. taxis and ride-sharing).

Technology is progressing for chargers, partly because of increasing interest in EVs for heavy-duty applications (primarily buses, but also trucks). Standards have been developed for high-power chargers (up to 600 kilowatts [kW]). There is growing interest in mega-chargers that could charge at 1 megawatt (MW) or more (e.g. for use in heavy trucks, shipping and aviation).

Private sector response confirms escalating momentum for electric mobility

The private sector is responding proactively to the EV-related policy signals and technology developments. Recently, German auto manufacturers such as Volkswagen announced ambitious plans to electrify the car market. Chinese manufacturers such as BYD and Yutong have been active in Europe and Latin America to deploy electric buses. European manufacturers such as Scania, Solaris, VDL, Volvo and others, and North American companies (Proterra, New Flyer) have been following suit. In 2018, several truck manufacturers announced plans to increase electrification of their product lines.

Battery manufacturing is undergoing important transitions, notably with increasing investment in China and Europe from a variety of companies, such as BYD and CATL (Chinese); LG Chem, Samsung SDI, SK Innovation (Korean) and Panasonic (Japanese). This adds to the already vast array of battery producers, which led to overcapacity in recent years, and confirms that major manufacturers have increased confidence in rising demand for battery cells, not least because major automakers such as BMW, Daimler and Volkswagen are looking to secure supply of automotive batteries.

Utilities, charging point operators, charging hardware manufacturers and other stakeholders in the power sector are increasing investment in charging infrastructure. This is taking place in a business climate that is increasingly showing signs of consolidation, with several acquisitions from utilities as well as major energy companies that traditionally focus on oil. This covers private charging at home, publicly accessible chargers at key destinations and workplaces, as well as fast chargers, especially on highways. Examples of investments covering various types of chargers come from ChargePoint, EDF, Enel (via Enel X), Engie (via EV-Box). Some utilities (e.g. Iberdrola), automakers and consortia including auto industry stakeholders (e.g. Ionity) focus mostly on highway fast charging.

Businesses are not only committing to increased EV uptake from a supply standpoint (vehicle availability or charger deployment), but also from a demand angle by committing to add EVs to their vehicle fleets. One of the most ambitious examples may be a pledge made by DHL to reach 70% clean operations of last-mile pick-ups and deliveries by 2025. This is part of a broader effort developed by the EV100 initiative led by The Climate Group.

Outlooks indicate a rising tide of electric vehicles

Dynamic developments in policy implementation and technology advances underpin the projections to 2030 in the New Policies Scenario, which aims to illustrate the consequences of announced policy ambitions. Projections in the EV30@30 Scenario are underpinned by proactive participation of the private sector, promising technology advances and global engagement in EV policy support. It is aligned with the goal of the EVI EV30@30 Campaign to achieve a 30% market share by 2030 for EVs in all modes except two-wheelers (where market shares are higher) (Figure 2).

In the New Policies Scenario, China leads with the highest level of EV uptake over the projection period: the share of EVs in new vehicle sales reaches 57% across all road transport modes (i.e. two-wheelers, cars, buses and trucks), or 28% excluding two/three-wheelers. It is followed by Europe, where the EV sales share reaches 26% in 2030,[5] and Japan, one of the global leaders in the transition to electric mobility with a 21% EV share of sales in 2030. In North America, growth is particularly strong in Canada (where EV market shares reach 29% by 2030), as well as in California and US states that have adopted zero-emissions vehicle (ZEV) mandates and/or have stated an intention to continue to improve vehicle fuel economy. Other parts of the United States are slower to adopt EVs, bringing the overall EV sales share to 8% of the US vehicle market in 2030.

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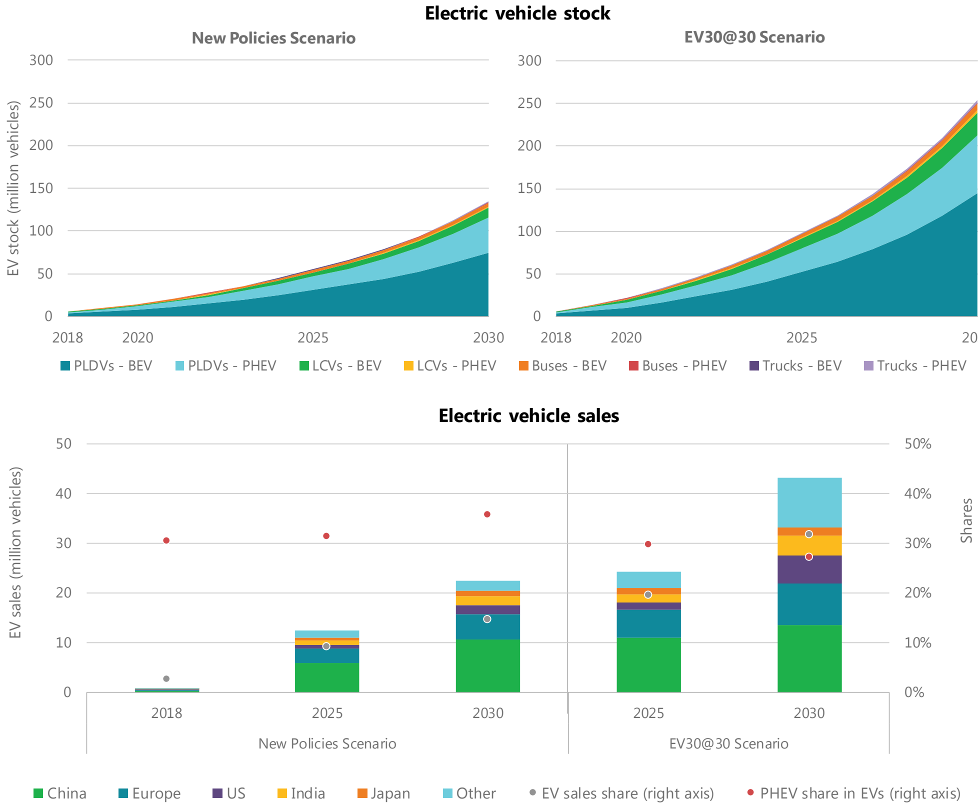
[5] Some individual European countries, such as Norway and Sweden, reach higher market shares than any other country or global region.

Figure 2. Future global EV stock and sales by scenario, 2018-30



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

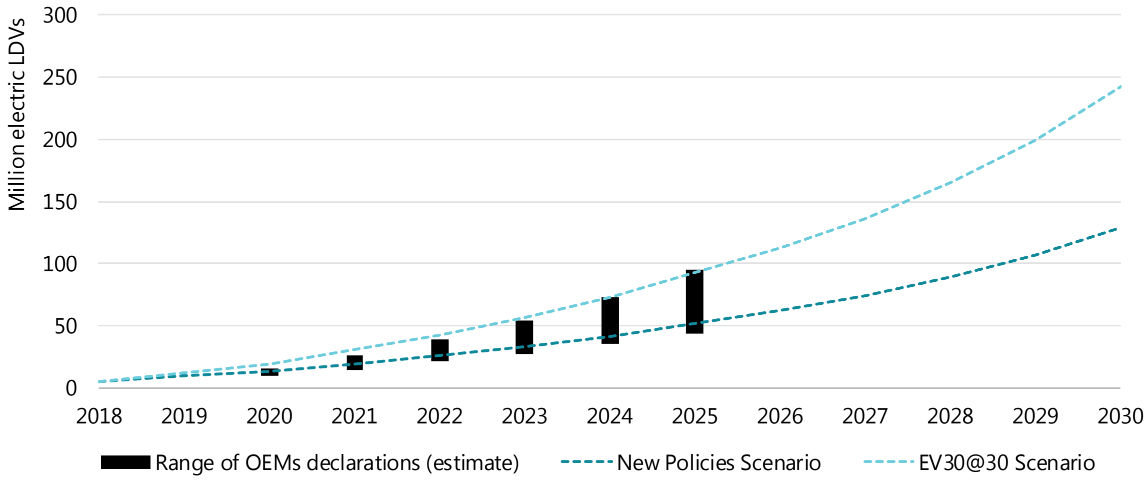
In 2030, global EV sales reach 23 million and the stock exceeds 130 million vehicles in the New Policies Scenario (excluding two/ three-wheelers). In the EV30@30 Scenario, EV sales and stock nearly double by 2030: sales reach 43 million and the stock is larger than 250 million.

In the EV30@30 Scenario, EVs make up 70% of all vehicle sales in China in 2030 (42% excluding two/three-wheelers). Almost half of all vehicles sold in 2030 in Europe are EVs, 37% in Japan, more than 30% in Canada and United States, 29% in India and 22% in other countries, taken together.

The electric car targets announced by automobile manufacturers align closely with the stock projections in the New Policies Scenario in 2020. In 2025, the auto industry targets range between the projections of the New Polices Scenario and of the EV30@30 Scenario (Figure 3).

Expansion of automotive battery manufacturing capacity will largely depend on the evolution of electrification in car markets. This is due to the number of electric cars sold that far exceeds sales volumes of other modes (except two-wheelers), and the size of their battery packs, which are much larger for cars than for two-wheelers. There is growing consensus that the electrification of cars will be a pivotal pillar to reduce unit cost of automotive battery packs. Thanks to their instrumental role to facilitate the availability of energy storage at lower costs, EVs are also likely to be a crucial step for the transition to a cleaner energy system.

Figure 3. Projected global electric car stock compared with OEM targets (2020-25)



Note: The cumulative sales shown in this figure are based on OEMs announcements on the number of EVs deployed in a target year and then extrapolating these values for the following years using a range of assumptions. The number of electric vehicles deployed by each OEM in its target year is calculated taking into account three possible inputs: i) an absolute target value of EV sales given by an OEM; ii) a target value expressed in terms of models deployed; or iii) a targeted percentage of the OEM sales.

OEM targets are close to the stock projections of the New Policies Scenario in 2020 and lie between the projections of the New Polices Scenario and of the EV30@30 Scenario in 2025.

Electric cars save more energy than they use

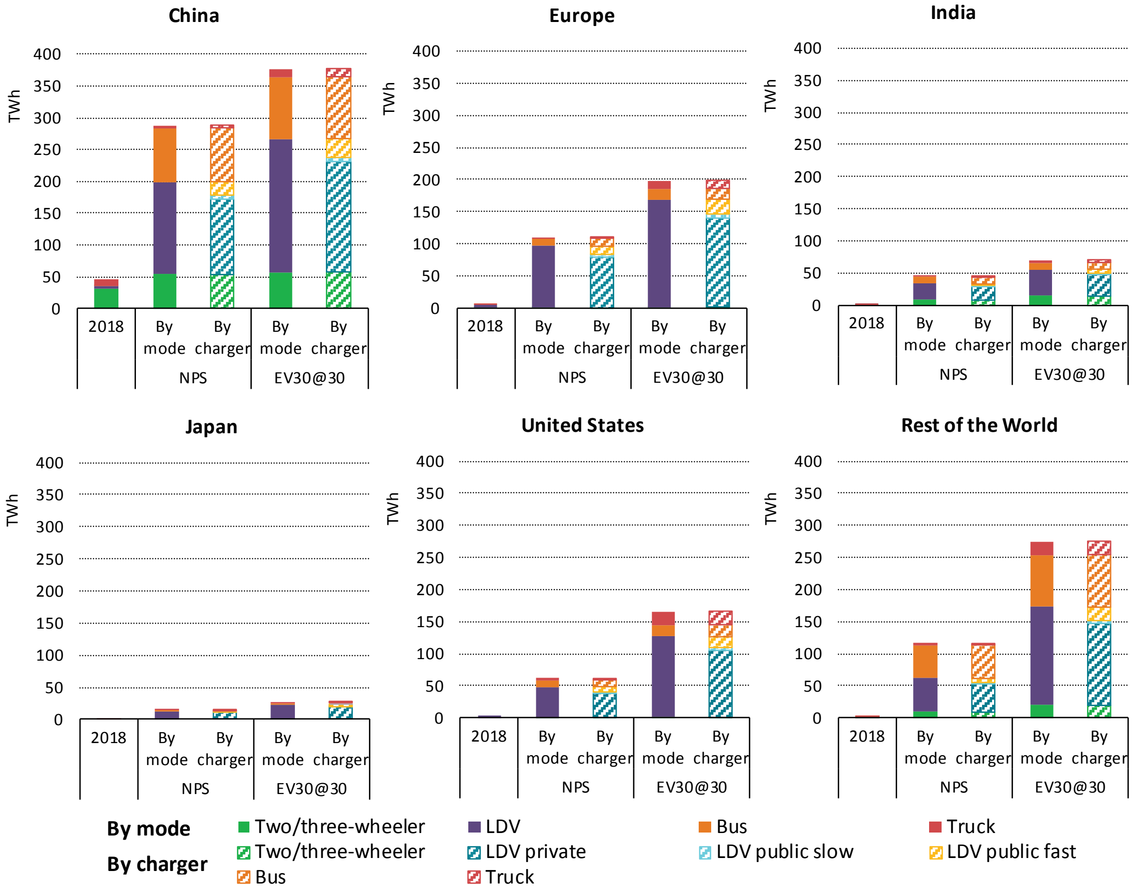
Projected growth of EVs across all modes will impact growth in oil demand for road transport. In the New Policies Scenario, the projected global EV stock is estimated to avoid 127 million tonnes of oil equivalent (Mtoe) (around 2.5 million barrels per day [mb/d]) of oil product demand in 2030. In the EV30@30 Scenario, the EV stock displaces 215 Mtoe (4.3 mb/d) of oil product demand in 2030.

On the other hand, electricity demand to serve EVs is expected to experience significant growth. In the New Policies Scenario, electricity demand from the global EV fleet is projected to reach almost 640 TWh in 2030 (Figure 4). This is more than a ten-fold increase compared to 2018 levels (58 TWh) and, altogether, it is equivalent to the combined final electricity consumption of France and Spain in 2016. In the EV30@30 Scenario, the larger volume of the global EV fleet leads to 1 110 TWh of electricity demand in 2030, nearly double the amount of the New Policies Scenario.

In the New Policies Scenario, light-duty vehicles become the largest electricity consumers among all road modes, surpassing two/three-wheelers in 2020. In 2030, LDVs account for about 60% of the total, followed by buses (26%), two/three-wheelers (12%) and trucks (2%). In the EV30@30 Scenario, LDVs represent the lion's share of electricity demand from EVs in 2030 (65%), followed by buses (20%).

Electricity demand projected in both scenarios suggests that EVs are going to be much more relevant for power systems than they have been in the past. With uncontrolled charging, EVs could drive incremental needs for peak power generation and transmission capacity. Understanding the extent to which power systems can be impacted depends on total annual electricity demand EVs, the impact of daily charging patterns on load profiles, location power levels used for charging.

Figure 4. EV electricity demand by region, mode, charger and scenario, 2018 and 2030



Notes: NPS = New Policies Scenario; EV30@30 = EV30@30 Scenario; LDV = light-duty vehicle.

In the columns with results by type of charger, green and blue correspond to slow chargers; red, yellow and orange correspond to fast chargers.

Main assumptions: 20% higher annual mileage for EVs than for conventional ICE vehicles. Fuel consumption (in kilowatt-hours per kilometre): 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. Ranges indicate the variation across countries. Charging losses are 5% and the share of electric driving for PHEVs is 70% of the annual mileage in 2030.

Source: IEA analysis developed with the IEA Mobility Model.

Global electricity demand from EVs is close to 640 TWh in 2030, concentrated in China and Europe in the New Policies Scenario and more widespread in the EV30@30 Scenario. Slow charging is the means that accounts for the largest share of electricity consumed by EVs.

Slow chargers (mostly private LDV chargers) account for more than 60% of the total electricity consumed globally to charge EVs in both the New Policies and the EV30@30 scenarios (shares differ region-by-region, as they depend on the extent of the uptake of EVs across transport modes). This is beneficial to power system management, since slow charging comes with opportunities for EVs to provide flexibility services to power markets, provided that controlled EV charging is in place. As fast charging demand is highest for buses in both scenarios, concentrating these charging events at night when electricity demand is lower could help flatten the overall shape of a power demand curve.

Controlled EV charging is well suited to contribute to increased flexibility in power systems. This feature has positive implications for the increasing contribution of variable renewable energy in a power generation mix and can also address grid stability issues. Features include:

- EVs can minimise impacts on load profiles of power systems by managing their charging patterns to coincide with low demand periods.
- EVs have potential to provide ultra-short-term demand response to a power system when required (e.g. frequency control), leverage the properties of EV batteries to allow very fast and precise response to control signals, as well as the ability to shift demand across time periods.
- EV batteries can store energy that may be used for other purposes than powering the vehicle, thanks to the opportunities offered by vehicle-to-grid and similar technologies (e.g. vehicle-to-home).

Electricity markets should facilitate the provision of ancillary services such as grid balancing in which EVs are among the potential participants, and allow for the participation of small loads through aggregators. To participate in demand response in the electricity market, it is important to minimise the transaction costs (including not only fees, but also other regulatory, administrative or contractual hurdles) to make it easier for aggregators to pool small loads.

EVs avoid GHG emissions if the electricity mix is not carbon-intensive

The well-to-wheel (WTW) GHG emissions from the EV fleet are determined by the combined evolution of the energy used by EVs and the carbon intensity of electricity generation. Today, based on the global average carbon intensity of power generation, WTW emissions from a global average EV are lower than from a global average ICE vehicle powered by liquid and gaseous fuel blends. In the New Policies Scenario, GHG emissions by the EV fleet are projected at roughly 230 Mt CO_2-eq in 2030, but would be almost double (450 Mt CO_2-eq) if the equivalent vehicle fleet was powered by ICE powertrains. In the EV30@30 Scenario, in which the accelerated deployment of EVs is coupled with a trajectory for power generation decarbonisation consistent with the IEA's Sustainable Development Scenario, the projected EV fleet emits around 230 Mt CO_2-eq in 2030, while an equivalent ICE vehicle fleet would emit about 770 Mt CO_2-eq. The rapid decarbonisation of power generation envisioned in the EV30@30 Scenario is important to limit the increase of GHG emissions from the rapid growth in the EV stock in the EV30@30 Scenario. Without these measures, WTW GHG emissions from the EV fleet in the EV30@30 Scenario would be around 340 Mt CO_2-eq by 2030.

Whether or not EVs deliver net benefits in terms of GHG emissions savings ultimately depends on the emissions that occur throughout the entire value chain, i.e. over the life cycle of EVs compared with other options. Overall, when accounting for the scale-up of battery manufacturing facilities (compatible with state-of-the-art plants, and in line with those that are assumed to be scaled up in the New Policies and EV30@30 scenarios) and assuming the current global average carbon intensity of power generation (518 g CO_2/kWh, including losses), a mid-sized global average BEV and a plug-in hybrid electric car emit less than an average global ICE vehicle using gasoline on a life-cycle basis (Figure 6).[6] The extent of the impact differs depending on the size of the ICE vehicle.

Net savings are larger for BEV cars with smaller batteries and therefore lower driving ranges. GHG emissions of BEVs using electricity characterised by the current global average carbon intensity are similar to those of fuel cell electric vehicles (FCEVs) using hydrogen produced from

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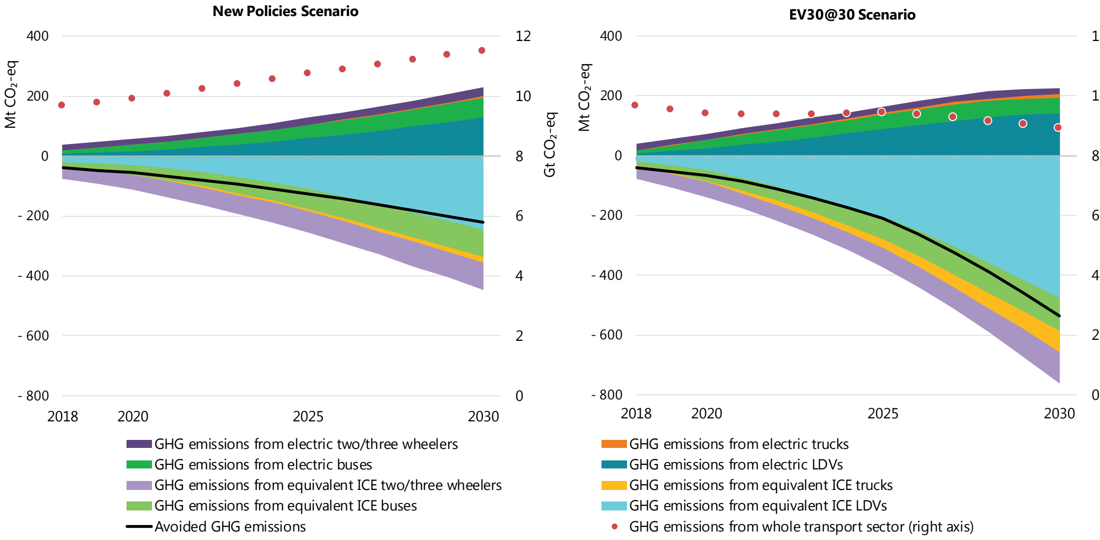
[6] This assessment considers 150 000 km over ten years of vehicle life.

steam methane reforming and to those of hybrid electric vehicles (HEVs) using gasoline. On average, the capacity of BEV cars to deliver net GHG emission savings in comparison with plug-in hybrid cars depends on the size of the battery pack.

Figure 5. Well-to-wheel net and avoided GHG emissions from EVs by mode and total GHG emissions from the transport sector, 2018-30



Notes: Mt CO_2-eq = million tonnes of carbon-dioxide equivalent; Gt CO_2-eq = gigatonnes of carbon-dioxide equivalent. Positive values are net emissions from the global EV fleet. Negative values are avoided emissions due to the global EV fleet, calculated as the difference between the emissions from an equivalent ICE fleet and the EV fleet. The WTW GHG emissions from the EV stock are determined in each country/region modelled as electricity consumption from the EVs times the carbon intensity of the power system from the IEA *World Energy Outlook* for the New Policies Scenario and its Sustainable Development Scenario for the EV30@30 Scenario. The WTW GHG emissions for the equivalent ICE fleet are those that would have been emitted if the EV fleet was instead powered by ICE vehicles with diesel and gasoline shares and fuel economies representative of each country/region in each year.

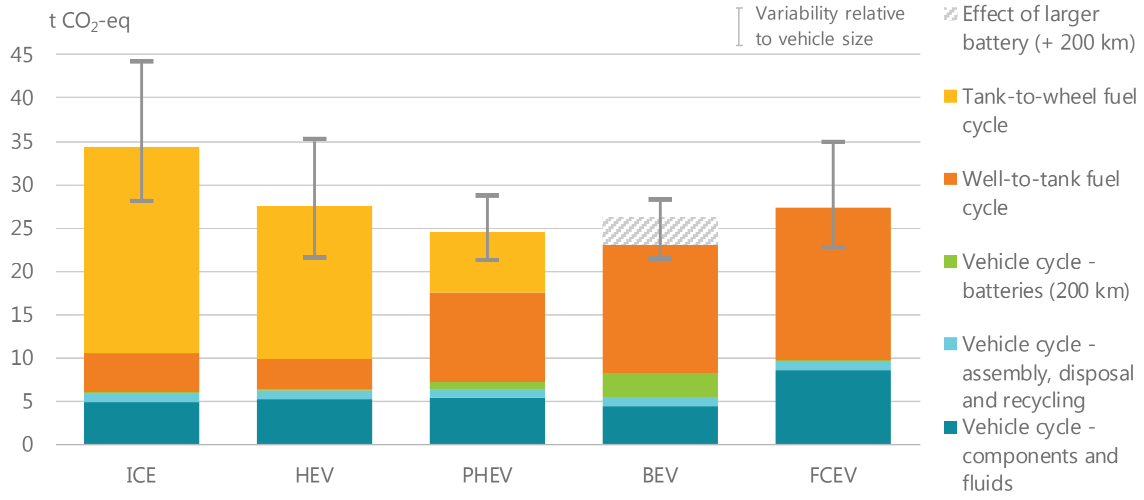
Sources: IEA analysis developed with the IEA Mobility Model; carbon intensities from the IEA *World Energy Outlook 2018*.

Electric vehicles reduce WTW GHG emissions by half from an equivalent ICE fleet in 2030, offsetting 220 Mt CO_2-eq in the New Policies Scenario and 540 Mt CO_2-eq in the EV30@30 Scenario.

In the large vehicle segment, EVs save more GHG emissions compared to ICE vehicles having similar characteristics. This is due to the higher fuel economy penalty related to the heavier weight of ICE vehicles in comparison with EVs.

The biggest emissions reduction potential over the vehicle life cycle of EVs is in the decarbonisation of power generation systems. Today, net savings are higher in countries where the carbon intensity of the generation mix is low. Moving forward, this can be a significant advantage for BEVs and PHEVs over other powertrain technologies if electricity generation decarbonises at a rapid pace. Nevertheless, as carbon intensities vary across power systems and regions, the capacity of EVs to deliver significant net GHG savings against competing technologies is not uniform across the world. In regions that largely rely on coal for electricity production, transitioning towards a lower carbon generation mix is essential to deliver GHG savings from the electrification of road transport.

Figure 6. Comparative life-cycle GHG emissions of a mid-size global average car by powertrain, 2018



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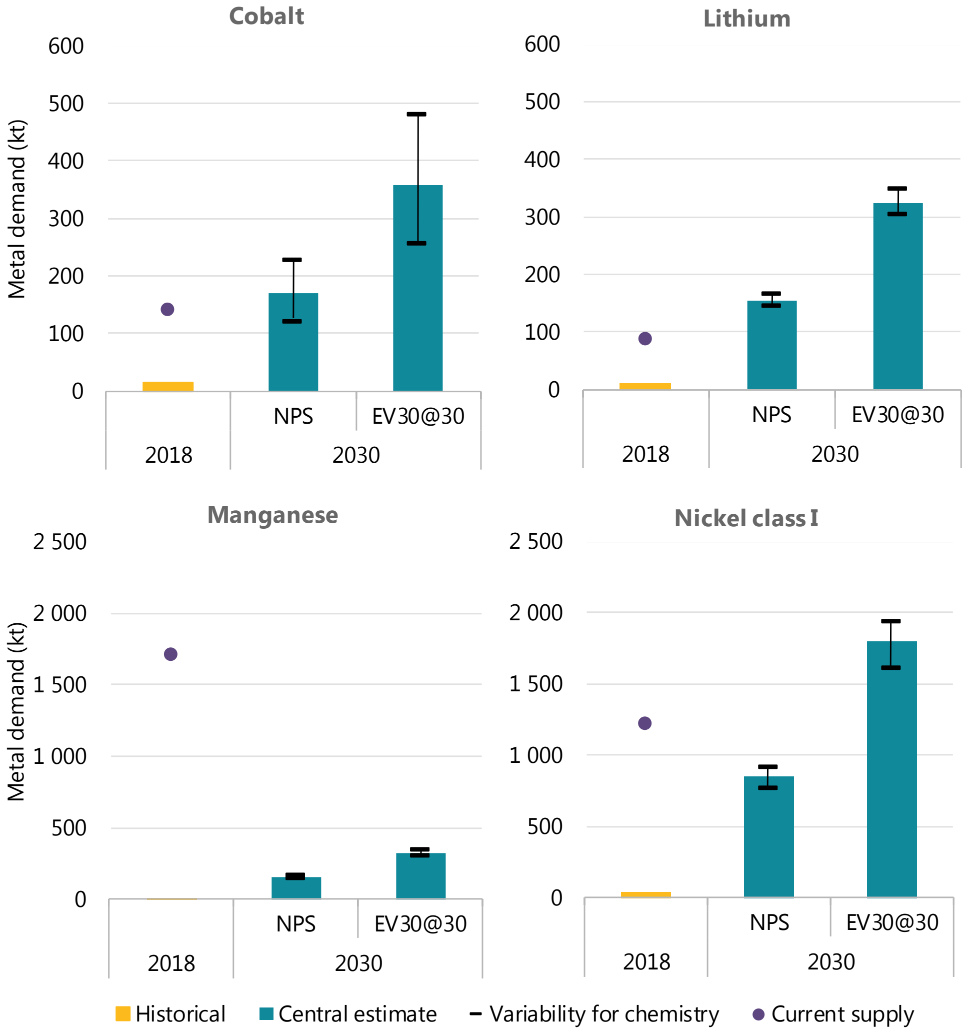
Notes: This figure portrays mid-size vehicles having similar performance with the exception of driving range. The BEV refers to a vehicle with 200 km range, the addition of the shaded area refers to a vehicle with 400 km range. The ranges suggested by the sensitivity bars represent the case of small cars (lower bound) and of large cars (upper bound) – for BEVs, the lower bound of the sensitivity bar represents a small car with a 200 km range, and the upper bound represents a large car with a 400 km range.The carbon intensity of the electricity mix is assumed equal to the global average (518 g CO_2/kWh). FCEVs are assumed to rely entirely on hydrogen produced from steam methane reforming. Other assumptions used to develop this figure are outlined in the Chapter 4 of the *Global EV Outlook 2019*, focused on life-cycle GHG emissions.

Today, the fuel cycle is the largest component of life-cycle GHG emissions of all powertrains. With a GHG intensity of electricity generation equal to the global average, EVs, FCEVs and HEVs all exhibit similar performance.

Electric mobility increases demand for raw materials

Increasing electric mobility and the ramp-up of related battery production imply increased larger demand for new materials in the automotive sector. The type of materials will vary according to advances in battery chemistry technologies. Assuming a mix of battery chemistry categories of 10% NCA, 40% NMC 622 and 50% NMC 811 for 2030, in the New Policies Scenario, the demand for cobalt increases to about 170 kilotonnes per year (kt/year), lithium demand to around 155 kt/year, manganese to 155 kt/year and class I nickel (>99% nickel content) to 850 kt/year. In the EV30@30 Scenario, the larger scale uptake of EVs implies volumes in 2030 more than twice as high as in the New Policies Scenario. For cobalt and lithium, these volumes mean that demand in the New Policies Scenario exceeds current supply. For class I nickel, this is the case in the EV30@30 Scenario. Cathode battery chemistry significantly affects the sensitivity of the demand of metals, particularly cobalt.

Figure 7. Increased annual demand for materials for batteries from deployment of electric vehicles by scenario, 2018-30



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Notes: NPS = New Policies Scenario, kt = kilotonnes.

Cobalt and lithium demand are expected to significantly rise in the period to 2030. Cobalt demand has the largest variation due to the type of cathode chemistry. Cobalt and lithium supplies need to scale up to enable the projected EV uptake.

Managing change in the material supply chain

For the automotive sector, the scale of the changes in materials demand for EV batteries requires increased attention for raw materials supply. It needs to anticipate and manage potential challenges and ensure the sustainability of supply chains. Besides cobalt, lithium, manganese and nickel, other materials affected include aluminium, graphite and copper. The main challenges associated with raw material supply include:

- Ramp-up of production, linked with the availability of raw materials, potential price spikes such as demand/supply unbalance and geographic concentration of extraction and/or refining.

- Environmental impacts, e.g. local pollution, supply chain related CO_2 emissions, landscape destruction, and impacts on local ecosystems and water resources.
- Social issues, including child labour and elements that influence the well-being of communities affected by mining operations.

Thanks to experiences developed with "conflict minerals" (3TGs: tin, tantalum, tungsten and gold), the traceability and transparency of raw materials supply chains emerged as a key instrument to help address some of the problems and foster sustainable sourcing of minerals. The Organisation for Economic Co-operation and Development (OECD) established high-level principles in the Due Diligence Guidance for Responsible Mineral Supply Chains, which are a significant resource to strengthen action in this regard. The Guidance provides detailed recommendations to help companies respect human rights and avoid contributing to conflict through their mineral purchasing decisions and practices. They are currently the leading international standard for responsible sourcing.

Experience developed to date suggests that the diversity of the issues for raw material supply also requires tailor-made solutions from both public and private stakeholders. For EVs, the risk of hazardous mining practices led automotive companies to increase their focus on raw material sourcing, for example through the development of cross-industry initiatives and on-the-ground actions to mitigate and address relevant issues. Nonetheless, there is still a gap between the efforts made to identify the risks and concrete actions to address them. The development of binding regulatory frameworks is important to ensure that the efforts started by the international multi-stakeholder co-operation underpinned by the OECD Due Diligence Guidance can effectively address these challenges. One example is the *devoir de vigilance* enforced in 2017 by the French government. It requires companies to establish and publish their strategies to identify and prevent environmental, human right abuses and corruption risks not only related to their work, but also for the activities of their suppliers and subsidiaries in France and abroad.

Battery end-of-life management is an important practice to reduce the need for critical raw materials and to limit risks of shortages. The options fall within the 3R framework (reduce, reuse, recycle), which, for batteries, is specifically for reuse and recycle. Regarding reuse, it is important to ensure that end-of-life regulations for automotive batteries allow their use in second-life application (rather than disposal and as an alternative to recycling). Regarding recycling, several countries have set standards for battery waste management including the recycling rate for the entire battery. These regulatory frameworks could be strengthened to ensure suitability with the electric mobility transition. There is also a need for the development of a regulatory framework for environmental requirements on the design phase of battery products. It should take account of the need to maximise the recovery of materials at battery end-of-life treatment while minimising costs, as well as the importance of thorough stakeholder consultation, given today's dynamic nature of battery technology developments.

Safeguarding government revenue from transport taxation

The efficiency advantage of EVs, combined with the energy switch to electricity from oil products, means that even at similar levels of taxation per unit of energy, BEVs and PHEVs are subject to lower charges per kilometre in comparison with ICE vehicles. The effect is stronger if the level of fuel taxation per unit of energy is not the same for oil products and electricity. This could become more common if fuels are taxed based on carbon content and if power generation progresses to low-carbon resources than the pool of liquid fuels used by road vehicles. A number of countries tax vehicle purchases on a basis differentiated for tailpipe GHG emissions per kilometre. Some offer purchase incentives for vehicles with the best performance at the expense of poor performing vehicles. Without adjustment to current taxation schemes, the expanding uptake of EVs and other zero-emissions enabling technologies could affect the tax revenue base derived from vehicle and fuel taxes.

In the near term, road-use policies and vehicle and energy taxes in transportation need to be ready to adapt to changes in the vehicle and fuel markets posed by the transition to electric mobility. Potential solutions include: adjustments of the emissions thresholds that define the extent to which vehicle registration taxes are subject to differentiated fees (or rebates); adjustments of the taxes applied to oil-based fuels; and revisions of the road-use charges applied to vehicles with varying environmental performances, such as tolls for the use of road infrastructure.

Revenue from transport charges and taxation are important to ensure continued availability of funding for the development and maintenance of transport infrastructure, among other goals. But they are also a burden on the budget of households, many of which rely on the use of cars for their economic activity. The long-term stabilisation of fiscal revenues from transportation cannot simply be based on marginal adjustments of vehicle and fuel taxes. This is due to the growing extent of the distortions that these adjustments would generate for the fiscal framework applied to the transport sector, as well as significant implementation challenges.[7] Gradually increasing taxes on carbon-intensive fuels, combined with the use of location-specific distance-based charges to recover infrastructure costs and to reflect the costs of pollution and congestion (something that requires the variation of distance-based charges depending on the extent of the pollution and congestion levels) can support the long-term transition to zero-emissions mobility while maintaining revenue from transport taxes. Location-specific distance-based charges are also well suited to manage the impacts of disruptive technologies in road transport, including those related to electrification, automation and shared mobility services. In all cases, careful consideration has to be made of the social implications of any taxation measure taken, so as to ensure public acceptability and that the needs of the poorer parts of the population are adequately addressed. Even if technological changes take time to percolate through the entire car fleet, early consideration of the implications for tax revenues is important. Thorough collaboration with stakeholders is required to reform tax regimes to the appropriate extent and depth for the longer term challenges posed by the transition to electric mobility.

New mobility modes have challenges and offer opportunities

Emerging changes related to connected, shared and autonomous mobility could significantly reshape road transport over the coming decades, with important implications for vehicle electrification. Close co-operation between EV manufacturers and fleet operators will be important to ensure that EVs can effectively meet the operational and technical requirements of shared mobility services and take advantage of their high vehicle utilisation rates. Ensuring that shared vehicles will be electric requires reducing financing barriers for the more expensive vehicle purchases (especially for vehicles owned by individuals, given that they are often capital constrained) and providing access to chargers. Combinations of policy measures and company

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[7] For example, a continued increase of taxes applied to oil products, without changes to taxes to electricity, would place a progressively unfair (and economically unsustainable) burden on vehicles that rely on oil products to recover costs capable to finance road transport infrastructure development and maintenance, given that this infrastructure would be shared by vehicle using multiple powertrain technologies. Compensating this by applying differentiated taxes for electricity used in transport and for other end-uses would not only lead to disproportionate levels of taxation on electricity (due to the much better energy efficiency of EVs), but also to significant implementation challenges, as this differentiation by end-use could be easily bypassed.

efforts could accelerate the electrification of fleets. For example, Uber's Clean Air Program in London works in concert with the city's Ultra Low-Emissions Zone to provide financial incentives to drivers to switch to EVs.

If (and when) fleets become highly automated, their utilisation rates may be higher than shared vehicles. Automation is likely to increase daily travel distances, which would require larger and more expensive battery packs or more frequent charging (and downtime). Autonomous cars may also require significant energy for on-board electronics, an issue that may be overcome by the rapid improvements in the efficiency of chips used in autonomous pilot vehicles, as it has already dropped from 3-5 kW in the first generation to less than 1 kW today.

Box 1. Policy considerations

Ensure a policy environment conducive to increasing EV uptake

Creating optimal circumstances for the uptake of EVs requires the adoption of a progressive set of measures that already have been proven in many countries.

- Countries that are starting to develop policy tools aiming to foster the deployment of electric mobility should establish a vision and a set of targets in parallel with the adoption of vehicle and charging standards.
- Procurement programmes are important instruments to kick-start demand for electric vehicles and stimulate automakers to increase the market availability of EVs. They also help to enable an initial roll-out of publicly accessible infrastructure.
- The use of appropriate economic incentives is effective, especially as long as electric vehicle purchase prices are higher than purchase prices for internal combustion engine vehicles. They are also relevant for the early deployment of charging infrastructure.
- Complementary measures often include regulatory instruments to increase the value proposition of electric vehicles, such as waivers to access restrictions. These are typically grounded on better environmental performance such as local air pollution.
- Minimum requirements to ensure the EV readiness in new or refurbished buildings and parking lots, and the deployment of publicly accessible chargers on highway networks and in cities are also crucial to achieve increased EV adoption and to boost consumer confidence.
- Scaling up EV adoption also requires measures that provide incentives to increase the availability of vehicles with zero- and low tailpipe emissions; crucial instruments include fuel economy standards, zero-emissions vehicle mandates and ratcheting up the ambition of public procurement programmes.

Anticipate long-term impacts of the transition to electric mobility

Without adjustment to the current taxation schemes, the growing uptake of electric vehicles may alter the tax revenue derived from vehicle and fuel taxes, reducing available funding (e.g. for the development and maintenance of transport infrastructure).

Gradually increasing taxes on carbon-intensive fuels, combined with the use of location-specific distance-based charges to recover infrastructure costs and to reflect the costs of pollution and congestion (which requires the variation of distance-based charges depending on the extent of the pollution and congestion levels) can help support the long-term transition to zero-emissions mobility while maintaining revenues from transport taxes. Location-specific distance-based charges are also well suited to manage the impacts of disruptive technological in road transport, including those related to electrification, automation and shared mobility services.

Even if technological changes take time to percolate through the entire car fleet, early consideration of the implications for tax revenues is important. Thorough preparation and discussion with all relevant stakeholders can help to develop appropriate reforms that consider the longer term challenges posed by transport decarbonisation as well as the needs of the population.

Maximise the GHG emissions reduction benefits of EVs

To ensure that the emissions reduction over the EV life cycle are maximised, governments need to ensure that policies aiming to support the uptake of EVs are coherently coupled with measures to decarbonise the electricity generation mix.

To prioritise the opportunities for EVs to increase of the flexibility of power systems for the integration of variable renewables in the electricity generation mix and to minimise costs associated with the adaptation of power systems, governments also need to ensure that power markets evolve to incorporate the services (e.g. grid balancing) that are suitable for EV participation. This requires the effective participation of small loads in demand-side response through aggregators in the electricity market. To enable this effective participation, government should ensure that transaction costs for aggregators (including not only fees, but also other regulatory, administrative and contractual hurdles) are reduced to be able to pool large number of small loads.

Increase policy support for the development of a battery industry value chain

The establishment of a policy framework that reduces investment risks (e.g. providing clear signals on the deployment of charging infrastructure, fuel economy standards, and zero- or low-emission mandates) is a prerequisite for the development of a battery industry value chain.

In addition to the development of policies that enable the mitigation of investment risks, governments should discuss key priorities to enable the scale up of capacity and investment with key industry players and stakeholders. Taking stock of the inputs from this dialogue, governments can effectively allocate funds to accelerate research and innovation, looking in particular at advanced lithium-ion and solid state battery technologies. Strengthened funding for battery manufacturing can be coupled with requirements regarding the sustainability of battery cell manufacturing, further improving the transparency of the raw material supply chains.

Scaling up the development of the battery industry value chain also requires investment to ensure that academic institutions and training centres are well equipped to close the skills gap. This is essential to enable the timely formation, development and strengthening of the professional profiles needed for the battery whole value chain.

Increase the attention on raw material supply

The scale of the increase in material demand for EV batteries calls for increased attention to raw material supply, anticipating and managing potential challenges and ensuring the sustainability of supply chains. Governments interested in fostering the development of a battery industry value chain can enable industry to access raw materials for batteries securing supplies from resource-rich countries or capitalising on the local availability of these resources. To address critical issues in the supply chains of raw materials, governments should work towards the improvement of their traceability and transparency.

The development of binding regulatory frameworks[8] will be important to support the efforts started by the international multi-stakeholder co-operation, underpinned by the OECD Due Diligence Guidance for responsible mineral supply chains.

End-of-life management of batteries is essential to reduce dependency on critical raw materials and to limit risks of shortages. There are policy options to manage this within the 3R (reduce, reuse and recycle) framework, specifically for batteries within the reuse and recycle elements. Regarding reuse, it is important to ensure regulations for end-of-life of automotive batteries enables their use in second-life applications (as opposed to disposal and as an alternative to recycling). Regarding recycling, several countries have set standards for battery waste management including the recycling rate for the entire battery. Governments need to strengthen these regulatory frameworks to ensure their suitability with the expected transition to EVs. The focus should move towards the development of requirements on the design phase for battery products that take into account the need to maximise the recovery of materials during end-of-life treatment of batteries while minimising costs. Thorough stakeholder consultation is important given the dynamic nature of battery technology advances.

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[8] One example is the *loi devoir de vigilance* adopted in 2017 by the French government. It forces companies to establish and publish their strategies to identify and prevent environmental, human right abuses and corruption risks not only for their own work, but also on their suppliers and subsidiaries' activities in France and abroad.

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.

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). 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.

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 2009 under the Clean Energy Ministerial. 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 2018-19 period include Canada, Chile, the People’s Republic of China (hereafter “China”), Finland, France, Germany, India, Japan, Mexico, Netherlands, New Zealand, Norway, Sweden and United Kingdom. Portugal was an observer, while the participation of the United States to EVI activities is being re-evaluated. Canada and China are the co-leads of the initiative. The International Energy Agency serves as the EVI co-ordinator.

For the development of EVI activities, the IEA secretariat co-operates with the IEA Technology Collaboration Programmes on Advanced Fuel Cells (AFC) and Hybrid and Electric Vehicle Technologies and Programmes (HEV). Other partners include: Argonne National Laboratory (ANL); C40; ClimateWorks Australia; ClimateWorks Foundation; Electrification Coalition; European Association for Electromobility (AVERE); Forum for Reforms Entrepreneurship and Sustainability (FORES) in Sweden; Global Environment Facility (GEF); GreenTechMalaysia; International Council for Clean Transportation (ICCT), which hosts the secretariat of the International Zero-Emission Vehicle Alliance); International Electrotechnical Commission (IEC); International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE); International Renewable Energy Agency (IRENA); Hewlett Foundation; King Mongkut's University of Technology Thonburi (Thailand); Lawrence Berkeley National Laboratory (LBNL); Mission 2020; Natural Resources Defence Council (NRDC); National Renewable Energy Laboratory (NREL) of the United States; Nordic Energy Research (NER); Partnership on Sustainable Low Carbon Transport (SloCaT); REN21; Rocky Mountain Institute (RMI); Swedish Energy Agency; The Climate Group; United Nations (UN) Environment (UN Environment); UN Human Settlements Programme (UN Habitat); UN Industrial Development Organization (UNIDO); World Resources Institute (WRI) and Urban Foresight.

EV 30@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 (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.

The campaign includes five implementing actions to help achieve the goal in accordance with the priorities and programmes of each EVI country. These include:

- Supporting the deployment of chargers and tracking progress.
- Galvanising public and private sector commitments for EV uptake in company and supplier fleets.
- Scaling up policy research and information exchanges.
- Supporting governments in need of policy and technical assistance through training and capacity building.
- Establishing the Global EV Pilot City Programme to achieve 100 EV-Friendly Cities over five years.

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.

To date, 39 cities are participating in the Global EV Pilot City Programme (Table 1.1).

Table 1.1. 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
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

Scope, content and structure of the report

This report analyses the development of the global EV market to end-2018. 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, despite data availability challenges.

The analyses are presented in five chapters.

- Chapter 1 looks at development of the EV market until the end of 2018, covering EV registrations (vehicle sales), EV stock estimates (mainly based on cumulative sales) and the availability and characteristics of the supply equipment they require.
- Chapter 2 looks at key determinants of the future prospects for EV uptake. It provides an overview of the current policy environment, followed by an analysis of the response of private sector stakeholders to policy signals, taking into account announcements made by automotive companies, battery manufacturers and stakeholders involved in the development of EV charging infrastructure.
- 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 New Policies Scenario aims to illustrate the consequences of announced policy ambitions. The EV30@30 Scenario represents the ambition of a global application of the EV30@30 Campaign and a progressive reduction of the carbon intensity of power generation, in line with the projections of the IEA Sustainable Development Scenario.
- Chapter 4 focuses on the assessment of GHG emissions over the life cycle of EVs, comparing performance with competing powertrain technologies.
- Chapter 5 looks at a number of areas where electric mobility may be facing important challenges. It suggests options to overcome them. It covers vehicle and battery cost developments, supply and value chain sustainability of battery materials, implications of electric mobility for power systems, government revenue from taxation and the interplay between electric, shared and automated mobility.

1. Status of electric mobility

Vehicle and charger deployment

Light-duty vehicles

Stock

Cars

The global stock of electric passenger cars[1] reached 5.1 million units in 2018, an increase of 63% from the previous year (Figure 1.1). This is similar to the year-on-year growth rate of 57% in 2017 and 60% in 2016. Battery electric vehicles (BEVs) account for 64% of the world's electric car fleet. (Box 1. 1 provides an update on fuel cell electric vehicle stocks).[2]

Around 45% of the world's electric car fleet was located in the People's Republic of China (hereafter "China") in 2018, compared to 39% in 2017. The stock of electric cars in China almost doubled between 2017 and 2018 to reach 2.3 million. In 2018, Europe[3] accounted for 24% of the global stock of electric cars at 1.2 million (of which 0.96 million were in European Union countries) and the United States accounted for 22% with 1.1 million. By far, Norway was the global leader in terms of stock share[4] in 2018, with 10% of electric cars in its total car stock. Even with the ongoing expansion of electric car sales, only five countries, including four Electric Vehicle Initiative (EVI) members, had an electric car stock share higher than 1% in 2018: Norway (10%)[5], Iceland (3.3%), Netherlands (1.9%), Sweden (1.6%)[6] and China (1.1%).[7]

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[1] In this report, an 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 that cannot be plugged-in (HEVs).

[2] This report focuses on BEVs and PHEVs. It excludes fuel cell electric vehicles (FCEVs) unless otherwise stated.

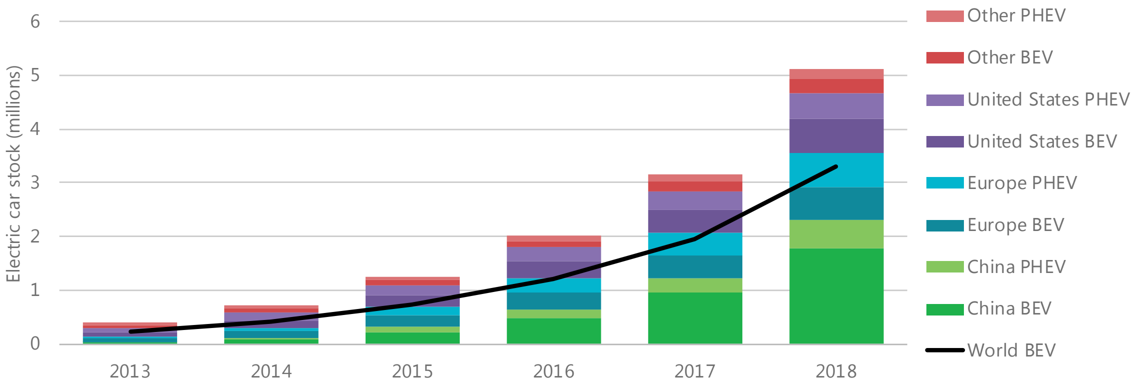
[3] In this report, the following countries are included in the "Europe" category: Austria, Belgium, Bulgaria, Croatia, Cyprus*, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom. * 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".
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 the effective control of the Government of the Republic of Cyprus.

[4] Market share is defined in this report as the share of new electric car registrations as a percentage of total new passenger light-duty car registrations, whereas stock share refers to the share of electric car stock as a percentage of total passenger light-duty car stock.

[5] In this analysis, EV sales and stock in Norway do not account for second-hand imported electric vehicles (20% of passenger car sales in 2018) to avoid double counting with exporting countries. This phenomenon 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 electric vehicles from other countries are also imported in Norway because of their cheaper price relative to new vehicles.

[6] In 2018 in Sweden, a fraction of the electric passenger cars registered did not reach Swedish roads, due to delays in PHEV deliveries and to exports to Norway. In this report, all the vehicles registered are accounted for in the EV stock.

Figure 1.1. Passenger electric car stock in main markets and the top-ten EVI countries



Notes: BEV = battery electric vehicle; PHEV = plug-in electric vehicle. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand.

Electric vehicle (EV) stocks by country are calculated as the sum of EV sales starting from the earliest data available in our time series (in most cases after 2011), i.e. without considering scrappage rates at this early market stage and excluding second-hand imports, unless access to sources with direct EV stock numbers was possible.

Stock shares are calculated based on EV stock by country and, for total rolling passenger light-duty vehicle stocks per country, on estimates developed with the IEA Mobility Model. The latter are estimated based on new vehicle registration data and the use of scrappage functions that account for a lifetime range of 13-18 years. Lifetimes at the low end of the range are used for countries with higher income levels (and vice versa).

Europe includes Austria, Belgium, Bulgaria, Croatia, Cyprus[8], 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. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand.

Sources: IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019); CAAM (2019).

There were 5.1 million electric passenger cars on the road worldwide by the end of 2018, of which 45% were in China.

Light-commercial vehicles

In addition to the 5.1 million passenger electric cars, there were almost 250 000 electric light-commercial vehicles (LCVs) on the road in 2018.[9] Electric LCVs are often part of a company or government fleet.[10] China had the largest electric LCV fleet worldwide (138 000 vehicles) in 2018, 57% of the global stock. The second-largest market for electric LCVs was Europe with 38% of the global stock and 92 000 vehicles. France (41 000 vehicles) and Germany (16 500 vehicles)

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[7] Further details on the method used for stock share calculation are in the notes for Figure 1.1

[8] 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".

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[9] LCV stocks in China for all years have been updated taking into account of information on the total of all commercial vehicle sales from the country submission and their distribution across LCVs, buses, minibuses, medium- and heavy-duty trucks from other sources (D1EV, 2018; Find800, 2019; EV Volumes, 2019).

[10] See Chapter 2, Box 2.2.

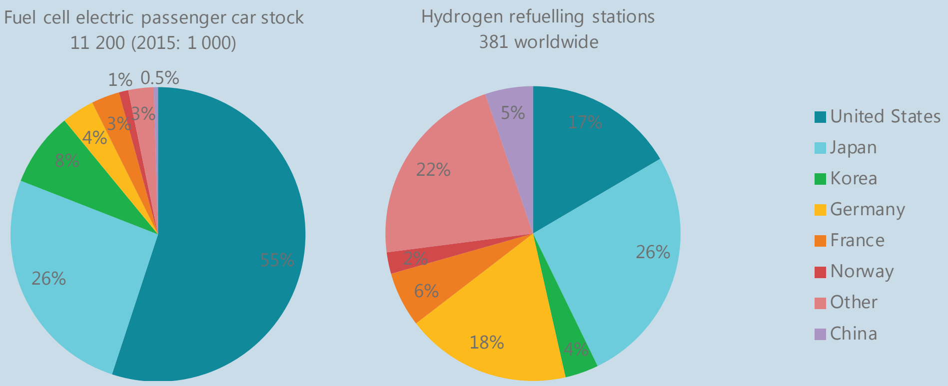
were the leading European countries in this regard. The vast majority of electric LCVs registered to date are BEVs (99%). This brings the number of electric light-duty vehicles (LDVs) on the road worldwide in 2018 to about 5.4 million.[11]

Box 1. 1. Fuel cell electric vehicles – stock and refuelling infrastructure

A fuel cell electric vehicle (FCEV) is a type of EV that uses hydrogen, via a fuel cell, to power an electric motor. In 2018, there were 11 200 fuel cell passenger cars worldwide. This is significantly lower than the number of BEVs and PHEVs in circulation in 2018 (1 FCEV per 460 PHEVs and BEVs).

More than half of the global FCEV passenger car fleet is located in the United States (6 200 cars), mainly in the state of California. Other countries with notable FCEV passenger car deployment include Japan (26%) and Korea (8%), which in 2018 were the only countries with more than 1 FCEV per 100 BEVs and PHEVs. In Europe, the number of FCEVs in circulation at the end of 2018 was 1 400 with the highest stock in Germany and France, as in 2017.

Fuel cell electric car stock and refuelling infrastructure by country, 2018



Sources: Data compiled by the IEA Technology Collaboration Programme on Advanced Fuel Cells 8 (2019), complemented with IEA analysis based on country submissions.

In addition to passenger cars, fuel cells have been used in various transport applications. For example, fuel cell buses, with the largest fleet in China with more than 400 buses by end-2018 (IEA AFC TCP, 2019). Similar deployments are observed in Europe (50 buses in 2017), United States, Korea and Japan (E4tech, 2018). Fuel cell technology also equips trucks, with more than 400 in China (IEA AFC TCP, 2019), highlighting the progress and interest of China in hydrogen for medium and heavy vehicles. In addition, two hydrogen trains with an 800 km range have been put into operation in Germany.

The hydrogen used to power the engine of FCEVs is stored in dedicated tanks at pressures of 35 to 70 megapascal. The vehicle refuelling process is similar to that of a gasoline vehicle. At the end of 2018, there were 381 hydrogen refuelling stations worldwide (public and non-public).

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[11] LDVs include both electric LCVs and electric passenger cars.

Sales and market share

Cars

Global electric car sales were close to 2 million in 2018, after having reached the 1 million mark in 2017 (Figure 1.2). This represents a year-on-year growth in electric car sales of 68% between 2017 and 2018, a strong rate comparable to 2015 (68%), after two years of weaker growth.

China remained the world's largest electric car market with nearly 1.1 million electric cars sold in 2018, up from almost 600 000 in 2017, and accounting for 55% of the global electric car market.[12] This increase contrasts with the overall decline in the total of all passenger car sales that took place in China, with respect to 2017, highlighting further the dynamism of its electric car market.

In 2018, Europe was the second-largest electric car market with sales of 385 000 units. The United States, the third-largest electric car market, had sales of 361 000 units.

In Europe, the increase in electric car sales in 2018 is 31% relative to 2017, a growth rate that is lower than 2017 relative to 2016 (41%) and below the global average. Europe hosts the countries with the largest penetration of electric car sales. Norway approached 50% in 2018, more than 2.5-times the next highest country, Iceland (17.2%) and six-times higher than Sweden, which has the third-highest (7.9%). In terms of sales volumes, Norway is followed by Germany, United Kingdom and France. Denmark and the Netherlands,[13] where sales had declined in 2017, rebounded strongly in 2018.

Sales in the United States rose by 82% in 2018, faster than the rate of the global market, a big increase compared to just 24% growth the year before. The release of the Tesla Model 3, with sales that fully cover the additional 134 000 BEVs sold in 2018 (compared with 2017), helps to explain this trend (Marklines, 2019).

In 2018, electric car registrations in Canada were 44 000 units, more than double the 2017 level.

Japan is the only major electric car market where sales fell between 2017 and 2018 (-8%). Other markets where electric car sales dropped, such as India, South Africa and Mexico, have much smaller electric car volumes.

Globally, more than two-thirds of electric car sales in 2018 were BEVs. This share has been steadily increasing from 50% in 2012 to 68% in 2018. This is consistent with China's rapid electric car sales growth, as it is a BEV-dominated market (76%). The share of PHEVs in sales dropped in the United States from 47% in 2017 to 34% in 2018, due to strong BEV sales, in particular the Tesla Model 3. Europe remained a strong market for PHEV sales. PHEV sales dominated in Finland (86%), Sweden (75%)[14] and United Kingdom (69%). In contrast, the PHEV share in electric vehicles (EV) sales significantly decreased in 2018 compared to 2017 in Japan (47% versus 67%) and the Netherlands (14% versus 22%). (Box 1. 2 highlights BEV and PHEV model availability and their distribution across major market segments.)

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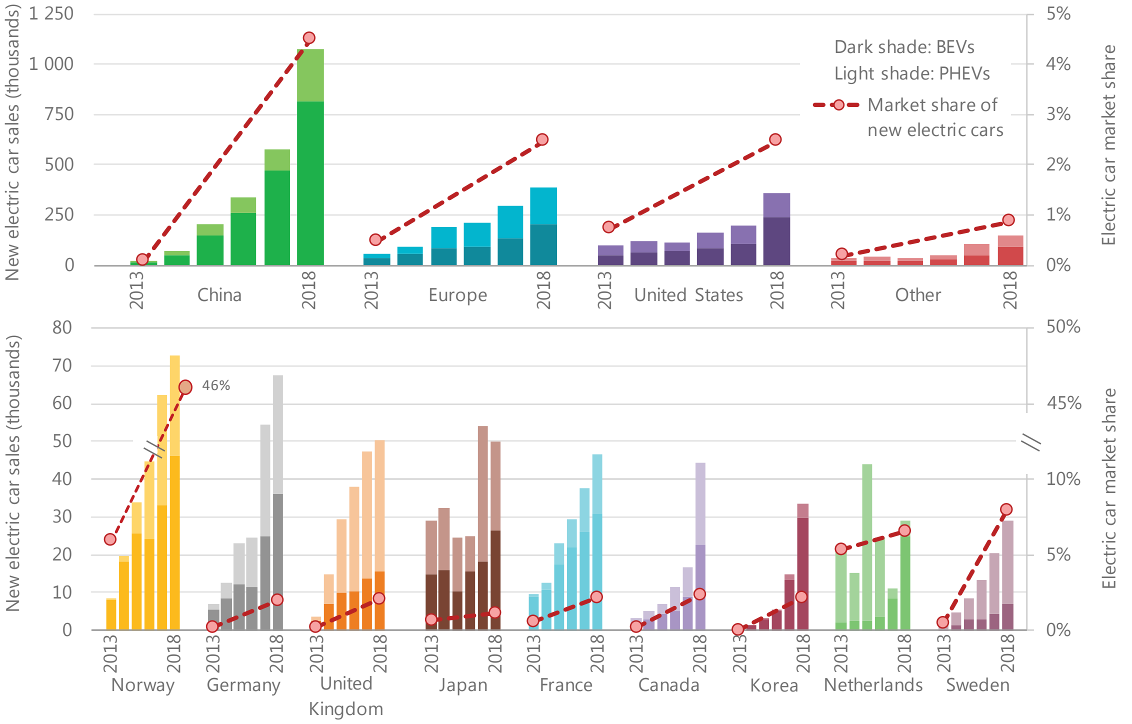
[12] China accounts for about one-third of the global car market when including internal combustion engine vehicles.

[13] Electric car sales in the Netherlands had decreased between 2013 and 2017 reflecting the termination of a tax incentive on PHEVs, but strong growth in BEV sales compensated in 2018.

[14] During the first months of 2019, BEV volumes reached those of PHEVs in Sweden and exceeded them in March, likely influenced by Tesla Model 3 deliveries.

Figure 1.2. Electric car sales and market share in the top-ten EVI countries and Europe, 2013-18



Notes: The countries in this figure represent the top-ten EVI countries. This ranking closely resembles the ten leading countries worldwide in term of electric car sales; the only exception is Korea, with 33 000 electric car sales in 2018. See footnote 3 for the list of countries in the Europe category. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand. Europe includes Austria, Belgium, Bulgaria, Croatia, Cyprus[15], 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. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand.

Sources: IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019); CAAM (2019).

China has the highest volume of electric car sales worldwide, followed by Europe and the United States, while Norway is the global leader in terms of market share.

Box 1. 2. BEVs and PHEVs: model availability and distribution across different segments in the main global EV markets

The figure shows the number of models and the model distribution across various vehicle segments of BEVs and PHEVs, looking at the three main global markets for electric light-duty

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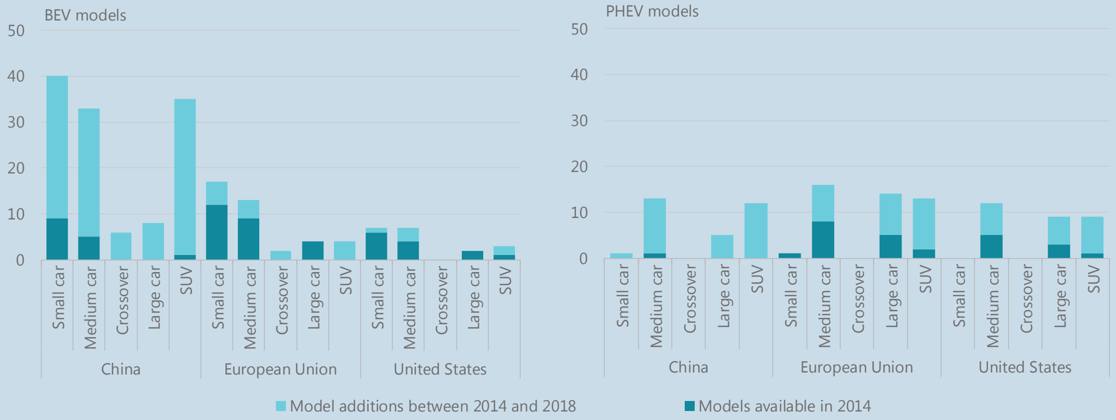
[15] Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting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

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 the effective control of the Government of the Republic of Cyprus.

vehicles: China, Europe and the United States. The figure also shows that electric LDVs are not uniformly distributed across these markets, neither in terms of model availability or coverage of different market segments. It highlights that model availability of electric LDVs differs between BEVs and PHEVs.

Model availability of electric light-duty vehicles in China, Europe and United States, 2018



Notes: The bars indicate the number and the share of EV models available in the various segments differentiated by BEVs and PHEVs. The classification of vehicles shown here is broadly consistent with the categories used in (IEA, 2019a): small car = city car; medium car; crossover = small sport-utility vehicle (SUV)/pick-up truck; large car = large SUV/pick-up truck.

Source: Marklines (2019).

PHEVs are more widely available in large size vehicles, with 60% of all models in the large car and SUV segments, and with no PHEVs available in the small car segment. This trend is observed in all markets. The main reasons for the prevalence of PHEV in large cars are: the presence of two powertrains is better suited to larger vehicles; and increased requirements for long-range capability for such vehicles. All major markets have a roughly similar number of PHEV models available, with Europe having most models and the United States having the least.

BEVs are more evenly distributed among market segments than PHEVs, but they are mostly available as small and medium cars. This is consistent with the fact that today's BEVs, which are characterised by lower driving ranges than conventional vehicles, are better suited for cars that are mostly used in cities for short-distance trips and can be equipped with smaller (and therefore cheaper) batteries than electric vehicles targeting long trip distances. The three main global EV markets differ in the availability of BEV models. There are about 16 models in the United States while the European Union has twice as many. A very broad array of available models numbering about 114 populates the market in China. This can be partially explained by the fact that the automotive market in China has higher fragmentation in terms of manufacturers than Europe and the United States, but also by the larger size of its domestic electric car market.

In China, very small cars have transitioned almost entirely to BEVs. In 2018, 90% of the cars sold in the very small car segment[16] were BEVs, up from 39% in 2016 (Marklines, 2019). The

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[16] These are small city cars, the smallest category of passenger cars defined, and exclude cars in the subcompact category, which are also in the small car segment.

availability of electric models in this segment preceded the increase in market penetration: in 2014, roughly one-in-three models available were BEVs. Electrification in this market segment progressed fast, despite limited performance in terms of driving range: in 2014, most of the cars sold in the very small car segment had a range below 150 kilometres (km) (New European Driving Cycle, NEDC),[17] and the current average range is 220 km (NEDC) (EV Volumes, 2019). This is delivered by batteries of modest size (on average 27 kilowatt-hours). This high electrification rate can be explained by the low daily driving range requirements of users of these vehicles, and the fact that subsidies currently bring the purchase price of such cars on par with their internal combustion engine (ICE) powered counterparts.

China also shows important differences with other markets because one-third of its BEVs models are in the SUV category. This may reflect pressure on domestic manufacturers to sell an increasing number of "new energy vehicles", requiring BEVs to broaden into different market segments, and by the growing consumer preference for SUVs (IEA, 2019a), making them an attractive option to gain market share. As the difference in energy use per km between a BEV and a conventional vehicle is highest in heavy vehicles (IEA, 2019a), original equipment manufacturers (OEMs) might also gain greater benefits to satisfy the requirements of fuel economy standards by electrifying vehicle segments where conventional ICE vehicles would be the most energy intensive.

Light-commercial vehicles

In 2018, about 80 000 electric LCVs (mostly BEVs) were sold, almost entirely in China (54 000 LCVs) and Europe (25 000 LCVs). Overall global growth of electric LCV sales was lower in 2018 (24%) than in 2017 (94%). It was higher in Europe in 2018, with a 42% year-to-year growth rate, compared with 36% the previous year.

Charging infrastructure

The number of charging points worldwide is estimated at 5.2 million (end-2018), up 44% from 2017 (Figure 1.3). Most of this increase was in private charging points, accounting for more than 90% of the 1.6 million installations in 2018. Publicly accessible installed fast chargers numbered 144 000 and slow chargers numbered 395 000 by end-2018.[18]

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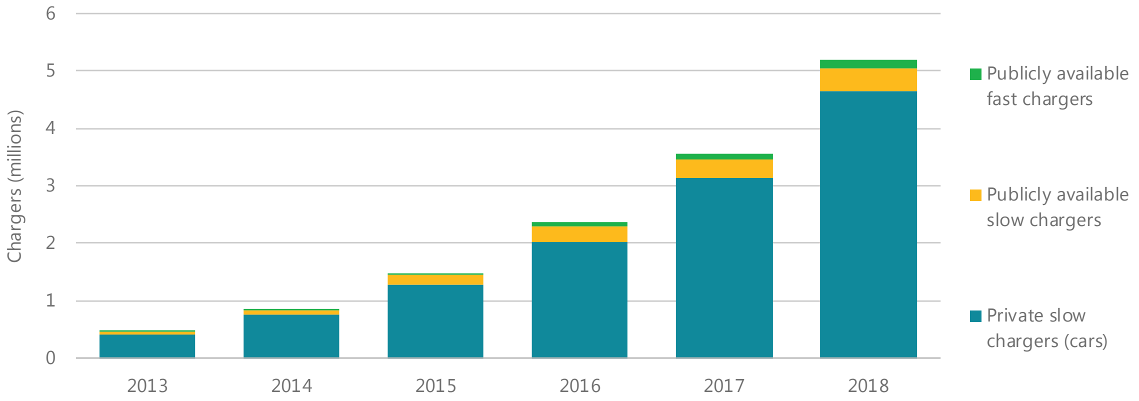
[17] The New European Driving Cycle (NEDC) is a driving cycle used in the regulations of the European Union and the United States since the late 1990s to assess the emission levels of car engines and fuel economy in passenger cars (which excludes light trucks and commercial vehicles). Due to evolution in technology and driving conditions, it became outdated. The European Union therefore has developed a new test, called the Worldwide Harmonised Light Vehicle Test Procedure (WLTP).

[18] Slow chargers provide power less than or equal to 22 kilowatts (kW) and fast chargers provide power higher than 22 kW.

Figure 1.3. Global installation of electric LDV chargers, 2013-18



Notes: Estimates for private chargers assume that each electric car is coupled with 1.1 private chargers (level 1, i.e. conventional wall plugs, or level 2, i.e. using a dedicated connector, with less than 240 Volts), either at home or the workplace, in all countries except China and Japan. This evaluation is based on surveys conducted in the United States and Europe (Newmotion, 2018; Melaina et al, 2016; Jadun, 2017).The estimates for China and Japan, with particularly dense urban areas where EVs are being deployed, are based on 0.7 chargers per EV for 2018. This is based on the information reported by a survey (looking at a sample of roughly one-third of electric car owners) by the China Electric Vehicle Charger Infrastructure Promotion Alliance, suggesting that the fraction of chargers sold to private electric car owners was close to 70% in China (Chinabaogao, 2019). For all years prior to 2018, a ratio of 0.8 chargers per EV is used for China and Japan, in line with analysis conducted in the *Global EV Outlook 2018* (IEA, 2018a).

Chargers can come with different connectors (e.g. direct current combined charging system [CCS] and CHAdeMO); it is possible to charge two vehicles simultaneously if the charger is equipped with one AC connector and one DC connector. However, this is not usually the case if the charger has two different DC connectors. This assessment attempts to avoid double counting of chargers that are equipped with both CHAdeMO and CCS connectors, with the intention to represent the number of vehicles that can simultaneously charge.

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

About 5.2 million LDV charging points were installed by 2018 and the majority were private chargers.

Private chargers

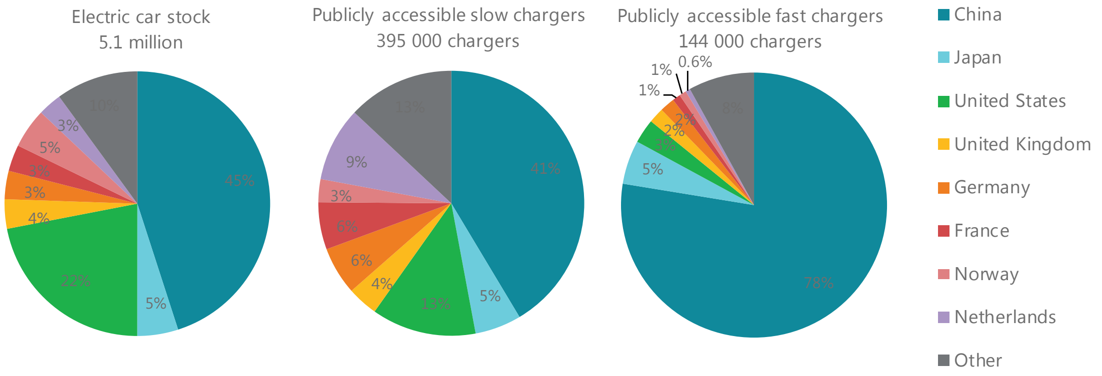
Gathering reliable statistics on private chargers is challenging, given methodological issues to track level 1 chargers (i.e. residential electrical outlets not exclusively used for electric cars) and the lack of information collected on level 2 chargers (i.e. using a dedicated connector, with less than 240 Volts) installed on private property.

The data shown in Figure 1.3 are based on the assumption that, in all countries except China and Japan, each electric car is coupled with 1.1 private charger (level 1 or level 2), either at home or the workplace. In China and Japan, the estimate is one private charger per 1.5 cars. These ratios are based on observations for major EV markets such as the Nordic region of Europe and the United States, where the ratio of electric cars to private chargers is close to 1, and where EV owners tend to charge at home in the vast majority of cases (IEA, 2018a; IEA, 2018b), and on a survey in China (Chinabaogao, 2019). (Additional details are in the note to Figure 1.3)

Publicly accessible chargers

The global number of publicly accessible chargers reached 539 000 in 2018, up 24% from 2017 levels. The growth rate of new installations of publicly accessible chargers is slowing in comparison to previous years (30% in 2017, 80% in 2016). In 2018, China remained the country with the largest installed publicly accessible charging infrastructure, accounting for half of the global total (Figure 1.4). Worldwide, in 2018, around a third of the publicly accessible chargers installed were fast chargers. In China, almost half of the newly installed publicly accessible chargers were fast, whereas in Europe and the United States a large majority were slow chargers.

Figure 1.4. Electric car stock and publicly accessible chargers by country, 2018



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

Half of the publicly accessible chargers in the world and over three-quarters of the fast chargers are installed in China.

The global number of publicly accessible chargers per electric car has decreased from 0.14 in 2017 to 0.11 at the end of 2018. This ratio remains higher than 1 charger per 10 electric cars, which is recommended by the European Union Alternative Fuels Infrastructure Directive (EC, 2014). Many leading countries in terms of electric car deployment remain below the global average of 1 charger per 10 electric cars: this is the case in Norway and the United States, with a ratio of 1 charger per 20 electric cars. Conversely, the Netherlands and Denmark have a relatively high number of publicly accessible chargers per electric car (about 1 charger per 4-8 electric cars). Therefore the need for extensive publicly accessible charging infrastructure as a prerequisite for EV deployment is not automatic; it depends on specific country features, such as population density (availability of access to home charging for each EV driver), access to workplace charging infrastructure and vehicle range. These country trends were identified and discussed in greater detail in the *Global EV Outlook 2018* report, where observations made for 2017 remain valid in 2018 (IEA, 2018a).

Small electric vehicles for urban transport

Stock and sales

Two/three-wheelers

The electric two-wheeler market is led by China, which produced 26 million in 2018 and had an estimated 250 million units in circulation (askci, 2019; IEA, 2018a).[19] This is over one-quarter of the global motorised two-wheeler stock (IEA, 2019b) of almost 800 million units, mostly in

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[19] This section excludes electric bicycles.

circulation in China, India and the Association of Southeast Asian Nations (ASEAN).[20] In Viet Nam, about 0.9 million electric two-wheelers were in circulation (UITP, 2017). In India, 0.1 million electric two-wheelers were sold in fiscal year (FY) 2018-19 and the fleet size reached 0.6 million (SMEV, 2019). Electric two-wheelers in European cities are mostly via shared rental schemes. The two largest operators, Coup and Cityscoot, have deployed 8 400 electric two-wheelers in Paris, Berlin and Madrid (Greis, 2019; Cityscoot, 2018).

The stock of electric three-wheelers exceeds 50 million in China and about 2.38 million in India (China News, 2018; SMEV, 2019).

In China, two-thirds of two-wheelers in circulation have limited but sufficient performance: 0.5-0.8 kilowatt-hour (kWh) batteries deliver around 50 km of range at low-speed (typically 20-25 km per hour [km/h] max speed). These characteristics make them well-suited for circulating in dense cities and allow them to have modest prices (around USD 400 [United States dollars]) and to compete with gasoline powered alternatives (IEA, 2018b). In China, electric two-wheelers are often exempt from vehicle registration and have the right to use bicycle lanes, while some cities have banned conventional gasoline two-wheelers from urban centres (Cherry, 2010). These characteristics and regulations were major drivers for rising demand for electric two-wheelers in China that is higher than in other Asian markets (IEA, 2018a). However, several Chinese cities are banning low-speed electric vehicles in an attempt to improve road safety (BBC, 2016).[21] Furthermore, regulations to cap the production capacity of manufactures for low-speed electric vehicles may further affect their sales (Government of China, 2018). These policies have been dampening demand for electric two-wheelers in China since 2014 (Ren, 2019).

In India, the sales of 0.1 million electric two-wheelers in FY 2018-19 doubled the volume from the previous year (SMEV, 2019). Electric two-wheeler sales make up less than 1% of the vehicle market share, but purchase subsidies have stimulated their uptake. The first phase of the Faster Adoption and Manufacture of (Hybrid and) Electric Vehicles (FAME) scheme grants a rebate of INR 7 500 – 22 000 (Indian rupees, USD 110 – 320) for the purchase of 62 eligible models from 11 OEMs.[22] About 40% of the eligible models are low-speed (25 km/h max) and they represent 80% of electric two-wheelers sales (SMEV, 2019). Similar to the models in China, they typically use a lead-acid battery and do not require a driving licence or vehicle registration. However, this category of electric two-wheelers has been excluded from FAME since the scheme's revision (FAME II) in February 2019 and their share within electric two-wheeler sales decreased from 90% to 80% from FY 2017-18 to FY 2018-19 (Autoportal, 2019; SMEV, 2019).

The two-wheeler market in the ASEAN countries is the third-largest after China and India, with sales of about 10 million in 2018. The market share of low-speed vehicles is negligible and there are no policies to discourage use of gasoline two-wheelers. As a result, sales of electric two-wheelers remain low compared to the total two-wheeler market size. For example, in Viet Nam there are about 0.9 million low-speed electric two-wheelers in its overall two-wheeler fleet of more than 40 million (UITP, 2017). Sales of full-size electric two-wheelers in Viet Nam increased

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[20] Association of Southeast Asian Nations includes: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam.

[21] These new measures affect the electric two-wheelers as well as low-speed electric vehicles, another China-specific phenomenon, discussed in the next section.

[22] The subsidy eligibility depends on battery size, with the models having larger batteries being eligible for a higher subsidy (National Automotive Board, 2019). Note that in the newly adopted phase 2 of the FAME scheme, low-speed electric two-wheelers (<25 km/h) are excluded from subsidies (Government of India, 2019) .

after such models were introduced and there are an estimated 6 000 full-size electric two-wheelers in circulation (NNA, 2018). In Thailand, there are just over 1 000 full-size electric two-wheelers registered (Government of Thailand, 2019). Fleet size of electric two-wheelers in Indonesia is about 3 000 (Solidiance, 2018).

Fleet operators of shared rental schemes have brought electric two-wheelers to European cities, with about 1 500 units in Berlin, 1 300 in Madrid and 5 600 in Paris from the two operators Coup and Cityscoot (Greis, 2019; Cityscoot, 2018). Users can rent the full-size electric two-wheelers via smartphone apps. Rentals are billed per time of use and there are no designated rental stations, which allow users to end journeys at a different place than the departure point. The modal share of two-wheelers remains small in European cities compared to passenger cars and public transit. Nonetheless, the availability of electric two-wheelers in the shared rental fleets complements existing transport modes and provides opportunities to experience electric mobility.

The stock of electric three-wheelers is concentrated in China, with more than 50 million, and in India. Government limits for production capacity for any type of low-speed electric vehicle in China is depressing growth in the electric three-wheeler market. In India there are over 2 million electric three-wheelers in operation and annual sales reached 630 000 units in FY 2018-19. The FAME programme provides purchase subsidies for eight electric three-wheeler models, further supporting the market (National Automotive Board, 2019).

Box 1. 3. Electric foot scooters: the new paragon of shared micro-mobility

Shared "free-floating" electric foot scooters have been flourishing in major cities in the world since 2017.[23] In one year, the first company active in this sector, Bird, surpassed 10 million rides in over 100 cities, mostly in the United States and Europe (Dickey, 2019). In Paris, eight companies were operating electric foot scooters at the beginning of 2019, just six months after the first shared electric foot scooter was deployed in the city by Lime in June 2018 (Landais Barrau, 2019). These schemes now exist in around 129 cities in the United States, 30 in Europe, 7 in Asia and 6 in Australia and New Zealand.[24] Their presence, so far, is extremely limited in Asian cities, possibly because of the domination of free-floating shared two/three-wheeler schemes for a few years (Lipton, 2017), which already serve similar mobility needs as electric foot scooters.

(Photo credit: Shutterstock)

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[23] The use of free-floating electric foot scooters is via a smartphone app. Battery recharging is done at night, either by the operator which collects and charges them in depots, or by individuals paid for charging the products at home, under an agreement with the operator (Bird, 2018).

[24] The figures have been determined based on data from 13 companies on their official websites (Lime, Bird, JUMP (Uber), Lyft. Skip, Spin (Ford), ScootNetworks, Bolt (Taxify), Beam, VOI, Neuron mobility, Hopr, TIER). This list aims to cover a large portion of the global market, but may not be exhaustive.

The success of electric foot scooters probably lies in the fact that this mode is well-suited to meet the "last-mile" challenge. The last-mile represents a trip that is too short to be undertaken with a bus or car ride, but rather long to walk. In San Francisco, for example, customers of the company Bird report riding on average 2.5 km per trip. It is longer than the average distance made on foot (around 1.5 km) and shorter than the average distance made by car (around 3.7 km) (Kaufman and Buttenwieser, 2018). Lime reports that 30% of their customers have displaced a car trip, during their most recent use of the shared electric foot scooter service (Lime, 2018). This type of use may very well conflict with the use of ride-sharing services for relatively short rides. Consequently, shared mobility operators initially operating in the ride-hailing segment, such as Uber and Lyft, are diversifying their services to include electric foot scooters and become increasingly involved in all aspects of the shared mobility systems (O'Brien, 2018).

However, the rapid expansion of shared electric foot scooters has posed some challenges to the cities concerned. They include: an uncontrolled number of units being deployed by new companies in the public space (to be shared with multiple road and sidewalk users) without co-ordination with public authorities; reports of accidents due to the potential high top speed of the foot scooters (up to 24 km/h); obstacles for the blind from random scooter parking (Boche, 2019); the lack of regulations for conditions of use (Githiru, 2018)[25] and the ability to adapt the existing regulations for a new transport mode. As a result, an increasing number of cities are implementing stricter regulations to monitor and control the use of electric foot scooters, with the aim to maximise their benefits to urban dwellers and mitigate adverse effects. For example, in Washington DC, in early 2019 the Department of Transportation capped the number of units per free-floating shared vehicle type per company to 600, with the possibility to request an allowance for 25% additional units four times a year. The maximum speed of the scooters has been limited to 16 km/h (Delgadillo, 2018). In Paris, the city council has decided to charge free-floating shared mobility companies for the commercial use of public space.[26] This aims to regulate shared electric two-wheelers as well as shared bikes and electric foot scooters. For electric foot scooters, the fee will reach EUR 50 (Euros, USD 56) per unit per year for the operator. A longer term strategy of the Paris municipality is to establish dedicated "drop-off" spots, instead of a fully free-floating system, placed every 150 metres at former roadside car parking spots (Blaquière, 2019). This aims to limit conflicts of public space use with micro-mobility modes crowding sidewalks.

Low-speed electric vehicles

The market for low-speed electric vehicles (LSEVs)[27] is concentrated in China, where it has emerged as an alternative to small urban vehicles and passenger cars because size and speed

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[25] In many instances, cities saw the number of electric foot scooters surge within just a few weeks. Often this was in the absence of established regulations regarding their use on sidewalks, in bike and bus lanes, roads or urban highways and no guidelines on the use of a helmet or other protective equipment. Some countries have regulations banning the use of motorised foot scooters in all public spaces (including sidewalks, roads and public parks), which has deterred most operators from launching electric foot scooter initiatives despite their success in other European cities. The United Kingdom is one of these cases. Despite this, some free-floating shared electric scooters were deployed in London, but only in the Queen Elizabeth Olympic Park area (Parsons, 2018).

[26] This should be enforced before mid-2019.

[27] LSEVs are small vehicles with four wheels and a maximum speed of around 40-70 km/hr with relatively short electric driving ranges.

exempts them from some registration requirements. The fleet size is estimated to exceed 5 million vehicles.[28] LSEV sales numbers in China reached 695 900 in 2018, only a slight increase from the previous year (D1EV, 2019). Recent policies tighten regulations to contain further market growth. In November 2018, the government temporarily banned further increases of production capacity for LSEVs due to road safety concerns (Government of China, 2018). Future developments will be managed according to national regulations which aim to limit further market expansion. Some manufacturers in China have responded to stricter regulation on LSEVs by increasing production of very small electric passenger cars, for which the electric market share increased from 39% in 2016 to 90% in 2018. This is the smallest passenger car segment subject to regular road regulations and registration requirements.

Charging infrastructure

Small-size electric vehicles (two/three-wheelers, LSEVs and foot scooters) generally do not have access to dedicated charging infrastructure. Personal vehicles often charge at residential buildings from regular power outlets, some via extension cords. Small battery home charging stations are used for models with portable batteries. Free-floating shared electric fleets use various approaches. For example, operator Coup exchanges discharged batteries of its free-floating shared fleets and recharges in central depots (Greis, 2018).[29] A number of operators of shared electric foot scooters (Box 1. 3) pay users to collect scooters with low battery levels and to charge them at home, co-ordinated through the user app (Runnerstrom, 2018).

Buses

Stock and sales

The global stock of electric buses increased by 25% in 2018 relative to 2017, reaching about 460 000 vehicles. China accounts for 99% of the global market for electric buses.

In 2018, over 92 000 new electric buses were registered, down from 104 000 in 2017.[30] Battery electric is the technology of choice accounting for 93% of new electric bus registrations.

Outside of China, about 900 electric buses were registered in 2018, mostly in Europe. Latin America had its first roll out with 200 electric buses in Chile and 40 in Ecuador. A tender for electric bus procurement was proffered in India under the FAME scheme (Box 1. 4). There are more than 300 electric buses in the United States (Reuters, 2017).

Charging infrastructure

Infrastructure dedicated to electric buses reached an estimated 157 000 chargers in 2018. Most are in China with 153 000 chargers, where the number increased by 25% from 2017. Electric bus chargers in Europe in 2018 reached 3 000. In China, the number of bus chargers does not only stand out in comparison with any other country, but it also exceeds the level of publicly available fast chargers for passenger cars (Figure 1.5). The similar magnitude of

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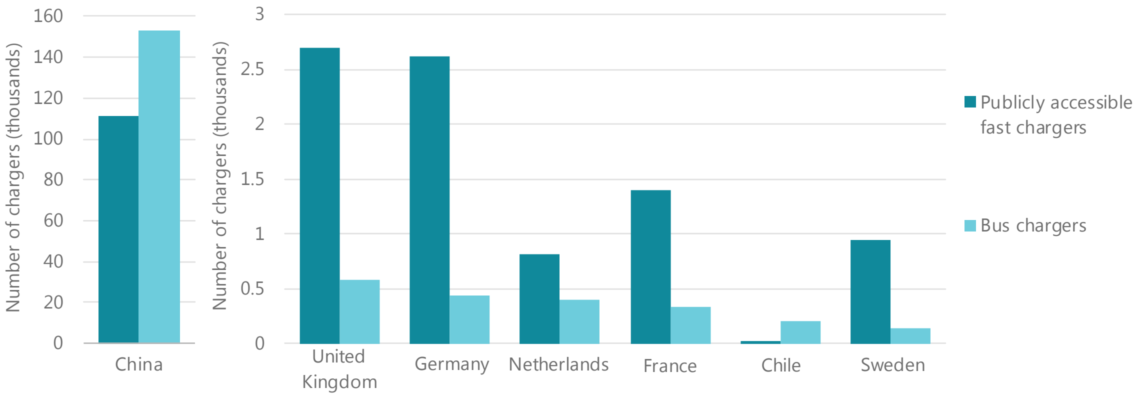
[28] This estimate is based on cumulative sales.

[29] Gogoro, the manufacturer of Coup's electric two-wheelers, operates the largest network of battery swapping stations in Chinese Taipei. Drivers of 123 000 Gogoro two-wheelers in this market can exchange discharged batteries at 1 000 charging stations (See Chapter 2, *Industry roll-out plans*).

[30] This report refers to "battery electric bus" as "electric bus" and the scope excludes electric trolley buses.

fast chargers for buses and cars in China, a country where even the fast charger to electric car ratio tends to be high, illustrates that buses currently have very significant relevance in the market development of fast chargers.

Figure 1.5. Dedicated bus chargers and publicly accessible fast chargers by country, 2018



Notes: In China, the bus fleet is mostly based on depot charging. Shenzhen has approximately one charger per three buses (Lu, Lulu and Zhou, 2018). In other regions, the ratio is closer to one charger per bus.

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

Bus chargers are an important driver of the global deployment of fast chargers. In China, which had 153 000 bus chargers in 2018, dedicated fast chargers for buses exceed the number of publicly accessible fast chargers.

Table 1.2. Charging regimes of selected electric bus operations

City	Number of vehicles	OEM	Charging regime
Santiago de Chile, Chile	100	BYD	Overnight depot charging with 100 chargers.
Santiago de Chile, Chile	100	Yutong	Charging at terminal.
Indore, India	40	Tata Motor Limited	2 chargers along route.
Kolkata, India	40	Tata Motor Limited	40 chargers.
Leiden, Netherlands	23	Volvo	Charging at terminal.
Nottingham	45	Optare	Charging at terminal and depot.
Paris	23	Bluebus	Overnight depot charging.
Schiphol Airport, Netherlands	100	VDL	Charging at terminal (450 kW) and overnight depot charging (30 kW).
Shenzhen, China	>16 000	BYD, Nanjing Golden Dragon	Mostly overnight depot charging.

Notes: This table includes a selection of recent electric bus projects with at least 20 vehicles. Depots provide parking during non-operating hours while terminals are larger bus stations (e.g. end-of-line station).

Sources: Shenzhen Bus Group (2019); Royal Schipol Group (2019); UITP (2018) and Singh (2019) for Kolkata and Indore, Morris (2018) for Leiden, ZeEUS (2017) for Nottingham and Paris.

The global electric bus fleet is supplied with electricity by chargers located in depots and/or at the end of the bus routes. Depot charging is the common regime in major electric bus operations in China, for instance in the city of Shenzhen, where more than 16 000 electric buses circulate (IEA, 2018a). Recent expansions of bus fleets in Europe and Latin America use depot charging or a combination of depot charging and fast charging along routes (Table 1.2). A review in more than 90 European cities which together account for almost 750 electric buses shows that about 90% of electric buses uses overnight depot charging, however, almost all also use fast charging during operating hours, mostly pantograph charging (analysis based on ZeEUS, 2017).

Choices for charging regimes aim to optimise bus operations and costs, and are location-specific to accommodate characteristics of the respective transport system as well as the regulatory regime. Off-peak electricity tariffs offer low fuel costs for overnight depot charging as well as no need to adjust operations or to train drivers for charging procedures. However, buses that use this charging method require larger batteries than buses that also charge during operating hours, which comes with higher battery costs and vehicle purchase prices. The development of battery costs may impact market trends for bus charging regimes, in which decreasing battery costs can drive the industry further to overnight charging at depots.

Box 1. 4. Major electric bus procurement schemes

Urban buses usually operate as a regulated public service. Licences to operate public bus transit are often granted through competitive tenders. Mandates to promote electrification of bus fleets from public transport agencies are influencing recent procurements and are often supplemented with subsidies for electric vehicles. A complementary market driver is the low fuel cost for electric buses, which can offer total cost of ownership (i.e. purchase and operating costs) that are lower than for diesel buses.[31]

Shenzhen and other cities in China

In the city of Shenzhen, 16 000 electric buses operate, the largest-scale electric bus transition observed in a city. The city government mandated operators to go electric. Operators received subsidies from both the national and municipal governments and completed the mandate by the end of 2017, one year ahead of schedule. Shenzhen-based manufacturer BYD delivered most of the electric buses. The systems uses depot charging augmented with fast charging on some routes. Other significant electric bus procurements in 2018 include orders for 4 000 electric buses for Guangzhou (Randall, 2018) and 200 double decker buses for Xi'an (Field, 2019a).

Schipol Airport and cities in the Netherlands

The introduction of 100 electric buses on routes in the Schiphol Airport area in the Netherlands represents the largest electric bus fleet procurement completed in Europe to date. The tender for

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[31] For further information, see Chapter 5, Figure 5.8 "Total cost of ownership gap between diesel and electric buses" in *Global EV Outlook 2018* (IEA, 2018a).

operating these lines included the requirement for the buses to be emissions free. The Dutch manufacturer VDL provided the buses, which use a combination of fast charging during the day at terminals and depot charging at night with slow chargers. The Schiphol Group financed parts of the charging infrastructure. The fleet size will increase to about 260 vehicles by 2021 (Royal Schiphol Group, 2019). The Netherlands leads the market for electric buses in Europe, with projects such as the confirmed purchase of 159 battery electric buses and 22 fuel cell electric buses in Groningen and 23 battery electric buses in Leiden, making Leiden's fleet all electric (IRIS Smart Cities, 2018; Morris, 2018).

Santiago de Chile and cities in Latin America

Electric buses arrived in Latin America in 2018 with the roll-out of 200 units in Santiago de Chile. This came after a fleet renewal negotiation that included 200 electric buses and 490 buses that comply with the Euro VI standard. BYD and Yutong, Chinese manufacturers, delivered 100 electric buses each. BYD buses deploy charging at two depots while Yutong buses charge at terminals. Three operators lease the buses from the energy companies Enel X and ENGIE which own the vehicles. The roll-out of electric buses in this region expands with the delivery of 20 battery electric buses to the city of Guayaquil (Ecuador) and confirmed order for 64 vehicles for Medellin (Colombia), both supplied by BYD (El Comercio, 2019; Field, 2019b).

Cities in India

Government funding for 390 electric buses made available in late 2017 under the first phase of the FAME scheme drove adoption of electric buses in India in 2018. (See Chapter 2, *Supporting policies* for information on the FAME scheme). The Government of India selected 11 cities with a population over 1 million to conduct tenders to obtain 390 electric buses for public transit systems. Cities were free to announce tenders either to purchase buses or to pay for their operation on a per kilometre basis for a certain period. Three domestic manufacturers (Tata Motors, Goldstone-BYD and Ashok Leyland) were selected (tender requirements excluded foreign OEMs), committing to deliver a total of 520 buses. Today Kolkata and Indore have electric buses in operation, with Kolkata buses using a combination of overnight slow charging and fast charging while fast charging is used in Indore (UITP, 2018).

Trucks

Stock and sales

The market for medium- and heavy-duty freight electric trucks was small in 2018 compared with other types of electric vehicles. An estimated 1 000-2 000 medium- and heavy-duty trucks were sold in 2018 in China, where the stock is likely to exceed 5 000 units.[32] In Europe, a group of OEMs delivered electric medium-freight trucks to selected fleet operators for commercial

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[32] The range is due to limited accuracy and discrepancies across various data sources, and it is informed by information on the total of all commercial vehicle sales from the country submission and their distribution across LCVs, buses, minibuses, medium- and heavy-duty trucks from other sources (D1EV, 2018; Find800, 2019; EV Volumes, 2019).

testing. These include over 50 electric trucks from MAN, DAF, Mercedes and Volvo (MAN, 2018; Volvo Trucks, 2019; Daimler, 2019a; Daimler, 2019b; DAF Trucks, 2018). The testing operators are from various sectors, including food retail, logistics companies and public service such as garbage collection. A number of retrofitted conventional trucks or special purpose vehicles with low-range profiles, such as at mines and ports, are also in service.

Early adoption of electric trucks focuses on urban mission profiles for several reasons. The roll-out in urban settings makes it easier to optimise charging stops along routes, bringing the mission profiles of these trucks closer to buses than long-haul vehicles. Urban trips thus pose lower requirements for battery capacity, especially in a context where suitable roadside high power charging along major long-distance corridors is practically non-existent. Moreover, electric trucks enjoy easier access in cities with regulations to curb noise or air pollution than diesel trucks, which is a potential competitive advantage for electric trucks. The size ranges from mid-sized vehicles of about 16 tonne payload (200-300 km range and 100-300 kWh battery capacity) to tractors that haul up to 37 tonnes (100 km range and 170 kWh battery capacity). Policy initiatives, growing interest in low- or zero-emissions medium and heavy-duty trucks from major logistic companies[33] and the attractiveness of the battery electric option from a cost perspective for specific mission profiles (e.g. urban deliveries), suggest that wider electric truck penetration is likely in the coming years. (See Chapter 2, *Vehicles* for a discussion of key policy instruments and plans of manufacturers to roll out electric trucks.)

Charging infrastructure

With battery sizes of about 300 kWh for medium-freight trucks and up to about 990 kWh for heavy-freight trucks, electric trucks have higher requirements for charging infrastructure power ratings than passenger cars in order to recharge in a reasonable time that is compatible with their commercial operation. Today publicly accessible chargers dedicated to trucks is minimal as electric trucks in circulation operate with small groups of trial clients on short routes, for instance, urban deliveries or waste collection. Complete charging of a 300 kWh battery truck takes six hours with DC fast charging at 50 kW. Existing electric trucks mostly use private depot charging.

Heavy-freight trucks and other size trucks with long driving ranges will require higher power than today's DC chargers (< 200 kW) and need to be installed along transport corridors. For example, the Tesla Semi will have a range up to 965 km and an estimated battery size of almost 1 000 kWh. Tesla announced the roll-out of a network of mega chargers that can provide charge for 640 km (400 miles) in 30 minutes, meaning that the capacity of these chargers will exceed 1 megawatt (MW) (Alvarez, 2018). Charging stations for trucks can achieve a high utilisation rate as a big share of long-distance road freight traffic concentrates on a limited number of major transport corridors. A high utilisation rate can realise economies of scale and reduce costs of operating the mega chargers.

Other modes

In 2018, 23% of the carbon dioxide (CO_2) emissions from the transport sector were from non-road modes, namely shipping, aviation and rail. Electrification is already playing a significant role in the reduction of carbon and pollutant emissions in the rail sector and will continue to do

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[33] Several logistics and food retail companies have pre-ordered electric trucks. There are 280 pre-orders from UPS, PepsiCo, Walmart and DHL (Matousek, 2018; Paez, 2019). This expected uptake is driven by the companies' willingness to make their operations "greener", as well as to reduce the total cost of ownership of the fleet.

so (IEA, 2019c). While the role of electric propulsion has been less prominent so far in shipping and aviation, recent developments indicate that electricity may play a bigger role in the future.

Shipping

In the maritime transport sector, several electric ships, mainly ferries, are operating on relatively short routes. The first electric ferry, named Ampere, was put into service in Norway in 2015 (InsideEVs, 2018). The technological and economic success of the ship and its charging system (a 1.2 MW fast charging infrastructure on both shores) led to the commercialisation of a similar vessel in Finland in 2017 and to the order of several others (Corvus Energy, 2019).

Industry players such as ABB have developed battery systems to retrofit ships and are scaling up their capacity production to keep up with demand. An iconic example of ship conversion to battery electric was recently announced for the ferry service between Helsingborg, Sweden and Helsingør, Denmark (ABB, 2018). Several other projects, including commuting electric boats that operate in urban environments (e.g. Netherlands and Sweden) are emerging in the rest of Europe, as well as in North America and New Zealand.

Other solutions that combine electric propulsion and oil-fired propulsion have been emerging over the last decade. Some hybrid ships are in circulation, for instance, since 2013 between Germany and Denmark. An issue hindering the rapid conversion of ferries to an all-electric fleet is the renewal rate of the vessels, as ships usually have a life span of several decades. Regulations also play a role in electrifying the maritime sector. For instance, the restriction on emissions in the UN World Heritage fjords in Norway that mandate all-electric operations for cruise ships from 2025 has led to some electric ships already being operated (UNESCO, 2018).

Electrification is significantly more challenging for long-distance, transcontinental cargo vessels, for which the current available range of batteries is too restrictive to cover entire trips. The possibilities to power long-distance ships with batteries are explored in the EU-funded E-FERRY demonstration project (E-ferry, 2019). The project aims to demonstrate that an E-ferry equipped with a 50 tonne modular lithium-ion battery system will cover distances of more than 22 nautical miles between charges (a dramatic improvement compared to current performance of electric ferries). An E-ferry is expected to start operating between the Danish island of Ærø and the mainland in June 2019. It will be charged by an automated shore connection system that will connect as soon as the ferry docks and will require the vessel to remain portside for 15-20 minutes. In the foreseeable future, expanded use of electricity may be in the electrification of ship energy use when docked and within areas close to port or shore.[34] The building of appropriate charging infrastructure at ports needs to be taken into consideration, and dockside charging infrastructure deployment can be triggered by more systematic cold ironing, at first.

Aviation

Electrification in aviation has shown encouraging progress in pilot projects in recent years, but it remains at an early stage of development. Several small battery electric powered planes are in demonstration phase, with two 2-seater plane designed by Pipistrel available on the market (Pipistrel, 2019). Current electric plane prototypes mainly have one or two seats and do not

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[34] The practice is called cold ironing. It helps reduce both CO_2 and local pollutants emissions in ports. The fraction of dockside energy use for ships can be as high as 60% of the total ship energy use for small ships and usually ranges 10-30% for large vessels such as oil tankers, containers or cargo vessels (DNV-GL, 2018).

exceed four seats. There are projects of hybrid 12-seater planes for short-haul flights, for instance from Zunum Aero, a start-up backed by Boeing (Reed, 2018).[35] In principle, hybrid planes will be backed by a traditional kerosene engine for take-off and landing, and would rely entirely on electric propulsion in cruising mode. In the longer term, the start-up Wright Electric, supported by Easy Jet, aims to fly an electric 150-seater plane by 2030, to cover relatively short distances such as between Amsterdam and London.

For large airline companies, full electrification, however, is unlikely in the foreseeable future. This is mostly because the energy density of batteries today is significantly too low compared with liquid fuels, especially since weight is a critical parameter in airplane design.[36] Nevertheless, Norway aims to fully electrifying all short-haul flights from 2040. Avinor, the Norwegian airport operator, aims to have the first commercial route using electric planes before 2030 (Avinor, 2019).

Energy use and well-to-wheel GHG emissions

Electricity demand and oil displacement

The global EV fleet consumed approximately 58 terawatt-hours (TWh) of electricity in 2018 (Figure 1.6), which is slightly less than total electricity consumed in Switzerland in 2017. Two-wheelers continued to account for the largest share (55%) of global electricity demand for EVs in 2018. LDVs are the mode that increased the most in 2018 compared with the previous year and accounted for 24% of power demand for electric vehicles.

Electricity demand for EVs was highest in China in 2018 at 47 TWh, 83% of the total, which is mostly attributable to two-wheelers and public buses. Electricity demand for EVs is over 5 TWh (9% of the total) in Europe and slightly more than 4 TWh in the United States.

Global electricity demand from EVs increased by 17% in 2018, slightly less than in the two previous years. EVs in 2018 continued to account for a small fraction (less than 0.5%) of global total final consumption of electricity.[37] Even in China, Norway and the Netherlands, the countries with the highest share of electricity demand from EVs, the percentage is just below 1%.

While consuming 58 TWh of electricity, the global EV stock in 2018 displaced the consumption of approximately 21 million tonnes of oil equivalent (Mtoe) (0.43 million barrels of oil per day) of oil products. The majority of oil displacement is attributable to two-wheelers (60%) followed by LDVs (23%) and buses (18%).

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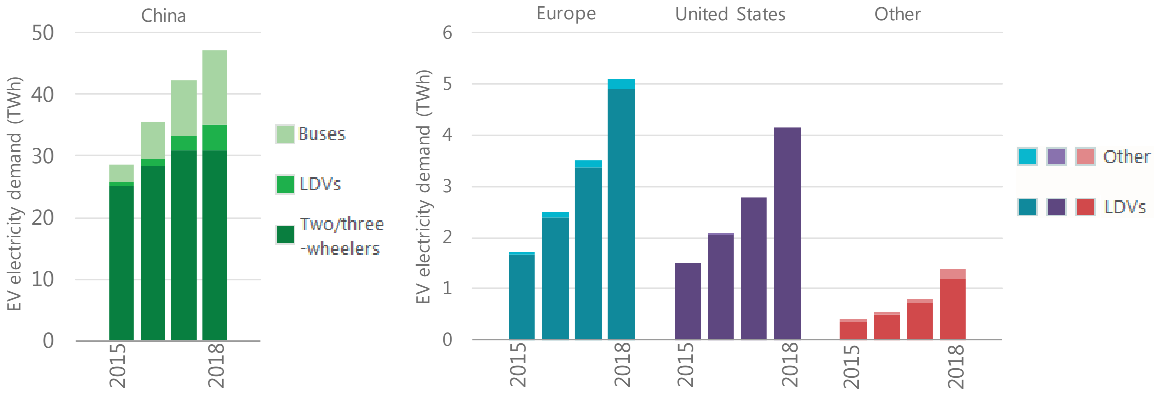
[35] The first flights were announced for 2022.

[36] In this regard, electric propulsion in aviation is being actively researched in the case of passenger and cargo drones for short trips and short-distance deliveries in urban areas. Boeing and Airbus have designed demonstration drones. Uber, in association with Boeing, is projecting first commercial flights in 2023. However, there remain technical and regulatory challenges to overcome before passenger drones fly in cities. It is unclear at this point what market segment such services would target and if they can attract and serve a large customer base.

[37] Note that the actual implication of EV charging on the power grid largely depends on the timing and rapidity of the charging events. This aspect is discussed in Chapter 5, *Implications of electric mobility for power systems*.

Figure 1.6. Electricity demand from EVs by region and type of technology, 2015-18



Notes: Electricity demand by EV mode and by country has been calculated using the following assumptions (where the range indicates the variation across countries). Passenger car: consumption (on road) 0.2-0.24 kWh/km, mileage 9 000- 20 000 km/year; bus: consumption 1.3-1.8 kWh/km, mileage 25 000-50 000 km/year; two-wheeler: consumption 0.03-0.04 kWh/km, mileage 5 000-7 300 km/year; truck: consumption 1-1.3 kWh/km, mileage 25 000-70 000 km/year. PHEVs have a share of electric driving of 55% and EV charging losses are 5%.

In this analysis, and only in this analysis, the countries considered are Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Finland, France, Germany, Iceland, India, Italy, Japan, Korea, Malaysia, Mexico, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, United Kingdom and United States. The number of electric vehicles not included in this analysis does not exceed 0.5% of the total stock.

Sources: IEA analysis based on country submissions and the Mobility Model.

China accounts for 83% of the total electricity consumed by the global EV fleet. Two-wheelers are the mode of transport accounting for most of the EV electricity demand.

Well-to-wheel GHG emissions

The 2018 EV stock emitted about 38 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq) on a well-to wheel (WTW) perspective. This compares to 78 Mt CO_2-eq that an equivalent internal combustion engine (ICE) fleet would have emitted, leading to net savings from EV deployment of 40 Mt CO_2-eq (Figure 1.7).[38,39] These savings were achieved through the combination of the high energy efficiency of the electric powertrain and the carbon intensity of the power grid. The EV fleet in China is the largest contributor to these savings, accounting for about 30 Mt CO_2, 77% of the total. This result reflects the large magnitude of the EV stock in China, rather than a significant advantage of EVs over ICE vehicles in terms of WTW CO_2 emissions given the high carbon intensity of China's power generation mix.

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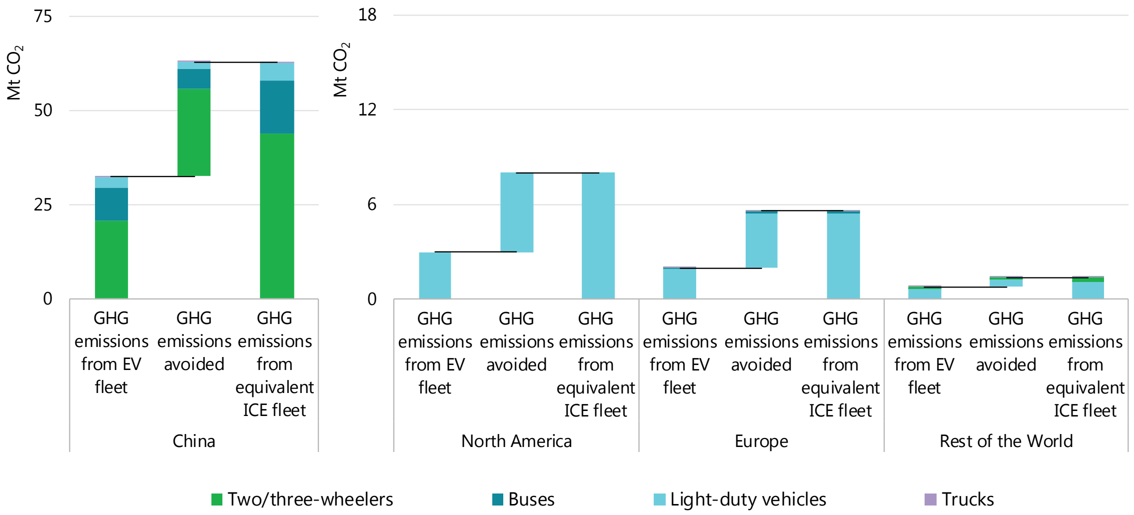
[38] These numbers have been evaluated with a well-to-wheel analysis, which accounts for well-to-tank emissions (upstream emissions due to oil extraction and processing, and to power generation and distribution) and tank-to-wheel emissions (tailpipe emissions). An analysis of life-cycle GHG emissions that takes into account the emissions due to the electric car manufacturing process is in Chapter 4.

[39] Emissions from the EV fleet are calculated by multiplying the electricity consumption by the average CO_2 intensity of electricity generation in each country. The avoided emissions are determined as the CO_2 that would have been emitted if the EV fleet was powered by ICE vehicles with a fuel economy representative of the country average.

Figure 1.7. GHG emissions avoided by EVs compared to equivalent ICE fleet by mode and region, 2018



Notes: GHG emissions from an equivalent ICE fleet indicate the WTW CO_2-eq emissions that would have been emitted if the EVs would have been ICE vehicles of equivalent size. The carbon intensity of the national power systems account for transmission and distribution losses. Light-duty vehicles include cars and light-commercial vehicles. Buses include buses and minibuses. Trucks include medium- and heavy-freight trucks.

Sources: IEA analysis based on country submissions; carbon intensity of the national/regional power systems from (IEA, 2018c); accounting for transmission and distribution losses from (IEA, 2018c).

The global EV fleet in 2018 avoided about 40 Mt CO_2-eq of emissions, with the largest contribution from EV use in China.

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2. Prospects for electric mobility development

A key step in the policy process to advance electric mobility is the establishment of standards, particularly for vehicle safety and charging infrastructure. Appropriate standards significantly reduce investment risks for the stakeholders that are integral to provide resources in the transition to expand electric mobility. Electric vehicle (EV) deployment targets, and, in some cases, bans on the sales of internal combustion engine (ICE) vehicles, are set out in public policy statements. Standards can be developed in parallel and support specific policy instruments. For example, public procurement programmes for zero-emission vehicles provide stimulus to underpin a nascent EV market, both in terms of vehicles and charging infrastructure. Since electric cars are still more expensive than ICE and hybrid models, purchase incentives often accompany initial public procurement plans to help drive the EV uptake in the private sector (both for fleets and individual vehicles).[1] This is also relevant for the early deployment of chargers. Fiscal incentives are often coupled with regulatory measures that boost the value proposition of EVs, such as waivers to access restrictions, often grounded on better environmental performances with respect to local air pollution.

There are positive signs in the deployment of EVs. As highlighted in Chapter 1, the global stock of electric passenger cars reached 5.1 million in 2018, an increase of 62% from the previous year. This chapter considers developments that affect the outlook for electric mobility, highlighting some major EV markets and industry roll-out plans. It builds upon and updates our considerable analyses on the topic, most recently the *Global EV Outlook 2018: Towards cross-modal electrification* (IEA, 2018a) and the *Nordic EV Outlook 2018: Insights from leaders in electric mobility* (IEA, 2018b).

Today, frontrunners in the electric mobility transition such as the People's Republic of China (hereafter "China") and the European Union are progressively transitioning policy approaches from purchase incentives for EVs (which remain in place) to zero-emissions vehicle mandates and/or regulatory requirements related to fuel economy, and pollutant and greenhouse gas (GHG) emissions. Recent policy announcements in several of the largest vehicle markets include: a "new energy vehicle" credit mandate for original equipment manufacturers (OEMs) in China; incentives for EV production in the European Union's carbon dioxide (CO_2) emission standard for light-duty vehicles; and a target to reduce GHG emissions by 80% for vehicles produced by Japanese automakers by 2050.

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[1] In some countries steps have been taken to improve the profile of the incentives from an equity perspective by limiting their application to low- and medium-priced vehicles. For example, Canada announced a new incentive scheme of up to CDN 5 000 for electric and hydrogen fuel cell vehicles that applies only to vehicles costing less than CDN 45 000 (Government of Canada, 2019a).There is a proposal in the Netherlands to limit direct purchase incentives for electric cars that cost less than EUR 6 000 (Euros) and incentives that reduce on a linear basis for EVs costing EUR 40 000-60 000 (Klimaatberaad, 2018). Germany has restricted incentives for EVs that cost less than EUR 60 000 (ACEA, 2019). In the United Kingdom, fully electric vehicles costing less than GBP 40 000 are exempt from the annual road tax (Government of the United Kingdom, 2019).

Policies that aim to stimulate EV uptake are raising ambitions in public procurement programmes. This is especially the case for high-use vehicles which are able to offset the increased investment cost with lower fuel costs and improved fuel economy. A key example is the Clean Vehicles Directive that boosts minimum public procurement targets for clean vehicles in a recent agreement between the European Council and the European Parliament. For chargers, key regulatory measures include minimum requirements to ensure the "EV readiness" in new or refurbished buildings and parking lots (as in the case of the European Energy Performance Buildings Directive) and the deployment of publicly accessible chargers on highway networks and in cities.

In parallel, all the leading countries that have a large automotive industry are developing industrial policies that aim to stimulate and support EV innovation and battery research. For instance, the European Battery Alliance and a recent plan for a new era of automobiles of the Japanese Ministry of Economy, Trade and Industry (METI) address strategic elements. These include: ensuring security of supply of critical materials; setting research goals for future battery performance; and accelerating research and innovation support for advanced (e.g. lithium-ion) and disruptive (e.g. solid state) technologies. In addition, they are fostering closer co-operation among industry, academia and the private sector, particularly in Japan with explicit references to co-operative approaches among industrial stakeholders.

Another positive indicator is that an increasing number of emerging economies are adopting polices to support the market uptake of EVs. Many of these markets depend on the import of second-hand EVs from advanced economies, where the EV fleet is broadening and increasing the pool of second-hand vehicles. In India, serious steps have been taken to incentivise the uptake of electric mobility by providing direct purchase subsidies. In Latin America, ministers in a number of countries are engaging in areas of common interest to progress electric mobility; several of these countries have started to incentivise and build their EV fleets.

The outcomes of these policy developments and decisions taken by major industrial stakeholders have important implications for the further uptake of EVs and the expansion of electric mobility. These dynamics are the focus of this chapter, which derive from analysis of four main components.

- At the outset, we update the development of electric mobility targets, including information on the Electric Vehicles Initiative (EVI) membership and its EV30@30 Campaign. A brief update on announcements banning the sale of ICE vehicles is included.
- Second, it reviews recent policy updates, focusing on major global players, citing selected case studies and diving into policy developments regarding both vehicles (including batteries) and charging infrastructure.
- Third, it reviews recent announcements from industry stakeholders. For vehicles, we consider OEMs in the automotive industry and battery suppliers. For charging infrastructure, we consider actors in the private sector that are involved in power supply and charging infrastructure.

Electric mobility targets: Recent developments

Country-level targets

An increasing number of governments are setting objectives for EV deployment, providing signals to manufacturers and other industry stakeholders, building confidence based on policy frameworks and mobilising investment. To date, ten countries, which together represent around two-thirds of the global electric car stock, have endorsed the EV30@30 Campaign by pledging to actively pursue the collective objective of 30% EV sales by 2030 (the target applies to the average of buses, trucks and cars) (CEM-EVI, 2018).[2] The ZEV Alliance, including a number of US states, Canadian provinces and European regions and countries, (some of which overlap with EVI membership countries), have set a common vision to strive to make all passenger vehicle sales electric by 2050 (ZEV Alliance, 2015). Worldwide, many governments have set targets for the deployment of electric mobility. Table 2.1 provides an overview of the EV deployment targets in place by mid-2019.

A smaller, yet significant, number of governments have taken a further step and announced bans on the sales of ICE cars or sales targets for 100% zero-emissions vehicle (ZEV), laying the groundwork for achieving a zero-emissions car fleet. Table 2.1 shows countries in this group. The most recent declarations are from Costa Rica, Denmark, Iceland, Israel, Portugal and Spain. Norway has the most ambitious objectives that aim to have only ZEV sales in the light-duty vehicle (LDV) and public bus segments by 2025.

Table 2.1. Announced 100% ZEV sales targets and bans on ICE vehicle sales

	2025	2030	2035	2040	2045	2050
Costa Rica						🟢
Denmark		🟢				
France				🟢		
Iceland		🟢				
Ireland		🟢				
Israel*		🟢		🔵		
Netherlands		🟢			🔵	
Norway	🟢					
Portugal				🟢		
Slovenia		🟢				
Spain				🟢		🔵

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[2] Countries that have committed to the EV30@30 Campaign are: Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden and United Kingdom.

	2025	2030	2035	2040	2045	2050
Sri Lanka				🔵		
United Kingdom				🟢		

🟢 ICE sales ban or 100% ZEV sales target 🔵 Fleet without ICEs

* 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.

Sources: Costa Rica - Presidencia de la Republica de Costa Rica (2019); Denmark - Government of Denmark (2018a); France - Government of France (2017); Iceland - Government of Iceland (2018); Ireland - Government of Ireland (2018); Israel - Government of Israel (2018); Netherlands - Rijksoverheid (2017); Norway - Avinor et al. (2016); Portugal - Republica Portuguesa (2018); Slovenia - Novak (2017); Spain - Government of Spain (2019); Sri Lanka - AFP (2017); Scotland - ChargePlace Scotland (2017); United Kingdom - Government of the United Kingdom (2017); complemented by SloCaT (2019).

City-level targets

Several municipal level administrations have pledged to restrict and/or prohibit access to certain areas for ICE vehicles.[3] Announcements made at the local level, with the stated intention to reduce air pollution and GHG emissions, are also responsible for a global push for electric buses. Examples include:

- With the C40 Fossil Fuel Free Streets Declaration more than 20 cities around the world committed to procure more than 40 000 electric public buses by 2020 (C40, 2015). In this context, Paris, London, Los Angeles, Copenhagen, Barcelona, Mexico City, Tokyo and Rome together with 19 other cities have committed to only purchase zero-emissions buses as from 2025, indicating that they will reach an all-electric fleet (battery electric or hydrogen fuel cell electric) fleet in the first-half of the 2030s (C40, 2019a).[4] Today these cities have combined bus fleets of 80 000 vehicles and will drive market growth for electric buses in the coming years (C40, 2019b).
- The California Air Resources Board has adopted a state-wide regulation to convert all city buses added to the fleet to ZEVs by 2029 and all buses on the road by 2040 (CARB, 2018).
- Beijing aims for more than half of its bus fleet to be electric by 2020 (over 11 000 vehicles) (Beijing City Council, 2018).
- Chinese Taipei announced a ban on the sale of fossil fuel-burning two- and four-wheel vehicles as part of an action plan to curb air pollution and promote renewable energy (Taiwan Today, 2017).

Policy updates: Vehicles and charging infrastructure

Charging standards

Harmonised charging standards are a key prerequisite for the deployment of electric mobility. They both ensure accessibility for EV charging networks and drastically reduce investment risks

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[3] A review of announced access restriction mandates in local jurisdictions is in Table 2.4 in the *Global EV Outlook 2018* (IEA, 2018a), available at: https://webstore.iea.org/global-ev-outlook-2018.

[4] Los Angeles aims to have a 100% zero-emission vehicle bus fleet by 2030 (Sierra Club, 2017).

for the stakeholders that are ready to mobilise resources, thereby constraining development costs. Standardisation has major implications for the nature of the hardware used for charging infrastructure and for communication protocols. We focus on these elements in this section.

Hardware

The three main characteristics that differentiate chargers include:

- Level: the power output range of the charger.
- Type: the socket and connector used for charging.
- Mode: the communication protocol between the vehicle and the charger.

Currently, 41 countries have specified a hardware charging standard.[5] Table 2.2 builds on the analysis developed for the *Global EV Outlook 2018* (IEA, 2018a) to provide an updated overview of the most prevalent charging standards. Four of the countries/regions have updated their specifications in the last year.

Table 2.2. Overview of the EV charger characteristics in key regions*

	Conventional plugs	**Slow chargers**	**Fast chargers**	
Level	Level 1	Level 2	Level 3	
Current	AC	AC	AC, Three-phase	DC
Power	≤ 3.7 kW	> 3.7 kW and ≤ 22 kW	> 22 kW and ≤ 43.5 kW	Currently < 400 kW
Australia	Type 1	IEC 62196-2 Type 2		Accepts all IEC 62196-3 standards (CCS Combo 2, CHAdeMO). Tesla has its own connector.
China	Type I	GB/T 20234 AC		Requires GB/T 20234 DC.
European Economic Area	Type C/F/G	IEC 62196-2 Type 2	IEC 62196-2 Type 2	Requires CCS Combo 2 (IEC 62196-3) and accepts all IEC 62196-3 standards (including CHAdeMO). Tesla has its own connector.
India	Type C/D/M	***IEC 62196-2 Type 2 and IEC 60309 (Bharat AC-001) (<10 kW)*** ***Bharat DC-001 (<15 kW)***	***IEC 62196-2 Type 2***	***Requires CCS Combo 2 and CHAdeMO (IEC 62196-3).***
Japan	Type B	SAE J1772 Type 1 Tesla has its own connector.		Accepts all IEC 62196-3 standards (CCS Combo 1, CHAdeMO). Tesla has its own connector.

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[5] This includes countries in the European Economic Area which includes European Union member states and three countries of the European FreeTrade Association (Iceland, Liechtenstein and Norway), and North America (Canada, Mexico and United States).

	Conventional plugs	Slow chargers	Fast chargers	
Level	Level 1	Level 2	Level 3	
Current	AC	AC	AC, Three-phase	DC
Power	≤ 3.7 kW	> 3.7 kW and ≤ 22 kW	> 22 kW and ≤ 43.5 kW	Currently < 400 kW
Korea	Type A/C	IEC 62196-2 Type 2		CCS Combo 1 (IEC 62196-3) and accepts all IEC 62196-3 standards (including CHAdeMO). Tesla has its own connector.
New Zealand	Type 1	***IEC 62196-2 Type 2***	***IEC 62196-2 Type 2***	***Requires CCS Combo 2 and CHAdeMO (IEC 62196-3).***
North America	Type B; SAE J1772 Type 1	SAE J1772 Type 1 Tesla has its own connector.	***SAE J3068***	Accepts CCS Combo 1 (SAE J1772 & IEC 62196-3) and CHAdeMO (IEC 62196-3). Tesla has its own connector.
Singapore	Type G	***IEC 62196-2 Type 2***	***IEC 62196-2 Type 2***	**Requires *CCS Combo 2 (IEC 62196-3).***
Thailand	Type A/B/C/F	***IEC 62196-2 Type 2***		***Accepts all IEC 62196-3 standards (CCS Combo 1, CCS Combo 2, CHAdeMO).*** **Tesla has its own connector.**

* Bold and italic font in the table indicates standards that have been updated since the *Global EV Outlook 2018* (IEA, 2018a).

The light blue shaded area indicates standards that are either under development or as yet undecided.

Notes: kW = kilowatt; AC = alternating current; DC = direct current; IEC = International Electrotechnical Commission; CCS = combined charging system; CHAdeMO = charge de move. The European Economic Area includes the European Union, Switzerland, Norway and Iceland. Type 2 IEC 62196-2 and 62196-3 (CCS Combo 2) connectors are mandated in the European Union by the Alternative Fuel Infrastructure Directive (EC, 2014) and apply to the European Economic Area. Conventional plugs refer to devices installed in households, the primary purpose of which is not recharging EVs. Since 2013, Tesla has had an adapter that can link the Tesla plug and the CHAdeMO plug and more recently an adapter for CCS Combo 2 in Europe.

The standards included in this table concern the plug, whereas all charging equipment needs to comply with the IEC 61851-x series for operation (e.g. safety and communication) (IEC, 2017). Battery-swapping is not included in this table, though several Asian countries continue to install battery-swapping stations. China has had a battery-swapping standard since 2012 (China National Standards, 2012).

Sources: IEA elaboration based on AFDC (2019a); Bohn (2011); CHAdeMO (2018a), (2012); CharIN (2019a), (2018a), (2018b)); European Commission (2014); EV Institute (2019); State Grid Corporation of China (2013); Government of India (2018a); Gordon-Bloomfield (2013); New Zealand Transport Agency (2017); Thailand Industrial Standards Institute (2019).

Key developments in 2018 and early 2019 include:

- Efforts to consolidate charging standards in Japan and China; the Japanese CHAdeMO Association signed a memorandum of understanding (MoU) with the China Electricity Council (GB/T standard) (CHAdeMO, 2018b). The MoU mainly revolves around the development of a common ultra-fast charging standard (up to 900 kW) including vehicle-to-grid functionality, though it also refers to the development of a new standard for two-wheelers and low-speed electric vehicles (IEEE, 2018). The MoU also involves business co-operation in markets beyond the two countries. The goal is to have a harmonised next generation standard which would still be backward-compatible with both the current Chinese and Japanese standards. Taken together, the CHAdeMO and GB/T standards can power more than 80% of the existing electric vehicles (including Tesla via an adapter).

- India made significant updates to its charging infrastructure guidelines in 2018. CCS Combo 2 and CHAdeMO have become the mandated plugs for DC fast chargers. The IEC 62196-2 Type 2 is retained as the main AC fast charging standard, as well as the Bharat standard for AC (IEC 60309) and DC slow charging (Government of India, 2018a). Unlike most other countries, India set specific charging standards for long-range EVs and heavy-duty vehicles (primarily targeting buses), requiring that 100 kW chargers are equipped with both a CCS and a CHAdeMO outlet.
- The United States has released the Society of Automotive Engineers (SAE) J3068 standard that specifically targets medium- and heavy-freight trucks (SAE International, 2018). This standard is similar to the IEC 62196-2 Type 2 and opens the possibility to use three-phase AC power (up to 166 kW) for fast chargers.
- Singapore confirmed IEC 62196-2 Type 2 as its standard for AC charging and CCS Combo2 as standard for DC charging (CharIN, 2019a).
- CHAdeMO officially released its new protocol (CHAdeMO 2.0) that enables high power charging up to 400 kW (CHAdeMO, 2018a). Besides the higher power capacity, the protocol is also compatible with the CHAdeMO plug-and-charge (PnC)[6] functionality, delivering more advanced software to enable improved functionality and inter-operability.
- Tesla is ramping up its efforts regarding charging standards. In March 2019, Tesla released its version 3 (V3) of the supercharger network. V3 enables charging up to 250 kW, which nearly doubles the recharging speed relative to V2, assisted by advanced battery management that allows for a higher state of charge (Tesla, 2019a). The first V3 (beta) charging station opened in the United States with additional openings expected in second- and third-quarter of 2019 in North America, to be followed by new stations in Europe, Asia and Oceania in fourth-quarter 2019. New Model 3 cars will have V3 available, whereas other Tesla models will be upgraded via a software update. In addition to the current accessibility to CHAdeMO standard via adapters, Tesla is making the combined charging system (CCS) standard accessible in several countries and regions. In Europe, where the CCS Combo 2 is mandatory according to the provisions of the EU Alternative Fuels Infrastructure (AFI) Directive (EC, 2014), the new Tesla Model 3 will make use of CCS Combo 2 for fast charging (Electrek, 2018). Tesla also sells a CCS adapter for the Tesla Model S and Model X for EUR 500 (USD 590 [United States dollars]). This would enable Tesla users to access a much wider network of charging stations (Auto Express, 2018). CCS Combo 2 also will be made available for the Model 3 in Australia and New Zealand, which includes retrofitting existing superchargers (InsideEVs, 2018). Tesla has not made public announcements to add CCS connectors used at existing superchargers in other regions, nor whether a similar strategy to open to CCS will be applied to the US market. The regional plug strategy is in line with the approach to deliver Model 3 cars in China with a GB/T standard (InsideEVs, 2019).

In addition to these key developments and the overview in Table 2.2, various companies have announced high power chargers of more than 400 kW (Tritium, 2019; Phoenix Contact, 2019; BMW Group, 2018; ChargePoint, 2019). This stretches the limits of existing standards to mimic conventional refuelling to serve heavy-duty vehicles. It adds challenges for power sector operators, since it adds significant loads to the electricity network and can increase peak loads, thereby stressing power system flexibility (see Chapter 5, *Implications of electric mobility for power systems*). However, some measures are being taken to limit the impact of fast chargers

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[6] The use of PnC removes the need for cards or apps with radio frequency identification. PnC allows a car to connect the charging plug into the car, which will authenticate and bill the vehicle owner directly without the need for a verification procedure through the charging pole.

during peak hours. For example, the City of Amsterdam aims to constrain the maximum capacity of chargers during peak hours[7] and Tesla plans to offset part of the potential power system constraints by adding large solar arrays to its supercharger network and upcoming mega chargers (Box 2.1) (TopSpeed, 2018; ElaadNL, 2018).

From a vehicle perspective, only a limited number of cars have batteries that allow for ultra-fast or high power charging, potentially leading to different battery costs (NREL, 2017). So far, only the Porsche Taycan has a battery that can handle 800 Volts or 240 kW (at 300 amperes) (Porsche, 2018).

Box 2.1. Dawn of the mega charger

Charging standards are spreading geographically and across modes. In 2018, expanded charging standards (e.g. pantograph charging) for power levels up to 600 kW in urban electric buses were supported by CHAdeMO, CCS and OppCharge (IEA, 2018a). Given the interest of several vehicle manufacturers to develop electric intercity buses, medium- and heavy-freight trucks (possibly even small ships and airplanes), which all require large batteries and have limited windows of time available for charging purposes, the interest in so-called mega chargers that could charge at 1 megawatt (MW) or above is destined to swell.

Tesla was the first company that used the label mega charger for the charging infrastructure envisioned for its Semi heavy-freight truck (Tesla, 2017). A specific power output was not indicated, but based on the claims on the battery of the truck and recharging speed, the recharging speed of a mega charger could be as high as 1.6 MW. However, as the Tesla Semi prototype has eight independent pins (four positive and four negative), the mega charger could be multiple plugs with lower power rating with a combined power rate above 1 MW (Teslarati, 2017).

In 2018, ChargePoint, a US-based charger manufacturer and operator, was the first company to present a concept for a connector intended for electric aircraft and heavy trucks that would use four 500 ampere interfaces with a maximum of 1 000 Volts, which would lead to a maximum combined power of 2 MW (ChargePoint, 2018).

In 2019, CharIN was the first organisation to release requirements for High Power Charging for Commercial Vehicles and to request inputs from the industry to submit proposals to assess the feasibility of mega chargers (CharIN, 2019b). The chargers would have a similar voltage as high power chargers announced to date (up to 400 kW) and would gain extra power by ramping up the current to max 3 000 ampere.

A MoU between CHAdeMO and the China Electric Council aims to develop a standard beyond current high power charging limits (400 kW), but the latest specifications reveal that the common fast charging standard is set at a maximum of 900 kW (just under mega level) (IEEE, 2018).

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[7] The FlexPower pilot in Amsterdam was able to reduce the peak power demand at public chargers while, at the same time, the average the charging rate of EVs was increased by 45% (from 4.05 kW to 5.86 kW) outside peak hours (Flexpower Amsterdam, 2018).

Communication protocols

There are differences in communication methods of the various charging protocols. Protocols rely on different physical connections and there is little scope to make these approaches compatible (IEA, 2018a). Basic charging requirements for nearly all chargers are described in the IEC 61851-1 standard (IEC, 2017). Level 1, level 2 and Tesla AC connectors have no direct communication in their cables and require off-board controls for authentication, payment and smart charging, such as via an app (ElaadNL, 2017). Level 3 AC chargers have basic signalling that only regulate the charging speed, thus requiring external controls for communication as well. In the case of DC fast chargers, CCS connectors are coupled with power line communication (PLC) protocols, while CHAdeMO, Tesla and GB/T use controller area network (CAN) communication (IEA, 2018a). The recent ISO/IEC 15118 protocol provides more functionality to enable vehicle-to-grid (V2G) communication and was added to the CCS protocol in 2018, whereas for AC charging the car manufacturer has to implement this from the vehicle perspective (CharIN, 2018c) (see Chapter 5, *Implications of electric mobility for power systems*). The option for V2G communication has been part of the CHAdeMO protocol for several years (CHAdeMO, 2019).

The use of the CAN communication, which mandates a minimum for peripheral communication (e.g. authentication, verification and payment) in DC charging, places less emphasis on the vehicle and more emphasis on the charger, which is effectively the master for any additional (and more complex) communication (for example those that govern smart charging practices and require communication with the power supplier). This has the implicit consequence of giving greater relevance to the role of the charging point operator (as opposed to the vehicle) and it appears consistent with the prominent role of TEPCO (a major utility in Japan and a supporter of the EV30@30 Campaign) in the development of the standard (Anegawa, 2010). Similarly, the use of the more complex PLC protocol in the CCS standard places more emphasis on the role of the vehicle (which is the master for more complex communications), but the latest version of the standard also provides that the master role can go to the charging point operator. This is consistent with the strong engagement of the car industry in the CharIN consortium (CharIn, 2019c), the main proponent of the CCS specifications.

The recent developments of different adapters (conversion device between standards) between charging standards (and therefore also the capacity for EVs to handle the related communication protocols) show that the issue of the double standardisation currently in place and the related differences on communication protocols (CAN versus PLC) can be overcome. Even if this does come at a net cost (which could be avoided if multiple standards converge into one standard), recent developments, (e.g. Tesla case), indicate that costs for facilitating the increase in flexibility to use multiple chargers are manageable.

Supporting policies

Many policy developments in 2018 and 2019 support the uptake of EVs and the roll-out of charging infrastructure. They will have varying levels of impact on the EV market. Some key regions cover all policy types for EV uptake and electric vehicle supply equipment (EVSE), whereas others focus on specific measures (Table 1). This section also provides updates detailed by country.

Table 2.3. Update of EV deployment policies in selected regions, 2018/19

		Canada	China	European Union	India	Japan	United States
Regulations (vehicles)	ZEV mandate	✓*	✓				✓*
	Fuel economy standards	✓	✓	✓	✓	✓	✓
Incentives (vehicles)	Fiscal incentives	✓	✓	✓	✓		✓
Targets (vehicles)		✓	✓	✓	✓	✓	✓*
Industrial policies	Subsidy	✓	✓			✓	
Regulations (chargers)	Hardware standards**	✓	✓	✓	✓	✓	✓
	Building regulations	✓*	✓*	✓	✓		✓*
Incentives (chargers)	Fiscal incentives	✓	✓	✓		✓	✓*
Targets (chargers)		✓	✓	✓	✓	✓	✓*

*Indicates that it is only implemented at state/local level.

** All countries/regions in the table have developed fundamental standards for electric vehicle supply equipment (EVSE). Some (China, European Union, India) mandate specific minimum standards, while Canada, Japan and United States do not.

Notes: A check indicates that the policy is set at national level. Hardware standards are described in Table 2.2. Building regulations means an obligation to install chargers in new and renovated buildings. Charger incentives include direct investment and purchase incentives for public and private charging.

Canada

The key policy updates that are expected to drive the transition to electric mobility in Canada are summarised in Table 2.4.

Table 2.4. Overview of EV and EVSE policies in Canada, 2018/19

Country	Policy type	Description
Canada	**Incentive** (vehicles)	Purchase incentive for ZEV available to individuals and businesses.
	Targets (vehicles)	Federal government aims for ZEVs to be 10% of new passenger light-duty vehicle sales by 2025, 30% by 2030 and 100% by 2040.
	Industrial policy	Incentives to OEMs for providing ZEVs on the Canadian car market.
	Incentives (chargers)	Incentives to support EVSE deployment.
	Target (chargers)	900 new fast chargers.

At the beginning of 2019, the Canada's federal government announced new deployment targets for zero-emissions cars:[8] 10% of new sales by 2025, 30% by 2030 and 100% by 2040 (Government of Canada, 2019a). Negotiations between the federal government and sub-national governments are underway to establish how each province and territory will contribute to the commitments. To support the EV targets, the federal government has enacted a number of measures (Government of Canada, 2019a). Those with direct relevance for EVs include:

- A budget allocation of CAD 300 million (Canadian dollars, USD 225 million) over three years for a federal purchase incentive on a ZEV car of up to CAD 5 000 (USD 3 750).
- CAD 5 million (USD 3.8 million) over five years to induce OEMs to supply ZEVs to the domestic market.
- A 100% accelerated capital cost allowance,[9] for medium- and heavy-duty ZEVs purchased by businesses.
- A budget allocation of CAD 130 million (USD 100 million) over five years to deploy new chargers (and hydrogen refuelling stations).
- A budget allocation of CAD 120 million to support the deployment of a coast-to-coast network of EV fast chargers (together with natural gas refuelling along key freight corridors and hydrogen stations in metropolitan centres), to develop codes and standards aligned with the United States and to fund research and development (R&D) of next generation charging technologies.
- The allocation of part of the CAD 800 million (USD 590 million) strategic innovation fund to stimulate ZEV manufacturing in Canada (Government of Canada, 2019a).

Even if the ambition stated in Canada's targets will need more policy action to be further substantiated, it signals clear intentions that Canada is more likely to be placed in the ambitious side of the policy developments taking place in the North American car market, along the lines of the group of 20 US states following the leadership of California.

Besides the efforts of the federal government, some provinces are implementing ambitious policies to promote the uptake of electric mobility. Quebec has a ZEV mandate similar to the one in California (Government of Quebec, 2019). British Columbia has recently announced legislation for the most stringent ZEV mandate worldwide: 30% ZEV sales by 2030 and 100% by 2040 (Government of British Columbia, 2019).[10]

China

China has taken large steps to transition its ICE car fleet to new energy vehicles (battery electric vehicles [BEVs], plug-in hybrid electric vehicles [PHEVs] and fuel cell electric vehicles [FCEVs]) in recent years. The key policy updates that are expected to drive the transition to electric mobility in China are summarised in Table 2.5.

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[8] Given the unique characteristics of its transportation system (e.g. large geography, long distances between urban centres and extreme climate), Canada has included FCEV, BEV and PHEV in its definition of ZEVs. There is no specific breakdown or expectation on which technology will make up what percentage.

[9] This is a measure allowing businesses in Canada to deduct the cost of their investment more quickly, thus increasing the attractiveness of making capital investments.

[10] This policy is in line with Canada's target described in Table 2.4. It is worth noting that for Canada as a whole this is a target, while for British Columbia, it is a mandate.

Table 2.5. Overview of EV and EVSE policies in China, 2018/19

Country	Policy type	Description
China	**Regulations** (vehicles)	Proposal to tighten average fuel economy for PLDV fleet in 2025. From January 2019, investments in new ICE production plants are prohibited. Voluntary standard for BEV fuel economy.
	Incentive (vehicles)	Gradual reduction of the subsidies available to the electric car industry.
	Industrial policy	New energy vehicle (NEV) credit mandate requires OEMs to produce a minimum share of NEV cars.
	Incentive (chargers)	Local incentives for private home charging and public charging.
	Target (chargers)	Around 150 000 public chargers by 2020.

Vehicle policies

The NEV credit mandate went into effect in 2018, setting a minimum production requirement for the car manufacturing industry, which is a central pillar of China's policy to promote EVs. It sets a minimum requirement for the production of NEVs (PHEVs, BEVs and FCEVs), with some flexibility offered through a credit trading mechanism that privileges BEVs with larger ranges and higher energy efficiency (and FCEVs with higher power ratings) (IEA, 2018a).

A fuel economy standard for light-duty vehicles has been in place in China since 2005. Phase IV, which took effect in January 2016, set a target for a new sales fleet average specific fuel consumption of 5 litres per 100 kilometres (L/100 km) by 2020 (based on the New European Driving Cycle [NEDC]) (TransportPolicy, 2019). A new standard for passenger cars of 4 L/100 km (NEDC) for 2025 was proposed in January 2019 and released for comment (Government of China, 2019a). Light-commercial vehicles (LCVs) are subject to standards that differ both in terms of target value and compliance structure; individual LCV models are subject to specific fuel consumption targets (TransportPolicy, 2019).

In February 2019, the State Administration of Market Supervision and the National Standardization Administration Committee announced a national voluntary standard for "energy consumption rate limits for electric vehicles" (Government of China, 2019b; China Standardization Administration, 2018). This is the world's first technical standard for specific energy consumption for BEVs. The voluntary standard sets maximum energy consumption requirements in kilowatt-hours per 100 kilometres (kWh/100 km) for 16 weight classes for vehicles up to 2 510 kilogrammes (kg). There are two phases, where phase 2 is a tightening of the recommended phase 1 standard. The first phase will be implemented 1 July 2019 and is based on existing passenger models that entered the Chinese market in 2019. The second phase is recommended for implementation in 2020. All models in 2019 already meet the phase 1 limit and 80% of the models meet the phase 2 limits (Sohu, 2019).

Charging infrastructure policies

China plans to deploy 12 00 stations to swap batteries, 4.3 million private EVSE outlets and 500 000 publicly accessible chargers to serve 5 million EVs[11] by 2020, and it intends to differentiate its target geographically to address asymmetrical development within its electric car market (IEA, 2018a). China is among the major global economies that ramped up their ambition to install fast charging facilities along highways (IEA, 2018a). The national government has urged local authorities to eliminate subsidies that support EV purchases to instead focus on charging infrastructure, emphasising the importance to align infrastructure investments with EV uptake (China Daily, 2019). More than 30 cities in China now offer incentives for private home or public charging (Hove, 2019). State Grid Corporation of China and China Southern Power Grid continue to roll out charging infrastructure to meet their 2020 targets of 120 000 and 25 000 chargers respectively (Teamwork Global Group, 2018; Government of China, 2016; State Grid EV Service, 2018). The State Grid Corporation of China reached more than 6 000 charging stations with more than 57 000 charging points along 31 000 km of highway (around 25% of all highways), whereas China Southern Power Grid added another 10% to that number (State Grid EV Service, 2018; Xinhua, 2018a).

Industrial policies

Alongside stimulating consumer demand for EVs, China has made the development of the NEV industry a top priority. Over the past years, China has employed an intensive effort, led by the government, to build a full supply chain of domestic NEV production, from the assembly of the vehicles to the production of batteries and key vehicle components. The 2018 NEV credit mandate is an important tool supporting this development. It includes differentiated incentives for vehicles based on their battery characteristics. It aims to stimulate innovation and the capacity to induce consolidation among battery manufacturers, giving increased relevance to those capable of deploying the technologies offering the best performance.

China also has a national New Energy Vehicle Subsidy Program, updated each year, which supports the adoption of EVs. The level of subsidy allocated though this programme, which depends on three characteristics (vehicle range, energy efficiency and battery pack energy density) is intended to stimulate innovation and induce consolidation in the battery manufacturing industry. A programme amendment in February 2018 lowered the subsidy level for PHEVs and low-range BEVs (<300 km) and increased the levels for long-range BEVs (>300 km) (IEA, 2018a). In April 2019, the government announced modification that go in the same direction. Starting in late June 2019, the overall amount of subsidies available to the car industry will be scaled back and subsides will focus on the battery electric cars with the best performance. The subsidy for battery electric cars with driving ranges of 400 km and above will be cut by half to RMB 25 000 (USD 3 700) per vehicle, and electric cars need to have a range of at least 250 km compared with 150 km previously to qualify for any subsidy (Bloomberg, 2019a; Government of China, 2019c). For commercial vehicles, a mileage requirement is also a prerequisite for receiving a subsidy. A portion of the subsidy will be paid at the vehicle sale/purchase, but the full subsidy amount can only be claimed if the vehicle reaches a mileage of 20 000 km within two years (Government of China, 2019c). Overall, subsidies on purchases of EVs, including buses and trucks will be scaled back in stages. Some

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[11] Deploying 4.3 million private EVSE outlets for 5 million EVs leads to a ratio of 0.93 EVSE outlet per EV, whereas 500 000 public charging points for 5 million EVs is 0.1 chargers per EV, similar to the EU Alternative Fuels Infrastructure Directive.

of the funds made available by the subsidy reform will be re-channelled to support development of charging infrastructure.

As of January 2019, investment in newly built independent enterprises producing ICE cars and ICE car companies (listed by the Chinese government) with poor energy consumption performance are banned (China's National Development and Reform Commission, Ministry of Science and Technology & Ministry of Finance and Industry, 2019).[12]

European Union

The key policies that are expected to drive the transition to electric mobility in the European Union are summarised in Table 2.6.

Table 2.6. Overview of EV and EVSE policies in the European Union, 2018/19

Country	Policy type	Description
European Union	**Regulations** (vehicles)	Tightened CO_2 emissions standards for LDVs in 2025 and 2030 with credits for EV sales, following the 95 g CO_2/km (NEDC) requirement for 2021. CO_2 emissions standards for trucks in 2025 and 2030. Clean Vehicle Directive mandates public procurement for clean LDVs and HDVs. Increasing number of member states announcing ICE and diesel bans.
	Incentive (vehicles)	Incentives schemes for zero- and low-emission PLDVs in 33 European countries.
	Industrial policy	European Battery Alliance to promote the development of a battery industry in Europe.
	Regulation (chargers)	Energy Performance of Buildings Directive approved in the EU mandates EV chargers for new and renovated buildings.
	Targets (chargers)	Through the AFI Directive, EU member states have set EVSE deployment targets for 2020, 2025 and 2030.

Notes: g CO_2/km = grammes of carbon dioxide per kilometre; HDVs = heavy-duty vehicles.

Vehicle policies

In April 2019, the European Parliament adopted new CO_2 emission standards for LDVs such that new cars in 2030 need to reduce CO_2 emissions per km by 37.5% compared with the 95 grammes of CO_2 per kilometre (g CO_2/km) (NEDC) requirement for 2021, and new vans by 31% compared with the 147 g CO_2/km (NEDC) requirement for 2020 (EC, 2019a). This is a strengthening of the standard adopted only two years earlier, in 2017, when the European Commission reinforced the CO_2/km emission standards with a 15% reduction for new vehicles in

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[12] Companies producing ICE passenger vehicles cannot circumvent the regulatory limitations restricting ICE investment by starting to producing ICE commercial vehicles, and existing ICE car companies will not be allowed to relocate to other provinces (except for the projects which are listed in the Regional Development Plan by the central government, or the projects whose ownership structure remains unchanged).

2025 and a 30% reduction in 2030 (IEA, 2018a). The regulation allocates a specific emissions target for each manufacturer. EV production thresholds are set to encourage the sale of more zero- and low-emission vehicles, including BEVs and PHEVs. 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 (up to 5%) (European Council, 2019a). Both PHEVs and BEVs are able to benefit from this lower overall stringency.[13]

In February 2019, the European Parliament and the European Council reached a provisional agreement on the first-ever CO_2 emission standards for heavy trucks (EC, 2019b). In the targets, average CO_2 emissions from new heavy trucks need to be 15% lower by 2025 and at least 30% lower by 2030, relative to 2019. The 2030 target is binding, but is subject to review in 2022 (European Parliament, 2019a; European Council, 2019b; ACEA, 2019; Transport & Environment, 2019a).[14] The agreement also includes an incentive scheme allowing manufacturers that reach 2% market share of zero- and low-emission vehicles to benefit from a relaxed stringency of the overall CO_2 emissions standards, and allows for the use of super credits to meet the 2% market share threshold, but only in 2025 .

The European Union is also stimulating the market for zero- and low-emissions vehicles by encouraging their use in public procurements. In February 2019, the European Council and the European Parliament reached a provisional agreement on a revision of the Clean Vehicles Directive of 2009 (2009/33/EC) (European Council, 2019c; European Parliament, 2019b). The reform increases the minimum target levels for public procurement for clean LDVs, trucks and buses for 2025 and 2030.[15] The binding requirements are expressed as minimum percentages of clean vehicles in the total number of road transport vehicles covered by the aggregate of all procurement contracts and public service contracts. The specific minimum percentages differ by country. For LDVs, member states must reach a share between 17.6% and 38.5% by 2025. For buses, member state targets range from 24% to 45% (2025) and from 33% to 65% (2030) and half of the minimum target for the share of clean buses has to be fulfilled by procuring zero-emissions vehicles (i.e. buses without an internal combustion engine). For trucks, targets range from 6% to 10% (2025) and from 7% to 15% (2030).

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[13] The extent to which BEVs can benefit depends on their CO_2/km tailpipe emissions. For PHEVs it depends on their all-electric range and on a corrective factor that enhances their capacity to generate credits. This has been flagged as an issue that may effectively reduce the overall ambition of the European Union policy (Transport & Environment, 2019b). Other issues recently flagged in this regard include an allowance to increase the overall of g CO_2/km threshold thanks to multiplicative factors applied to zero- and low-emissions vehicles sold in 14 EU countries that have nascent markets, as well as the inclusion of Norway, which aims to have 100% zero-emissions cars by 2025, for the accounting of the g CO_2/km average across the European Economic Area (Transport & Environment, 2019b).

[14] The new regulation applies, in a first step, to four subcategories of large heavy-duty trucks covering about 70% of the total emissions of the truck fleet. Trucks, other than large heavy-duty ones, and intercity buses will not be subject to the CO_2 reduction requirements for 2025, but should be taken into account for the purpose of the incentives given to zero and low-emissions vehicles. In 2022 (and for the 2030 requirements), the scope of the regulation will be extended to include other vehicle types such as smaller trucks, urban and intercity buses, and trailers.

[15] For LDVs, the proposal provides a definition of clean vehicles based on combined CO_2 and air pollutant emissions thresholds. For heavy-duty vehicles, it uses a definition requiring the use of alternative fuels which serve as a substitute for oil and have the potential to contribute to the decarbonisation and enhanced environmental performance of the transport sector. These include electricity, hydrogen, liquid biofuels, synthetic and paraffinic fuels, natural gas (including biomethane) and liquefied petroleum gas, and exclude fuels produced from high indirect land-use change-risk feed stock for which a significant expansion of the production area into land with high-carbon stock (European Parliament, 2019b; EC, 2014).

Several European countries also recently implemented or updated incentive schemes for electric mobility. In 2018, 33 European countries (26 within the European Union) had a national EV incentive for passenger cars. Italy is the last big European country to implement a purchase incentive for electric cars. At the end of 2018, Italy proposed a "bonus-malus" incentive policy for the 2019-21 period (Gazzetta Ufficiale, 2019). The bonus (subsidy) can be up to EUR 6 000 (USD 7 100) for cars emitting less than 20 g CO_2/km up to a malus (tax) of EUR 2 500 (USD 2 800) for cars emitting more than 250 g CO_2/km (values measured according to the NEDC test procedure). The bonus level is similar to France and Sweden, whereas the malus is only one-quarter of the maximum used in France (Transport Agency Sweden, 2019; Government of France, 2019; Gazzetta Ufficiale, 2019) and comparable to Sweden. Bulgaria implemented a purchase subsidy of up to EUR 10 000 (USD 11 800) per BEV (EAFO, 2018). Outside the European Union, Ukraine extended the derogation of the value-added tax for EVs from the end of 2018 through 2022 (Government of Ukraine, 2018). Besides incentives for electric cars, Germany initiated support for electric bus purchases in 2018, providing up to EUR 70 million (USD 83 million) through 2021 (IEA, 2018a).

Charging infrastructure policies

The EU Alternative Fuels Infrastructure Directive requires countries in the European Union to set deployment targets for publicly accessible chargers in 2020 (mandatory), 2025 and 2030 as part of their national policy frameworks (EC, 2014). The same directive includes the definition of indicative targets for the deployment of chargers along the Trans-European Network for Transport (TEN-T) core network. The analysis developed in the *Global EV Outlook 2018* (IEA, 2018a) indicated that the publicly accessible charging points indicated by the submissions for 2020 fall short of the publicly accessible charging points required across the European Union (as indicated in the Action Plan on Alternative Fuels Infrastructure) (EC, 2017). However, as several countries are expected to exceed the deployment targets, the ratio of one publicly accessible charger per ten cars is likely to be achieved in 2020 (IEA, 2018a). Individual EU member states have set targets for chargers in order to electrify their government fleets. For example, in 2019, the Netherlands committed to install 2 000 charging points to support electrification of its government fleet by 20% in 2020 and 100% by 2028 (Rijksoverheid Government of the Netherlands, 2019).

The Energy Performance Buildings Directive (EPBD) was approved in the European Union in May 2018. It requires member states to specify minimum requirements for charging infrastructure in new and renovated buildings by March 2021 (EC, 2018a). For new or renovated non-residential buildings, the EPBD mandates at least one-fifth of the parking places to be equipped with conduits allowing the installation of chargers. Moreover, at least one charging point needs to be installed if more than ten parking places are available. For new or renovated residential buildings with more than ten parking places, all parking places need to be prepared with conduits for future chargers.

The EPBD has to be implemented within national building codes in order to take effect. Spain, France and Portugal already had charging infrastructure mandates within their national building codes before the EPBD update (Government of France, 2016; Government of Spain, 2017; IEA HEV TCP, 2016). Denmark is the only EU country that has published an updated building code since the EPBD update (Government of Denmark, 2018b), though it was too close to its approval to include a rule on charging infrastructure.

Various European countries provide incentives at a city level as well. For example, by mid-2019 in the Netherlands, 192 municipalities (55% of the total), including nearly all big cities, had adopted the approach to allow on-demand deployment of street public charging for EV users without private parking, initiated by the municipality of Amsterdam and highlighted as a good practice in the *Global EV Outlook 2017* (IEA, 2017; Nederland Elektrisch, 2019). The United Kingdom offers incentives through its network of local councils.[16]

Industrial policy

The European Commission has identified batteries as one of the nine strategic value chains for the competitiveness of EU industry and for achieving decarbonisation targets. In 2017, the European Commission launched the European Battery Alliance, a platform gathering countries, key industrial and innovation stakeholders, and banks to work together to develop an innovative, sustainable and competitive battery "ecosystem" in Europe (EC, 2019c). With the launch of its "Strategic Action Plan for Batteries", in 2018, the European Commission has set concrete measures to support this initiative (EC, 2018b). The main goals of the action plan are to: secure access to raw materials; support European battery cell manufacturing at scale and develop a comprehensive competitive value chain in Europe; strengthen industrial leadership through strengthened EU research and innovation; develop and strengthen a highly skilled workforce in all parts of the battery value chain; support the sustainability of EU battery cell manufacturing industry with the lowest environmental footprint possible; and ensure consistency with the broader enabling and regulatory EU policy framework. The determination to develop a battery industry in the European Union is also demonstrated by the willingness to encourage more risk-taking and step up investment in research and innovation, facilitating access to public funding that would be compatible with the European state aid rules for important, large, highly innovative and transnational battery manufacturing projects with European Interest (Auto Alliance, 2018; IFRI, 2019; EC, 2019d). Germany committed to fund battery production in the European Union with up to EUR 1 billion (USD 1.1 billion), while France developed a EUR 700 million (USD 800 million) action plan to support the battery value chain. In 2018, France and Germany committed to enhance industrial co-operation for the production of battery cells, a development considered indispensable not only for the electrification of the automotive sector, but also for storing electricity produced from variable renewables and for accelerating decarbonisation of power systems (Government of France, 2018).

India

The key policy updates that are expected to drive the transition to electric mobility in India are summarised in Table 2.7.

Table 2.7. Overview of EV and EVSE policies in India, 2018/19

Country	Policy type	Description
India	**Regulation** (vehicles)	CO_2 emissions standards for LDVs in 2022.
	Incentive (vehicles)	Approved FAME II, providing incentives for public and shared three-wheelers, LDVs, buses and private two-wheelers.
	Target (vehicles)	Target of 30% EV sales by 2030 across all modes.

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[16] However, more than a quarter of local councils (around 100) in the United Kingdom are limiting their support for charging infrastructure as council budgets were cut for 2019 (The Climate Group, 2019a).

	Incentive (chargers)	FAME II dedicates 10% of the budget to the deployment of EVSE.
	Targets (chargers)	Targets for public chargers in cities and along highways.

Vehicle policies

In February 2019, the government approved the proposal for implementation of the "Faster Adoption and Manufacturing of Electric Vehicles in India Phase II" (FAME Phase II) scheme that reduces the upfront purchase price of hybrid and electric vehicles (The Gazette of India, 2019). The Phase II scheme includes the allocation of a USD 1.4 billion budget to encourage the uptake of electric vehicles and will be implemented over a period of three years from April 2019. It follows an attempt to kick-start the Indian EV market from public procurement programmes that, so far, have not delivered to the extent expected.[17] It scales up the earlier FAME scheme, which was launched in 2015. The emphasis of Phase II will be on public and shared transportation. It includes incentives for electric three- and four-wheelers (including rickshaws), as well as for buses, where the incentives are mainly applicable to those vehicles used for public or shared transportation or for commercial purposes. In the case of electric two-wheelers, the incentives are targeted to private vehicles. To encourage more advanced technologies, it is indicated that the incentives only apply to those vehicles using advanced battery chemistries such as a lithium-ion battery, although it is not clear which chemistries are excluded from the incentive.

Charging infrastructure policies

India's FAME Phase II scheme includes substantial commitments for charging infrastructure (The Gazette of India, 2019). Specifically, it sets an indicative target of 2 700 charging stations in cities above 4 million inhabitants, fast charging stations along major highways at an interval of about 25 km each and ultra-fast charging stations every 100 km (Government of India, 2018a; Government of India, 2019a). India's FAME Phase II policy has also allocated INR 10 billion (Indian rupees, USD 145 million) between 2019 and 2022 to EVSE deployment. This is nearly 10% of its total budget.

India also updated its Model Building By-Laws from 2016 to mandate 20% of parking space within residential and non-residential complexes must provide EV charging infrastructure (Government of India, 2019b) and placed a cap on the maximum tariff that can be asked by a public charging station (15% above the average cost of supply) (Government of India, 2018a).

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[17] India's Energy Efficiency Services Limited (EESL) aims to replace 500 000 government cars over a period of three to four years (India Energy Efficiency Services Limited, n.d.). In September 2017, EESL put out its first public EV procurement tender for 500 electric cars, followed by another tender for 10 000 electric cars in March 2018 (Government of India, 2018b). However, in January 2019 the plan to complete the distribution of the first lot of 10 000 electric cars ordered for government use was delayed for a second-time to September 2019, as only 10% of the order, initially expected to be delivered by June 2018, had been delivered (Saluja, 2019).

Japan

The key policy updates that are expected to drive the transition to electric mobility in Japan are summarised in Table 2.8.

Table 2.8. Overview of EV and EVSE policies in Japan, 2018/19

Country	Policy type	Description
Japan	**Regulations** (vehicles)	Fuel economy standards for HDVs in 2025. Fuel economy standards for LDVs in 2020 and 2030.
	Incentives (vehicles)	Tax incentives and/or exemptions for the acquisition of HEVs, PHEVs, BEVs and FCEVs.
	Targets (vehicles)	15-20% EV sales in PLDVs by 2020 and 20-30% by 2030.
	Industrial policy	Reduction of 80% of GHG emissions per vehicle produced by Japanese automakers by 2050.
	Incentives (chargers)	Available for charger deployment.
	Targets (chargers)	Targets for public chargers in cities and along highways.

Vehicle policies

In March 2019, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) introduced new fuel economy standards for heavy vehicles running on diesel, including trucks and buses (Government of Japan, 2019a).[18] According to the regulation, new trucks and other heavy vehicles should have a fuel economy of 7.63 kilometres per litre (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 13.4% relative to the 2015 standards). The regulation has relevance for electric mobility due to its capacity to improve efficiency, but it does not have specific provisions for EVs.

Japan also updated its fuel economy standard for LDVs to align it with the 2030 next generation vehicle target. The update sets a limit of 25.4 km/L (3.9 L/100 km), calculated with the Worldwide harmonized Light-duty Test Cycle (WLTC) (Government of Japan, 2019b), tightening the 2020 limit of 19.4 km/L (5.2 L/100 km)[19] and opening up the scope for increased vehicle electrification.[20]

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

[19] These values are expressed here in WLTC terms, but were initially set according to the JC08 test cycle. In its original formulation, the 2020 threshold was 20.3 km/L (4.9 L/100 km) (JAMA, 2018).

[20] The 2020 target, already met in 2014, had only a limited scope for electrification (IEA, 2019).

Japan also uses tax incentives for the purchase of hybrid electric vehicles (depending on the degree of fuel economy improvements), PHEVs, BEVs and FCEVs. It exempts PHEVs, BEVs and FCEVs from purchase and weight taxes as part of the clean energy vehicle subsidies scheme.[21]

Charging infrastructure policies

Japan's direct support for charging infrastructure has been decreasing in recent years. It allocated JPY 100.5 billion (Japanese yen, USD 1 billion) to charging infrastructure in the first-half of the last decade (Marchetti, 2013). The budget allocation fell to JPY 6.9 billion (USD 63 million) between 2016 and 2019.[22] This is partly due to the fact that roughly a third of the 2013-15 budget was expended. In addition to the incentives, Japan's New Era of Automobiles Strategy includes plans to harmonise future charging standards, which is fostering collaboration with China (Government of Japan, 2018). The New Era of Automobiles Strategy provides support to various R&D projects for the 2018-23 period that are assessing the feasibility of wireless charging and vehicle-to-grid applications.

Industrial policy

In April 2018, METI launched a strategic commission for a "new era of automobiles", which is developing a long-term goal and strategy for the Japanese automotive industry to tackle climate change. An interim report of the strategic commission outlines a 2050 goal to reduce 80% of GHG emissions per vehicle produced by Japanese automakers (Government of Japan, 2018). For passenger vehicles, the ambition outlined in the interim report is more ambitious at 90% reduction of GHG emissions per vehicle to be achieved with a 100% market share of EVs (HEVs, PHEVs, BEVs or FCEVs). Importantly, METI's strategic commission specifies that its goal is to realise well-to-wheel zero emissions, thus linking the strategy to its efforts to fully decarbonise the energy supply (electricity and hydrogen) (Government of Japan, 2018). The strategy also states the ambition to stimulate innovation in terms of "how vehicles are used", for example looking into concepts such as mobility as a service (MaaS), and connected and autonomous driving.

Regarding batteries, the strategy makes explicit references to a co-operative approach across industrial stakeholders, to the formulation of policies on joint procurement and stock of resources (such as cobalt). Moreover, it includes elements related to research and innovation in "next generation electrification technology", citing ambitious targets for automotive batteries, including a cost reduction target of JPY 10 000 per kilowatt-hour (kWh) (USD 90/kWh) for solid state batteries and an energy density objective of 500 watt-hour per kilogramme (W-h/kg). Fuel cell stacks are also covered, with a target of 75% price reduction for the stack by 2025. Altogether, this strategy provides a clear implicit signal of the ambition to phase out the production of ICE vehicles by Japanese automakers, and the vision of METI to fully transition passenger vehicles to a zero-emissions fleet.

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[21] In 2017, the latter had a budget allocation of JPY 13.0 billion (USD 116 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 22 million) to promote FCEV buses utilising hydrogen generated by renewable energy (Sato, 2018).

[22] Personal communication with Zuiou Ashihara, Japanese Ministry of Economy, Trade and Industry. A similar magnitude is also indicated in Sato (2018). Subsidy for projects to build hydrogen supply facilities totalled JPY 5.7 billion (USD 5 million) in 2017 (Sato, 2018).

Korea

The key policy updates that are expected to drive the transition to electric mobility in Korea are summarised in Table 2.9.

Table 2.9. Overview of EV and EVSE policies in Korea, 2018/19

Country	Policy type	Description
Korea 	**Regulations** (vehicles)	Fuel economy standards for LDVs in 2020.
	Incentives (vehicles)	Subsidies and rebates on purchase taxes, reduced highway toll fees and public parking fees.
	Targets (vehicles)	Stock of 430 000 BEVs by 2022.
	Industrial policy	Target to increase electric car production ten-fold by 2022, industries benefit of liquidity and loan support.
	Incentives (chargers)	Available for both public and private chargers.
	Targets (chargers)	10 000 fast EV chargers by 2022.

Vehicle policies

Korea aims to have 430 000 BEVs and 67 000 FCEVs on the road by 2022 (Government of Korea, 2019a; Manthey, 2018). In 2019, the objective is to register 46 000 passenger cars and more than 1 300 heavy-duty BEVs, and initiate hydrogen-fuelled public buses in seven major cities, including Seoul and Busan (Government of Korea, 2019b).

Korea supports the increased uptake of EVs with a number of measures, including subsides and rebates on national and local vehicle purchase taxes, reduced highway toll fees and public parking fees.[23] It also gives priority to low-emissions vehicles in public procurement programmes.

Tax rebates per EV (including BEVs and FCEVs) are capped at a maximum of KRW 5.3 million (Korean won, USD 4 500) (Korea Environment Corporation, 2019). The number of low-carbon vehicle that can benefit from from national subsidies (available on the top of the tax rebates) increased from 32 000 vehicles in 2018 to 57 000 in 2019 (Government of Korea, 2019a). BEV subsidies per vehicle are capped at a maximum of KRW 19 million (USD 16 400, up from KRW 14 million [USD 12 000] in 2018) and PHEVs at KRW 5 million (USD 4 300) (Government of Korea, 2019a).[24]

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[23] In Seoul, EVs are exempt from parking fees for the first hour used for charging and can benefit from 50% discount for additional hours (Korean Environment Corporation, 2016).

[24] By comparison, the FCEV subsidy cap is KRW 36 million (USD 31 000). Despite the increased cap, the amount of EV subsidy from the government (per vehicle) has declined from KRW 12 million (USD 10 million) to KRW 9 million (USD 7.7 million) (Government of Korea, 2019a). Subsidies for an additional purchase of a vehicle within two years of the first purchase are not allowed. Institutions buying a large number of vehicles for research purposes will also not be eligible for subsidies (Government of Korea, 2019a).

Charging infrastructure

The government targets for 2022 are 10 000 fast EV chargers (with 1 200 added in 2019) and 310 refuelling stations for FCEVs (46 added in 2019) (Government of Korea, 2019a; 2019b).

In 2019, the deployment of chargers will benefit from subsidies of KRW 3.5 million (USD 3 000) for publicly accessible slow chargers,[25] KRW 1.3 million (USD 1 200) for private chargers[26] and KRW 0.4 million (USD 350) for portable chargers (Government of Korea, 2019a). For fast chargers, subsidies were at KRW 35 million (USD 30 000) in 2018 (Korea Environment Corporation, 2018). Fast chargers are restricted to collective entities and not available for private individuals.

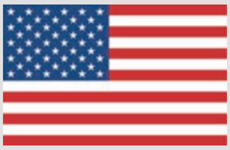
Industrial policy

Like Japan, Korea has ambitions to scale-up overseas sales of low-emission vehicles, with a goal to boost production capacity of zero-emissions cars ten-fold, from the current 1.5% to more than 10% by 2022. To encourage this, manufacturers will receive support to promote ZEV exports in the form of liquidity support and loan guarantees (Government of Korea, 2018). The government also anticipates that BEV exports will increase seven-times from the current 36 000 units to 250 000 units, while exports of FCEVs will rise to 5 000 a year by 2022 (Government of Korea, 2018). To help reach these ambitious targets, the government will increase support for R&D in the areas of chips and batteries to develop key technologies such as solid state, lithium-sulphur and lithium-metal batteries (Manthey, 2018).

United States

The key policy updates that are expected to drive the transition to electric mobility in the United States are summarised in Table 2.10.

Table 2.10. Overview of EV and EVSE policies in the United States, 2018/19

Countries	Policy type	Description
United States of America 	**Regulations** (vehicles)	The federal government has proposed to freeze GHG emission standards for LDVs from 2022 to 2025. Twenty US states have signalled willingness to adhere to the previously declared update of corporate average fuel economy (CAFE) standards. ZEV mandate in ten states.
	Target (vehicles)	California aims to have 5 million EVs on the road by 2030.
	Industrial policy	US Department of Energy’s Vehicle Technologies Office supports the development of battery and electric drive systems.
	Incentives (chargers)	Incentives to deploy charging infrastructure are provided in more than half of US states.

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[25] The number of slow charging stations eligible for state support will be limited to a maximum of ten within a “large community” (defines as more than 1 000 households) to prevent concentration of charging points in particular regions.

[26] Subsidies for private charging stations will be suspended at the end of 2019.

Vehicle policies

In April 2018, the US Environmental Protection Agency (US EPA) announced a review of the GHG emissions standards for new LDVs sold in the United States between 2022 and 2025 (IEA, 2018a). The information released for comment proposed a freeze of the GHG emissions standards for vehicles sold between 2021 and 2026 (US EPA, 2018). A group of 20 states, led by California,[27] has challenged the administration proposal as unlawful and suggested litigation if federal regulators move forward with the freeze (Shephardson, 2019). Despite calls to revisit the fuel economy regulations in the form that preceded the change, the Auto Alliance, whose members produce more than 70% of cars and light-duty trucks in the United States, expressed support for continued improvements in fuel economy rather than a freeze (Shepardson, 2017; Automotive News, 2016). Auto Alliance indicated a clear preference for a single regulatory environment rather than a split system, calling for a negotiated compromise between the federal administration and the state of California (Auto Alliance, 2018).

Charging infrastructure

The United States is among the countries that have ramped up their ambition to install fast charging facilities along highways (IEA, 2018a). Our 2018 analysis also noted that California had boosted its infrastructure deployment target for 2025, along with its 2030 target of 5 million EVs. California's Executive Order B-48-18 includes a proposal to invest USD 900 million to deploy 250 000 charging points by 2025, of which around 10 000 outlets should be DC fast chargers (Electrify America, 2019; State of California, 2018).[28] Various other states are augmenting financial commitments for charging infrastructure, mostly through electric utilities. New Jersey, California and New York announced investments totalling nearly USD 1.3 billion, adding more than 50% to the existing government-driven investment in the United States so far (Bloomberg, 2018a). Combined with previous announcements through Electrify America (USD 2 billion), Maryland (USD 104 million) and Massachusetts (USD 45 million), the total announced investments add up to almost USD 3.5 billion between 2017 and 2027 (Electrify America, 2019; The National Law Forum, 2018). Overall, more than half of the state-level administrations in the United States had EVSE incentives in place in 2018 (AFDC, 2019b).

Industrial policy

The United States has a long history of funding battery R&D. The US Department of Energy's Vehicle Technologies Office (VTO) supports a variety of work to lower the cost and increase the convenience of EVs by collaborating with national laboratories and industry to improve batteries and electric drive systems. An example is VTO's Batteries, Charging and Electric Vehicles Program, which supports R&D and aims to: reduce the cost of EV batteries to less than USD 100/kWh and ultimately to USD 80/kWh; increase the range of EVs to 300 miles; and decrease charging time to 15 minutes or less (US Government, 2019a). In February 2019, the Argonne National Laboratory announced the opening of a battery recycling centre to reclaim and recycle critical materials (e.g. cobalt and lithium) (US Government, 2019b).

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[27] California was granted a waiver by the EPA to implement its own GHG emissions standards in 2009 (US EPA, 2009) and is subject to a proposal by the federal administration to strip its ability to do so. California has announced its intention to maintain the more stringent rules even if federal standards are rolled back (Davenport and Hiroko, 2018). However, the federal government is considering a withdrawal of the waiver (NHTSA, 2018).

[28] California also aims to deploy 200 hydrogen stations by 2025.

Other countries

Significant developments have been made in a number of countries in **Latin America** to initiate a transition to electric mobility. The region has favourable conditions for electric mobility. Three large vehicle producers operate in the region (Argentina, Brazil and Mexico), and three countries (Argentina, Bolivia and Chile) have large reserves of lithium – one of the critical materials for the production of the batteries used in EVs (UN Environment, 2018).[29] Moreover, Latin American countries have one of the highest shares of renewable-based electricity production. Two key countries deserve specific mention: Costa Rica and Chile.

Costa Rica is the first Latin American country to pass a law to promote electric mobility. In 2017, its congress passed Law 9518 to promote and provide incentives for electric transport (Government of Costa Rica, 2018; UN Environment, 2018). The law grants tax incentives to several modes of transport (cars, buses, two-wheelers) for public, private and institutional fleets. It established mandates for the state to electrify at least 5% of the bus fleet every two years and to deploy electric charging infrastructure. It also opens the door to public-private partnerships for the deployment of charging points. The law was followed by the announcement in February 2019 of the "National Decarbonisation Plan 2018-2050" (Government of Costa Rica, 2019), which states the aim to become a fully decarbonised country by 2050. With its electricity supply already being almost fully decarbonised, decarbonisation of the transport sector is one of its biggest challenges. As part of the plan, buses and taxi fleets are expected to become fully electric by 2050. As for private transportation, measures will be taken so that users gradually abandon fossil-fuelled cars and opt for zero-emission vehicles and car-sharing.

In the framework of the 11th Meeting of the Forum of Ministers of Environment of Latin America and the Caribbean, held in October 2018 in Buenos Aires, Costa Rica presented a proposal for a "Dialogue on Electric Mobility", which was supported by Argentina, Barbados, Belize, Bolivia, Chile, Colombia, El Salvador, Grenada, Guatemala, Honduras, Mexico, St. Lucia and Uruguay (UN Environment, 2018). This dialogue aims to promote joint learning with regard to strategies and regulatory frameworks for electric mobility, development of financial instruments and new business models, facilitate capacity building and knowledge sharing, and promote joint collaboration in pilot projects, with emphasis on innovation and the creation of new jobs.

Chile is also one of the leading countries in electric mobility, having launched its "Electric Mobility Strategy" in 2017 (Government of Chile, 2018) and having joined the Electric Vehicles Initiative in 2018. Chile aims to make 100% of public transport electric by 2040 and 40% of private transport electric by 2050 (Revistaei, 2018). The most progress in Chile has been made in electric buses, and it now has one of the largest electric bus fleets in the world after China.

New Zealand has taken steps to encourage a transition to electric mobility. It joined the Electric Vehicles Initiative in 2018. The government has stimulated EV growth with a programme of interventions, including an EV public information campaign and a Low Emission Vehicles Contestable Fund.[30] The information campaign develops and provides information to dispel myths about EVs and to motivate people to choose EVs. The fund supports innovation and investment in low-emissions vehicles and associated infrastructure. Over the past five rounds,

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[29] Chile also has vast copper reserves.

[30] Information obtained through personal communication with the EVI contact point of New Zealand.

the fund has committed more than NZD 17 million (New Zealand dollars, USD 11 million) in government money to 93 projects. A key focus of the fund has been to boost public charging infrastructure making a significant contribution to the installation of over 200 fast chargers across the country. This is helping to achieve the government's vision to have DC fast chargers every 75 km on the main highway network. Other government activity includes a plan to transition to an emissions-free government vehicle fleet, where practicable, by 2025/26. In 2019, New Zealand plans to introduce legislation to help transition to a net zero-emissions economy by 2050. The government is aiming to deliver further initiatives to incentivise the uptake of EVs, including investigation of new standards for vehicle fuel efficiency.

Indonesia in 2019 set a target to deploy 2 200 electric cars by 2025 (Market Research Indonesia, 2019). The regulatory framework for EVs is currently under discussion and an update of EV targets is under consideration.[31]

The emergence of a Global Electric Mobility Programme

Interest in a transition to electric mobility is not limited to specific regions or individual countries. To respond to growing global demand to build capacity on policies enabling greater EV uptake, to know more about the transition to electric mobility and to help ensure that the associated significant policy needs and challenges can be properly managed and anticipated, the International Energy Agency and UN Environment Programme have been actively working on the development of a global programme to support developing countries with the introduction of electric mobility.

The programme has been proposed for funding from the Global Environment Facility (GEF). If the programme is approved under the 7th four-year cycle of the GEF, its central activities will be to support countries with the introduction and transition to electric mobility.

The Global Programme would be one of the leading global initiatives on EV policy development and would include the following components:

- Global working groups to develop policy packages, tools and methodologies to help developing countries to better understand the policy requirements and the challenges associated with the transition to electric mobility. The working groups will look specifically at light-duty and heavy-duty vehicles, the integration of EVs in power systems, sustainability of the supply chain and end-of-life treatment of automotive batteries.
- Regional platforms to disseminate the outputs of the global working groups; develop training and capacity-building activities; facilitate the establishment of platforms to ease financing of EV purchases; generate opportunities for replication; and to build communities of practice involving policy makers from different countries.
- A framework to facilitate expansion of the global tracking activity already initiated by the IEA with the development of the annual *Global EV Outlook* to monitor progress and enlarge the scope of the collection of data and information on electric mobility.

Countries that have declared intentions to join the programme include a large emerging economy (India), countries that can play a leading role in their global region (e.g. Armenia, Burundi, Costa Rica, Cote d'Ivoire, Chile, Madagascar, Peru, Sierra Leone, Togo and Ukraine) and a number of small island states (Antigua and Barbuda, Jamaica, Maldives, Seychelles and

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[31] Information obtained through personal communication with Andi Novianto, Assistant to the Deputy Minister for Energy, Mineral Resources, and Forestry Coordinating Ministry for Economic Affairs of the Republic of Indonesia.

Saint Lucia), which are well placed (thanks to their small scale) to develop demonstration projects characterised by a rapid and full transition to electric mobility.

Industry roll-out plans

The main private actors involved in the deployment of charging infrastructure can be grouped into those that have a stake in EV or EVSE roll out from a "supply" perspective, and those that are influencing the deployment of chargers from the "demand" side. The supply group includes:

- Vehicle manufacturers, primarily focused on vehicle production but also active (sometimes directly, sometimes through consortia) in the deployment of charging infrastructure.
- Manufacturers of the hardware needed for the chargers and charger providers involved in the operation of charging outlets.
- Energy companies, including stakeholders closely associated with the electricity sector (e.g. utilities, transmission and distribution network operators) as well as major oil companies and fuel distributors.

The demand group includes logistics companies that install chargers for their EV fleet, companies active in the installation of workplace chargers and stakeholders involved in the acquisition of EV fleets. In addition, the players involved in the roll-out of destination chargers (typically located at hotels, restaurants and shopping centres).

This section focuses on the actors involved in the supply-side of vehicle and chargers. The demand-side is represented in the EVSE deployment pledges in the framework of the EV100 Initiative (Box 2.2). It is a significant initiative led by The Climate Group that is contributing to stimulate the deployment of EVs and chargers (The Climate Group, 2019b).

Box 2.2. EV 100 Initiative

Vehicle fleets

Companies joining the EV100 Initiative can sign up to various commitments, including pledging to transition the company fleet (including both owned and leased vehicles) to EVs by 2030. To date, 10 000 out of the 145 000 committed vehicles have been transitioned to EVs. Ambitious examples of commitments include DHL, which pledged to convert 66 390 of its vehicles and aims to achieve 70% clean operations of last-mile pick-ups and deliveries by 2025 (The Climate Group, 2019b).

Charging infrastructure

The geographical coverage of the commitments on workplace and destination charging points deployment in the EV100 Initiative covers the world, with almost half in Europe, less than a third in Asia, a quarter in North America and the rest in Oceania, South America and Africa (The Climate Group, 2018).

By September 2018, 38% of the sites had achieved their commitments. Most of the chargers installed have been slow (41%) and medium-speed (51%). In total, 5 718 charging points were installed with an estimated power range of 116-170 MW (based on data available from member companies by September 2018). Almost half of the new charging stations are in Europe with the majority being built by E.ON, Metro AG and Vattenfall. (Details are available in the EV100 Annual Report, The Climate Group 2018).

Vehicles

Light-duty vehicles

In 2018, the dynamic developments on the policy front continued to be mirrored by announcements from automakers on their electrification strategies, even beyond what had been observed in previous years. Table 2.11 summarises these announcements.

Table 2.11. OEM announcements related to electric cars

Original equipment manufacturer	Announcement
BMW	15-25% of the BMW Group's sales in 2025 and 25 new EV models by 2025.
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.
Chonquing Changan	***21 new BEV models and 12 new PHEV models by 2025, 1.7 million sales by 2025 (100% of group's sales)***.
Dongfeng Motor CO	6 new EV models by 2020 and 30% electric sales share in 2022.
FCA	***28 new EV models by 2022.***
Ford	40 new EV models by 2022.
Geely	1 million sales and 90% of sales in 2020.
GM	20 new EV models by 2023.
Honda	15% electric vehicle sale share in 2030 (part of two-thirds of electrified vehicles by 2030, globally and by 2025 in Europe).
Hyundai-Kia	12 new EV models by 2020.
Mahindra & Mahindra	0.036 million electric car sales in 2020.
Mazda	One new EV model in 2020 and 5% of Mazda sales to be fully electric by 2030.
Mercedes-Benz	0.1 million sales in 2020, ***10 new EV models by 2022 and 25% of the group's sales in 2025.***
Other Chinese OEMs	7 million sales in 2020.
PSA	0.9 million sales in 2022.
Renault-Nissan-Mitsubishi	12 new EV models by 2022. Renault plans 20% of the group's sales in 2022 to be fully electric. Infiniti plans to have all models electric by 2021.
Maruti Suzuki	A new EV models in 2020, ***35 000 electric car sales in 2021*** up to ***1.5 million in 2030.***
Tesla	Around 0.5 million sales in 2019 and a new EV model in 2030.

Original equipment manufacturer	Announcement
Toyota	**More than** ten new models **by the early 2020s** and 1 million BEV and FCEV sales **around** 2030.
Volkswagen	0.4 million electric car sales in 2020, up to ***3 million electric car sales in 2025***, 25% of the group's sales in 2025, 80 new EV models by 2025 and ***22 million cumulative sales by 2030.***
Volvo	50% of group's sales to be fully electric by 2025.

Notes: Bold and italic font indicates updates since the *Global EV Outlook 2018* (IEA, 2018a). This table is based on the IEA's understanding of companies' announcements 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 give no specific indication regarding the PHEV/BEV share are not included here..

Sources: BMW - Electric Cars Report (2018); BMW Group (2017); Mitchell (2017). BAIC - Xinhua News (2017); Finance Sina (2017); Dixon (2017); ICCT (2018). BYD - China Economic Net (2018). Chonquing Changan - Energy Saving and New Energy Vehicle Yearbook (2018); Changan (2017); ICCT (2018). Dongfeng Motor Co. - Tabeta (2018); Online Car Market (2017). Fiat Chrysler - Automotive News Europe (2018). Ford - Carey and White (2018). Geely - Xinhua (2018); National Business Daily (2018a); Finance Sina (2018). GM -General Motors (2017). Honda - Healey (2016). Hyundai-Kia - Jin (2017). Mahindra & Mahindra - The Economic Times (2018). Infiniti – Bloomberg (2019b). Mazda – Mazda (2018); Charged Electric Vehicles Magazine (2017). Mercedes-Benz - Daimler (2018a); Reuters (2016). Other Chinese OEMs - personal communication with Jiang Liu (Energy Research Institute of the National Development and Reform Commission, China); Energy Cngold (2018). PSA - Reuters (2017b); InsideEVs (2017). Renault-Nissan-Mitsubishi (2019) Groupe Renault (2017). Maruti Suzuki – Maruti Suzuki (2018); Nikkei Asian Review (2018b). Tesla – Tesla (2018); PSA (2019); Nussbaum (2017); Cobb (2015); Voelcker (2017); Marklines (2018); Sheehan (2017); Chiba and Fujino (2019). Volkswagen - Reuters (2018a); Reuters (2017a) Volkswagen (2016); Volkswagen (2017); Autocar (2018); China Economic Net (2018). Volvo – Volvo (2019). Toyota - Toyota (2017).

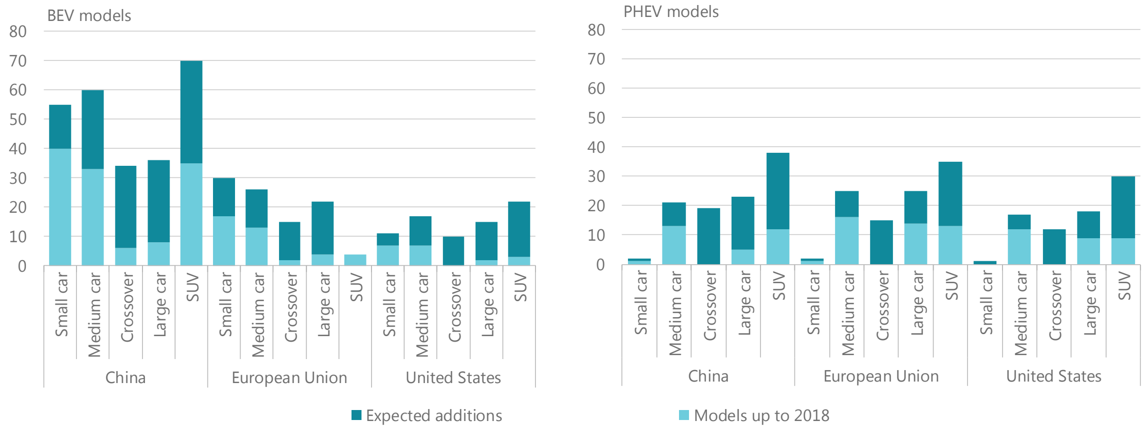
German OEMs were among the most far reaching in their statements regarding the intention to embrace vehicle electrification. In March 2019, Volkswagen announced they would consider leaving the German car industry association *Verband der Automobilindustrie* (VDA) in the absence of a change to concentrate more efforts on battery electric cars (Welt, 2019). Shortly thereafter, BMW and Daimler agreed that electric mobility will be one of the central technologies in the coming decade to comply with environmental legislation in the European Union and that VDA will work towards a consensus paper as the basis for the expansion of the charging infrastructure as well as future funding schemes (Murphy, 2019).

In Japan, Toyota stated its intention is to continue investing in hydrogen-fuelled vehicles and releasing new models (Tajitsu and Shiraki, 2018).

Some of the OEMs that are leading the way in vehicle electrification opted to share technologies and platforms with other manufacturers. For example, Volkswagen announced that it is willing to share its new EV platform (the Modular Electric Toolkit-MEB) with others (Volkswagen, 2019a). Similarly, Toyota announced that it will share its hybrid technology patents with other OEMs (Omoto, 2019), a move that resembles the one made by Tesla in 2014 (Tesla, 2014). This can be interpreted as a way to hedge against the risk of taking a major technology initiative in isolation from other manufacturers and therefore as something that increases chances of wider consumer awareness and buy-in for the new technology. In the case of Volkswagen, sharing the technology platform would also help all OEMs to reach economies of scale faster. Overall, increased co-operation among manufacturers is likely to accelerate the technological transition to electric mobility.

As a result of these announcements, the number of electric car models available is expected to increase significantly in the coming years, diversifying the products available. Figure 2.1 shows the distribution of BEV and PHEV models in 2018 and beyond in the three main global electric car markets – China, Europe and United States – classified by passenger car segment. It illustrates that China will remain ahead of other regions in terms of model availability. It also indicates that BEVs and PHEVs will be subject to a more homogeneous introduction across all passenger car segments, with the main exception of PHEVs in the small vehicle segment.

Figure 2.1. Electric car models available: 2018 and expected additions



Notes: Data refer to unique models from all manufacturers.
Sources: EV Volumes (2019), Marklines (2019).

In 2018, EV models were not represented equally across car size segments, but announced models are more equally distributed. PHEVs are unlikely to be available for the small car segment.

Two/three-wheelers

The production of electric two-wheelers has been centred in China and focused mainly on low-speed and short-range vehicles (see Chapter 1, *Small electric vehicles for urban transport*). However, the market is beginning to move towards electrification of two-wheelers with performance characteristics (speed in particular) that are compatible with competing ICE technologies.

Part of this change can be attributed to new players. The Chinese company NIU, which sold 290 000 electric scooters in 2018, entered joined the stock market and is expanding its sales to Europe and North America (NIU, 2019). Another important new player is Gogoro, which is based in Chinese Taipei but is present in Europe as well (Box 2.3). Govecs, an electric scooter start-up in Europe with around 15 000 sales annually, is rapidly expanding and will soon join the stock market (Randall C. , 2018).

Incumbent manufacturers are also joining the electric two-wheeler market: BMW, Honda, Peugeot and Piaggio all have at least one electric model in their line-up. In India, the main two-wheeler manufacturer, Hero Moto Corp, offers seven electric models. Ducati and Harley Davidson, premium motorcycle companies, have announced ambitious electrification plans. The technical specifications of premium two-wheelers are very high as all-electric range of 100-200 km is not uncommon. It is interesting to note, that in premium electric scooters, regenerative braking is becoming a common feature, thus further reducing their energy consumption.

Box 2.3. Electric two-wheelers: industry roll-out of battery-swapping

In 2018, electric two-wheelers were 8% of sales in Chinese Taipei. Over 120 000 vehicles registered were sold by Gogoro (Chinese Taipei , 2019). The electric two-wheelers come with a monthly subscription to access a network of swapping stations where batteries are charged. This makes Gogoro both an OEM and a charging network operator. This system frees users from range limitations and concerns that the battery capacity of their scooter degrades over time. The local government supports the expansion of Gogoro with about USD 1 140 per vehicle and USD 10 800 per charging station (Chinese Taipei, 2018; Chen, 2017). Charging stations are open to users of other brands, provided they use the same battery standard. This roll-out of high-performance electric two-wheelers can be an example for other markets that seek to introduce electric two-wheelers and where slow speed two-wheelers are not popular. However, the success of Gogoro in Chinese Taipei is specific for an area with high population density, high modal share of two-wheelers and availability of public funds. Gogoro has also introduced shared scooters (without battery-swapping) in partnership with Bosch and without public funds in several European cities, branding the scheme as Coup.

Sources: Wang (2018); (Chinese Taipei , 2019); Li (2015).

Buses

Most activity in the electric bus market is in China and the largest key players in this field are Chinese OEMs. During 2018, policy action and increased interest in bus electrification spread widely across other regions relative to previous years. Notable leading developments include:

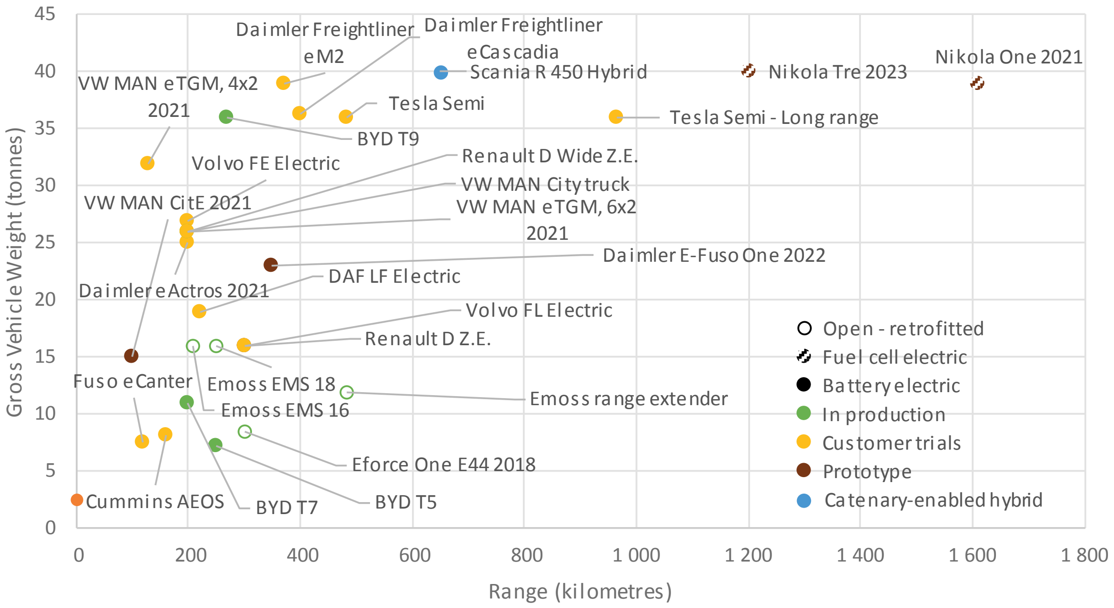
- In Europe, BYD, a Chinese manufacturer, started production at its second European battery factory (in France) and is supplying buses to the United Kingdom (BYD, 2018b) (ADL, 2018). Alfabus, also a Chinese manufacturer, began supplying its products in Italy (Sustainable Bus, 2018a). Today at least three major Chinese OEMs are offering their models on the European market (BYD, Yutong and Alfabus). European OEMs including Daimler, Scania, Solaris, MAN, VDL, Volvo, and Iveco continue to increase their electric bus supply (Transport & Environment, 2018).
- In the FAME Phase II scheme in India, the ambition to promote the electrification of public transportation includes an aim to deploy 7 000 buses (Cabinet of India, 2019). Co-operation between Indian and Chinese OEMs has started. For example, Olectra Greentech Limited (formerly Goldstone) and BYD are producing electric buses for India with a target to manufacture 5 000 units annually by March 2021 (Sustainable Bus, 2018b). Other Indian OEMs such as Tata Motors and Ashok Leyland have taken steps to increase production or introduce new models (UITP, 2018).
- The three main suppliers of electric buses in North America are BYD (Chinese), New Flyer (Canadian) and Proterra (United States). Both BYD and New Flyer have announced increased investments in electric bus factories in the United States (CleanTechnica, 2018; Mass Transit, 2018). Proterra has received investment by Daimler with the aim of jointly developing electric school buses (Proterra, 2018).
- In other regions, electric buses are being supplied by Chinese OEMs including BYD, Sunwin Bus Corporation, Yutong, Zhongtong Bus, Higer Bus and King Long. This is the case for

several cities in Chile and Colombia, and a few others in Latin America (China Dialogue, 2019). In Australia, companies such as Yutong and Zhongtong have also begun trials for some routes (Australasian Bus & Coach, 2019).

Trucks

In 2018, OEMs announced ambitious plans to electrify their product lines and some of the first models have become commercially available. Significant plans to electrify medium- and heavy-duty vehicles have been announced by DAF, Daimler, MAN, Navistar, Nikola, PACCAR, Volkswagen and Volvo (Daimler, 2019a, 2019b, 2019c; Hurt, 2018; Randall, 2019a; (DAF Trucks, 2018); MAN, 2018a, 2018b; Volvo Trucks, 2018).[32] Emerging OEMs such as Tesla and Thor Trucks and others have joined incumbent OEMs with their announcements to roll out production (Kolodny and Petrova, 2018; Tesla, 2019b).

Figure 2.2. Heavy-duty electric truck models announced for commercialisation



Notes: Heavy-duty electric trucks here have a gross vehicle weight > 15 tonnes. Model launch in 2019 or before if no other year indicated.

Sources: E Force One - E Force One (2018). EMOSS - EMOSS (2018) and Allison Transmission (2018). Cummins AEOS - Baumann (2018). eFuso and eActros - Daimler (2018b; 2018c). MAN - MAN (2018a; 2018c). Volvo FL Electric and FE Electric - Volvo Group (2018). Tesla Semi - Tesla (2019b); Ayre (2018).

A growing number of electric heavy-freight truck models will hit the market soon, offering larger sizes and wider driving ranges.

Efforts are concentrated around the electrification of medium-duty trucks that are mostly used for urban delivery or waste collection. These categories are the most favourable for electrification due to relatively short driving range requirements (around 200 km). All OEMs with electric ambitions have announced at least one model for this segment and models by

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[32] These plans mention driver comfort and noise reduction as important benefits yielded by electrification, in addition to the traditional benefits of reduced fuel costs, emissions and pollution.

Daimler and BYD are commercially available. Some of these announcements (including Navistar – together with Volkswagen, Thor Trucks and Tesla) relate to the introduction of electric medium- to long-haul trucks. Longer range BEV trucks have been announced by Tesla and Freightliner, both class 8 trucks with electric ranges of 480-960 km. The Tesla Semi is in commercial testing and market introduction is expected as early as 2019. Figure 2.2 provides an overview of selected electric trucks which have been introduced to the market recently or will be available for sale in the near term. It focuses on freight vehicles with a long driving range, which excludes terminal vehicles and service vehicles for street cleaning or waste collection.

Figure 2.2 includes FCEV options that have been proposed for long-haul road freight by Toyota (Toyota, 2018) and three other models of FCEV long-haul trucks by the North American start-up Nikola (Nikola Corp, 2018). The longer ranges of FCEVs (up to 1 600 km) compared to BEV are mentioned as a key advantage for this market segment.

Automotive batteries

It is estimated that approximately 70 gigawatt-hours (GWh) of battery cells were produced for electric LDVs in 2018. Production is concentrated in China, which accounts for over 50% global market share, with the rest being split between the United States, Korea and Japan. There are currently around 60 manufacturers in China with the top-two companies, BYD and CATL, accounting for more than half of the Chinese market. To reap the benefits of economies of scale, battery manufacturing is moving to increase manufacturing capacity. Even if the majority of production still is sourced from small plants (3-8 GWh/year capacity), several recent announcements of production capacity expansion point to an increase in plant size as well as new entrants in the automotive battery market (Table 2.12), adding to increases in capacity utilisation rates of existing plants (Benchmark Minerals, 2018). Each of the three biggest battery factories currently in operation, all recently built, have a capacity of 20 GWh/year and account for roughly 21% of the total installed capacity (EV Volumes, 2019).[33] Most of these are located in China, Japan and Korea.

Eight plants with a capacity of more than 20 GWh/year are expected to be in production by 2023. In total, these will have a production capacity of more than 180 GWh/year, almost 2.5-times more than LDV battery production in 2018. In the longer term, plants with capacities around 100 GWh are being discussed. Panasonic considered expanding production (to 105 GWh/year) at its Gigafactory, but the expansion plans were suspended in April 2019 (Lambert, 2018a). CATL has spoken about the possibility of expanding its Erfurt plant to up to 100 GWh/year (Hetzner, 2019).

Table 2.12. Announced battery manufacturing facilities

OEM	Country	Announcements
Panasonic	United States	35 GWh/year factory by 2020.
CATL	China	24 GWh/year and 18 GWh factories in 2020.
	European	14 GWh/year factory in 2021.

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[33] The size of battery manufacturing plants currently is 0.5 GWh/year for minor manufacturers and up to 22 GWh/year for global market leaders (EV Volumes, 2019).

OEM	Country	Announcements
	Union	98 GWh/year factory (date to be determined) to be launched.
BYD	China	24 GWh/year factory in 2019. 20 GWh/year and 30 GWh factories in 2023. 10 GWh/year factory (date to be determined).
LG Chem	European Union	15 GWh/year factory in 2022.
	China	32 GWh/year factory in 2023.
SK innovation	China	7.5 GWh/year factory in 2020.
	European Union	7.5 GWh/year factory in 2021.
	United States	9.8 GWh/year factory in 2022.
LIBCOIN/BHEL	India	30 GWh/year factories, in 2025, 2026 and 2027.
Samsung SDI	European Union	1.65 GWh/year factory in 2020.
Northvolt	European Union	32 GWh/year factory in 2023.
Lithium Werks	China	8 GWh/year factory in 2021.
Terra E	European Union	4 GWh/year factory in 2020.

Note: Announcements of capacity additions of the largest battery manufacturers in the market categorised by region and by year of expected factory completion.

Sources: Bloomberg (2018b); SAIC Motors (2017); Electrive (2019); Ma (2018); Lithium Werks (2018); NBD (2018b); Automotive News China (2018); Argus (2018); Byung-yeul (2019); Min-hee (2019); Kumar (2019); TerraE (2018); Northvolt (n.d.); Reuters (2018b); BHEL (2018); SK Innovation (2018) and Chiba and Fujino (2019).

The market for battery cells[34] has been characterised by overcapacity in recent years and this appears to still be the status. This was favoured by tax exemptions available to electric cars under the New Energy Vehicle Subsidy Programme (Government of China, 2018). Investment in battery manufacturing in China also came from foreign companies. Major examples include LG Chem, which is investing over USD 1 billion to expand their battery production in Nanjing (LG Chem, 2018), and Panasonic, which at its Dalian plant in 2018 started producing over 5 GWh/year (Nikkei Asian Review, 2018c). Lithium Werks, a European battery company, also announced the construction of a 8 GWh/year factory (Lithium Werks, 2018). Foreign investments in battery manufacturing in China may be explained by two factors. First, factories in China can be used for export to other markets. Second, if the announced phase-out of the New Energy Vehicle Subsidy Programme in 2020 is maintained, it can open a large market for all battery manufacturers.

While some manufacturers are suffering the effect of overcapacity, which is leading to market consolidation, recent announcements of upward revision of production targets suggest that

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[34] The battery cell is the basic element that composes a battery pack. Other components of battery packs include interconnections between cells, temperature sensors and other control systems to manage charging.

major manufacturers have increased confidence in the demand for battery cells.[35] This is the case for battery manufacturing giants like LG Chem, which announced that it will raise its 2020 production target from 70 GWh/year to 90 GWh/year (Korea JoongAng Daily, 2018) (Bloomberg, 2018c) and BYD, which has modified plans for its third Chinese factory such that it will produce 24 GWh/year (BYD, 2018a) rather than 10 GWh/year as originally planned (Bloomberg, 2018b).

Table 2.12 also shows that Asian OEMs are investing in production capacity in Europe to supply the expected increase in production of EVs. This follows the signature of large contracts by major OEMs, especially in Germany. Examples include BMW's USD 4.7 billion contract to procure batteries from CATL (Reuters, 2018c), as well as Daimler's commitment to purchase USD 20 billion of battery cells over the coming decade from yet unspecified suppliers (Daimler, 2019d) and Volkswagen's statement announcing the selection of LG Chem, SK Innovation, CATL and Samsung as strategic battery cell suppliers (Volkswagen, 2019b). The European battery manufacturer with the most advanced plans to begin large-scale battery manufacturing in Europe is Northvolt, currently building a factory in Sweden with a capacity of 8 GWh/year that is to be expanded to 32 GWh/year by 2023 (Hampel, 2019).

It is important to highlight that European companies are investing in solid state battery R&D, hoping to gain an edge over Asian competitors in the next generation of battery cells instead of trying to compete on current technologies. Examples include SAFT investment of EUR 200-300 million in solid state technology (Reuters, 2018d), as well as Volkswagen's investment of USD 100 million in a company specialised in solid state batteries (Volkswagen, 2018). At the same time, large investments in solid state battery research are being made in Japan, where an alliance of domestic manufacturers is joining forces (with public support from Japan's New Energy and Industrial Technology Development Organization) to develop solid state batteries (Nikkei Asian Review, 2018a). Toyota already has experience in solid state battery research since it has filed numerous patents and has built several prototypes. Recently, Toyota and Panasonic created a joint venture with the aim of developing solid state batteries in the early 2020s (Toyota, 2019).

Charging infrastructure

The collection of information on private sector announcements on EV charger deployments made for the *Global EV Outlook 2018* focused primarily on the deployment of highway chargers (IEA, 2018a). In this edition, we broaden the coverage of the announcements to also look at other types of chargers. Expanding the scope of the announcements covered leads to an important challenge, closely related to the information shown in Figure 2.3. It summarises announcements on deployment of EV charging infrastructure and categorises them in three main groups: commitments that relate to all types of chargers (coupled with the largest magnitudes); pledges only for publicly accessible chargers; and statements only targeting highway charging infrastructure.

Figure 2.3 illustrates announcements related to charging infrastructure in 2018/19. The most significant are announcements by two large operators: ChargePoint, the world's largest

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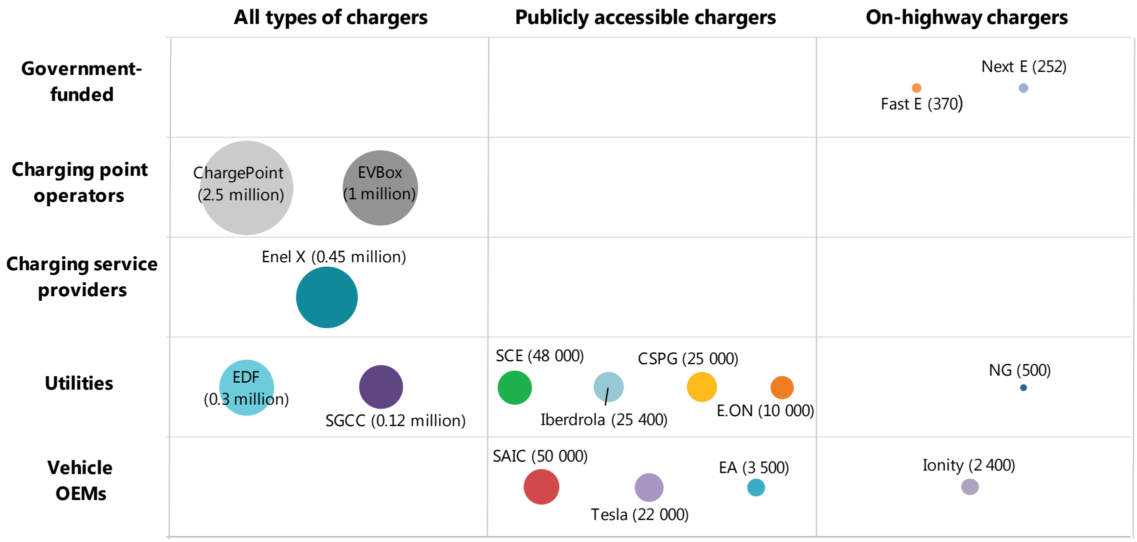
[35] An example is OptimumNano – the third-largest battery manufacturer by volume in 2017 – which has closed 80% of its capacity in 2018 due to financial unsustainability (Reuters, 2018b). Market consolidation is likely to be reinforced from 2020 onwards, as competition with foreign manufacturers will increase due to the end of EV subsidies in China. After 2020, a car manufacturer will not have subsidised incentives to buy cells from a Chinese battery supplier, if it does not have a competing advantage over a non-Chinese supplier.

network of EV charging stations in the United States and Europe (also a supporter of the EV30@30 Campaign) and EV-Box, a provider originally based in the Netherlands and recently acquired by ENGIE, a large company in the power sector (ENGIE, 2017). The magnitude of these announcements is boosted by the fact that these operators include private chargers and have a multinational presence. Other large-scale EV charging deployment pledges (including private chargers) are from EDF, a major utility. In addition, Enel X, a subsidiary of Enel, is focusing on services for the power market and scaling up its international presence (primarily in Europe and in South America) and targeting businesses, cities and individuals. In the United States, utilities are active in deploying charging infrastructure in states such as California, New York, New Jersey and Maryland (The National Law Forum, 2018). Various large US utilities are in the phase of pilot projects, such as DTE Energy, Duke Energy and Consumers Energy Company. Utilities are also taking action through infrastructure investment (e.g. upgrading transformers) and deploying smart meters.

Figure 2.3. Selected providers of charging infrastructure and recently announced plans/targets



Notes: SGCC = State Grid Corporation of China; SCE = Southern California Edison; CSPG= China Southern Power Grid; SAIC= Shanghai Automotive Industry Corporation; EA= Electrify America; NG = National Grid.

The figure includes a selection of major announcements made by market players active in charging infrastructure deployment. In some cases, announcements partially cover already built chargers. The values associated with each announcement represent the number of chargers. When announcements used various terminology, they were translated into "charger equivalents" by assuming: charging station: 4 chargers; charging facility: 4 chargers; charging parks: 4 chargers; charging site: 4 chargers; charging terminal: 4 chargers; charging spot: 1 charger; charging port: 1 charger; charging pole: 1 charger; charging bay: 1 charger. Tesla chargers include only superchargers.

Sources: EDF - Keohane (2018); Electrify America - Krivevski (2019); Iberdrola (2018); Ionity - Lambert (2018b); Mega-E - Manthey (2019); Southern California Edison (2019); State Grid Corporation of China - Xin (2018); Tesla - Supercharge (2019); EV-Box (2018); fast E (2019); National Grid - Climate Works (2018); SAIC - Reuters (2015); China Southern Power Grid - Teamwork Global Group (2018); E.ON - Autocar (2017); EVI submission for Vattenfall.

EVSE deployment pledges are emerging. The largest pledges focus on private chargers, while commitments for highway chargers indicate fewer units.

OEMs, such as Tesla, and charging point operators (both metropolitan and highway) released announcements on the order of thousands of chargers, though those planned for highways are on the order of the hundreds of chargers. Vehicle OEMs (mostly active in this market through joint ventures) tend to focus on either public destination chargers or highway chargers: Tesla, Electrify America (a subsidiary of Volkswagen) and Porsche all announced public chargers across the United States. Ionity (a joint venture of BMW Group, Daimler AG, Ford Motor Company and Volkswagen Group with Audi and Porsche funded by the European Commission) focuses on highway chargers. In Europe, significant numbers of highway chargers are expected to be developed by electric utilities. For example, in 2018 Iberdrola (a supporter of the EV30@30 Campaign) started deploying fast charging stations in Spain, aiming to install 400 chargers (at least one charging station every 100 km on the main roads) by the end of 2019 (Iberdrola, 2018). Other highway chargers in Europe are set to be deployed through government and EU funded projects. "Connecting Europe Facility" is a key initiative funded by the European Union to install fast chargers across the trans-European transport network (TEN-T), providing full basic coverage in most countries with plans to upgrade to higher power rates (EC, 2019e).[36]

Even though China has the largest market for EV charging infrastructure, private sector announcements are lower than for European and North American companies. Most publicly announced targets in China originate from state-owned utilities and OEMs. These currently cover less than half of the available chargers. The State Grid Corporation of China has a target of building 120 000 charging points by 2020 and China Southern Power Grid plans to build 25 000 for the same year (Xinhua, 2018b; Teamwork Global Group, 2018). Among automakers, SAIC targets 20 000 charging points by 2020, whereas BAIC and NIO set targets for a total of 4 100 battery-swapping stations (Hove, 2019; Autoblog, 2017; Reuters, 2015).

This overview indicates that a diversified set of private sector stakeholders operate EV chargers. Given that the charging infrastructure market is growing fast, understanding how this market will evolve is not an easy task. Box 2.4 summarises recent market developments, providing key elements to understand how potential consolidations will be shaping the deployment of EV charging infrastructure in the years ahead.

Box 2.4. EV charging infrastructure market: time for consolidation?

In China – the world's largest EV charging infrastructure market – a consolidation trend is well represented by the recently formed joint venture Xiongan Lianxing Network Technology. It consists of four of the largest private[37] and public[38] charging infrastructure providers and today controls 80% of China's charging points (Randall, 2019b).

In Europe, since 2017 large utilities have been substantially increasing investment in EV charging infrastructure. In 2017, Enel acquired eMotoreWerks, a leading supplier of EV chargers in North America, thus expanding its geographical presence (Enel, 2017) and accounting for around 50 000 charging points worldwide in 2018. Also in 2017, ENGIE acquired EV-Box, which currently owns more than 60 000 charging points (ENGIE, 2017). Other European utilities focused on acquiring companies that specialise in charging infrastructure services and software, such as E.ON acquiring a stake in Virta, a charging service company, and Fortum acquiring Plugsurfing (Electrive, 2018; Fortum, 2018). Oil companies are becoming increasingly active in the charging infrastructure

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[36] TEN-T is a Europe-wide network of major roads, railway lines, inland waterways, maritime shipping routes, ports, airports and rail-road terminals.

[37] Qingdao Teld New Energy and Jiangsu Star Charge.

[38] State Grid Corporation of China and China Southern Power Grid.

market, in several cases beyond highway charging, acquiring charging infrastructure companies that currently operate more than 75 000 charging points. Royal Dutch Shell ("Shell") acquired NewMotion in late 2017 and EV charging software company Greenlots in 2019 (Reuters, 2017c; Greenlots, 2019; Shell, 2017). At that point, NewMotion already had a deal with oil major Total to allow its customers to use NewMotion's network. In 2018, BP followed suit by buying the United Kingdom's largest EV charging network Chargemaster and US manufacturer Freewire Technologies Inc. (BP, 2018a; BP, 2018b). In September 2018, Total purchased the French charging point operator G2mobility (Total, 2018). Oil majors based in the United States are less active in the charging infrastructure market so far, though Chevron took a stake in ChargePoint during the latest USD 240 million funding round, along with American Electric Power (Green Car Congress, 2018).

The main question around traditional refuelling and charging infrastructure concerns highway charging, where utilities are increasingly involved with petrol station operators to roll out highway infrastructure. E.ON and EnWB are working with German petrol station operator Tank and Rast to deploy ultra-fast chargers (Autocar, 2017; EnBW, 2019). Gronn Kontak (joint venture of several Nordic utilities) has collaborated with tank station operator Circle K since 2017 (Gronn Kontakt, 2018). However, in some countries, such as the Netherlands, independent charging point operators have been involved in legal disputes with petrol station owners who can sell electricity for refuelling in stations along highways (FastNed, 2018). At the same time, OEMs are making deals with petrol station operators as well, such as Ionity with Shell, OMV, Tank & Rast and Eni (Green Car Congress, 2017; Ionity, 2018).

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3. Outlook

Scenario definitions

This chapter quantifies the implications of transport electrification for the period 2018 to 2030. It provides insights on electric vehicle (EV) deployment, charging infrastructure roll out, battery capacity of the overall EV fleet and relative material demand, electricity demand for EVs, greenhouse gas (GHG) emissions savings and avoided consumption of fossil fuels. The analysis considers two scenarios:

- The New Policies Scenario (NPS) is the central scenario of the IEA *World Energy Outlook*. The scenario incorporates the policies and measures that governments around the world have already put in place, as well as the likely effects of announced polies that are expressed in official targets or plans. It includes key policies in place as well as recent EV-related updates (See Chapter 2, *Policy updates: Vehicles and charging infrastructure*). It aims to illustrate the consequences of existing and announced policy measures and ambitions to advance the adoption of EVs and the deployment of charging infrastructure.[1] A summary of the policies and targets for electric light-duty vehicles (LDVs) is included in Table 3.1 and similarly for heavy-duty vehicles in Table 3.2. The New Policies Scenario in this outlook also accounts for announcements from original equipment manufacturers (OEMs) regarding plans to scale up EV car production (see Chapter 2, Table 2.11) and automotive battery production (see Chapter 2, Table 2.12).
- The EV30@30 Scenario is in line with the ambitions of the Electric Vehicle Initiative (EVI) signatories of the EV30@30 Campaign Declaration, which is to achieve by 2030 a 30% market share for EVs in all modes (except for two-wheelers, where this goal has been exceeded) (CEM-EVI, 2018). In the EV30@30 Scenario, the target of 30% sales share in 2030 for LDVs, buses and trucks collectively is met 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 the progressive reduction of the carbon intensity of electricity generation, ways to reduce average trip distances and fewer trips by car, and to enable a larger share of movements on public transportation and non-motorised modes of transport.[2]

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[1] Where commitments are aspirational, this scenario makes a judgement as to the likelihood of the commitments being met in full.

[2] If travel demand management measures and the uptake of EVs and other zero- and low-emissions vehicles persist after 2030 (our scenario timeframe) and are accompanied by a 50% reduction in average carbon intensity of power generation, then the EV30@30 Scenario can be considered aligned with the goals of the Paris Agreement (IEA, 2017).

Electric vehicle projections

Policy context for the New Policies Scenario

Several governments worldwide have developed policy tools and established targets to foster EV deployment. Table 3.1 summarises recent policy instruments and goals related to the electrification of LDVs. Table 3.2 does the same for medium- and heavy-duty vehicles (buses and trucks). Taken together, these measures outline the policy context taken into account for the development of the New Policies Scenario in this outlook.

Table 3.1. Key government policy measures and targets to advance deployment of electric light-duty vehicles

Country/ region	**Key policy measures and targets***	**Announced** (year)	**Source**
Asia			
China (EV30@30 signatory)[a]	Target of 5 million EVs by 2020 (including 4.6 million PLDVs).	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)
	Roadmap for NEV sales share: 7-10% by 2020, 15-20% by 2025 and 40-50% by 2030.	2017	Marklines_(2017)
	Proposal for tightened fuel economy standard (4 L/100 km *[NEDC]* ***by 2025)***. (Current fuel economy standard until 2020).	2019	Government of China (2019)
India	Target of 30% EV sales by 2030 across all modes.	2018	Government of India (2018)
	Public procurement from EESL (target 500 000 vehicles, implementation delayed).	2018	
	CO_2 emissions standard of 113 g CO_2/km in 2022.	2015	Ministry of Power of India (2015)
Indonesia	***2 200 EVs in PLDVs by 2025.***	2019	Market Research Indonesia (2019)
Japan (EV30@30 signatory)	Target of 20-30% BEV and PHEV sales in PLDVs by 2030 (in addition to 40% HEVs and 3% FCEVs).	2014	Government of Japan (2014) and Government of Japan (2018)
	Long-term goal ("by the end of 2050") of a reduction of 80% of GHG emissions per vehicle produced by Japanese automakers.	2018	Government of Japan (2018)
	Fuel economy target of 19.7% reduction in specific fuel consumption by 2020 compared to 2009 and an additonal 23.8% between 2020 and 2030.	2011 and 2019	ECCJ (2011) and Government of Japan (2019a)
Korea	***Targets of 430 000 BEVs and 67 000 FCEVs on the road by 2022.***	2019	Government of Korea (2019)
	Subsides and rebates on national and local vehicle acquisition taxes, reduced highway toll fees and public parking fees.	2018	Korean Environment Corporation (2019)

Country/ region	Key policy measures and targets*	Announced (year)	Source
Thailand	***Target of 1.2 million EVs by 2036.***	2016	Harman (2018)
Malaysia	***Target of 100 000 passenger LDV stock in 2030.***	2017	Government of Malaysia (2017)
Europe[d]			
European Union	***Emission standards for g CO_2/km of LDVs, requiring 15% reduction between 2021 and 2025 and 37.5% (30% for vans) by 2030, including incentives attached to 15% and 35% zero- and low-emissions vehicle shares.***	2019	European Council (2019a)
	Revision of the Clean Vehicles Directive on public procurement, including minimum requirements of 17.6% in 2025 and 38.5% in 2030.	2018	European Parliament (2019a)
Denmark	***Target of 1 million electrified vehicles stock in PLDVs by 2030.***	2018	Government of Denmark (2018)
Finland (EV30@30 signatory)	Target of 250 000 EV stock in PLDVs by 2030.	2016	Government of Finland (2017)
France (EV30@30 signatory)	Ban on the sales of new cars emitting GHG in 2040.	2017	Government of France (2017)
	Multiply by five the sales of BEVs in 2022 compared to 2017.	2018	Government of France (2018)
	Reach a fleet of 1 million BEVs and PHEVs in 2022.	2018	
Ireland	Target of 500 000 EVs in passenger LDVs by 2030.	2018	Government of Ireland (2018)
Netherlands (EV30@30 signatory)	Target of 100% ZEV sales in PLDVs by 2030.	2017	Kabinetsformatie (2017)
Norway	100% EV sales in PLDVs and LCVs by 2025.	2016	Government of Norway (2016)
Poland	***1 million EVs in PLDVs by 2025.***	2016	Government of Poland (2016)
Slovenia	Targets of: - 100% EV sales in PLDVs by 2030 - 17% EV stock in PLDV by 2030.	2017	Novak (2017)
Spain	***Targets of:*** ***-5 million EVs in LDVs, buses and two/ three-wheelers.*** ***-100% ZEVs sales in PLDVs by 2040.***	2019	Government of Spain (2019)
Sweden (EV30@30 signatory)	Targets of: -Reduction of CO_2 emissions from transport by 70% in 2030 compared to 2010. -Net zero GHG emissions by 2045.	2017	Government of Sweden (2017)
United Kingdom	Target of 50-70% EV sales in PLDVs by 2030.	2018	Government of the UK (2018)

Country/ region	Key policy measures and targets*	Announced (year)	Source
(EV30@30 signatory)	Ban sales of new ICE cars from 2040.	2018	Government of the UK (2017)
Other European Union[e]	Targets of: - 370 000 to 680 000 electric cars by 2020. - 4.4 million to 5.24 million electric cars by 2030.	2017	EC (2017a)
North America			
Canada (EV30@30 signatory)	***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)
	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)
United States (selected states)	Targets of: - 3.3 million EVs in eight states combined by 2025.[f]	2014	ZEV Program Implementation Task Force (PITF) (2014)
	- ZEV[g] mandate in ten states[h]: 22% ZEV credit sales in passenger cars and light-duty trucks by 2025.[i]	2016	ZEV PITF (2014)
	- California: 1.5 million ZEVs and 15% of effective sales by 2025, and 5 million ZEVs by 2030.	2016	State of California (2018; 2016) CARB (2016)
Other countries			
Costa Rica	***Target of 37 000 EVs stock in PLDVs by 2023.***	2017	Government of Costa Rica (2017)
Chile	***40% EVs in PLDVs by 2050.***	2018	Government of Chile (2018)
Israel[3]	***Targets of:*** ***- 177 000 EV stock in PLDVs by 2025.*** ***- 1.5 million EV stock in PLDVs by 2030.***	2018	Government of Israel (2018)
New Zealand	Target of 64 000 EVs stock in PLDV by 2021.	2016	Government of New Zealand (2016)

* The text in bold and italic font indicates that the targets are new or updated since the *Global EV Outlook 2018* (IEA, 2018a).

Notes: LDVs = light-duty vehicles; PLDVs = passenger light-duty vehicles; BEVs = battery electric vehicles; LCVs = light-commercial vehicles; HEVs = hybrid vehicles; FCEVs = fuel cell electric vehicles; ZEV = zero-emissions vehicle; ICE = internal combustion engine; g CO_2/km = grammes of carbon dioxide per kilometre.

(a) Countries that joined the EV30@30 Campaign set a collective aspirational goal to reach 30% sales share for EVs across PLDVs, LCVs, buses and trucks by 2030 (CEM-EVI, 2018).

(b) New Energy Vehicle (NEV) 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 2 and 5 (ICCT, 2018).

(d) Several European countries also apply vehicle registration and circulation taxes differentiated on the basis of environmental performance (not included in this table).

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[3] 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.

(e) This field summarises the European Union country targets stemming from the Alternative Fuels Infrastructure Directive (AFID) 2017 submissions for countries that included a target and are not otherwise covered in this table. Countries included in this category are: Austria, Belgium, Bulgaria, Cyprus*, Czech Republic, Hungary, Italy, Latvia, Lithuania, Luxemburg, Poland, Portugal, Slovak Republic and Spain. These countries are EU member states that are not signatories to the Electric Vehicles Initiative and countries that have not revised their targets since the AFID submission. Note that Germany submitted a 1 million electric car target by 2020 in the AFID, however, the chancellor announced in 2016 that this target could not be met; therefore this target was excluded from this field. * 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".

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 the effective control of the Government of the Republic of Cyprus.

(f) California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island and Vermont.

(g) Zero-emissions vehicle includes BEVs, PHEVs and FCEVs.

(h) This includes the eight states listed above in note 6 plus Maine and New Jersey, which joined in 2016.

(i) The 22% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible for credits between 0.5 and 3.

Table 3.2. Key government policy measures and targets to advance deployment of electric heavy-duty vehicles

Country/ region	Key policy measures and targets	Announced (year)	Source
Asia			
China (EV30@30 signatory)[a]	Target of 5 million EVs by 2020 (including 0.4 million buses and 0.2 million trucks).	2015	Government of China (2012)
	Proposal to improve fuel economy of trucks by 15% by 2021 compared to 2015 levels.	2016	ICCT (2016)
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 compared to 2015 levels.	2019	Government of Japan (2019b)
Malaysia	2 000 EVs in bus stock by 2030.	2018	Government of Malaysia (2017)
Europe			
European Union	CO_2 emission standards for heavy-duty trucks for 2025 and 2030 (including incentives to achieve a 2% market share for zero- and low-emissions vehicles).	2019	EC (2019).
	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 Council (2019b); European Parliament (2019a)

Country/ region	**Key policy measures and targets**	**Announced** (year)	**Source**
Ireland	Ban on sales of ICE diesel-only buses in 2019. Target of 70% EVs in bus stock by 2035	2018	Government of Ireland (2018)
Netherlands (EV30@30 signatory)	Target of 100% electric public bus share of purchases by 2025 and 100% electric public bus stock by 2030.	2016	Government of the Netherlands (2017)
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)
Sweden (EV30@30 signatory)	Targets of: - Reduction of CO_2 emissions from transport by 70% in 2030 compared 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 trucks from 2021 and increasing stringency up to 25% compared to 2017 in 2027.	2018	Government of Canada (2018)
United States	Fuel economy of heavy-duty trucks should be reduced by 30% by 2027 compared to 2010 levels.	2011	NHTSA (2011)
Other regions			
Chile	100% electric public transport sector by 2040.	2018	Revistaei (2018)
Costa Rica	Targets of: - 70% EVs in bus stock by 2035. - 100% EVs in bus stock by 2050.	2019	Government of Costa Rica (2019)

Notes: 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 (BEVs and FCEVs).

(a) Countries that joined the EV30@30 Campaign set a collective aspirational goal to reach 30% sales share for EVs across PLDVs, LCVs, buses and trucks by 2030 (CEM-EVI, 2018).

(b) Faster Adoption and Manufacturing of Electric Vehicles.

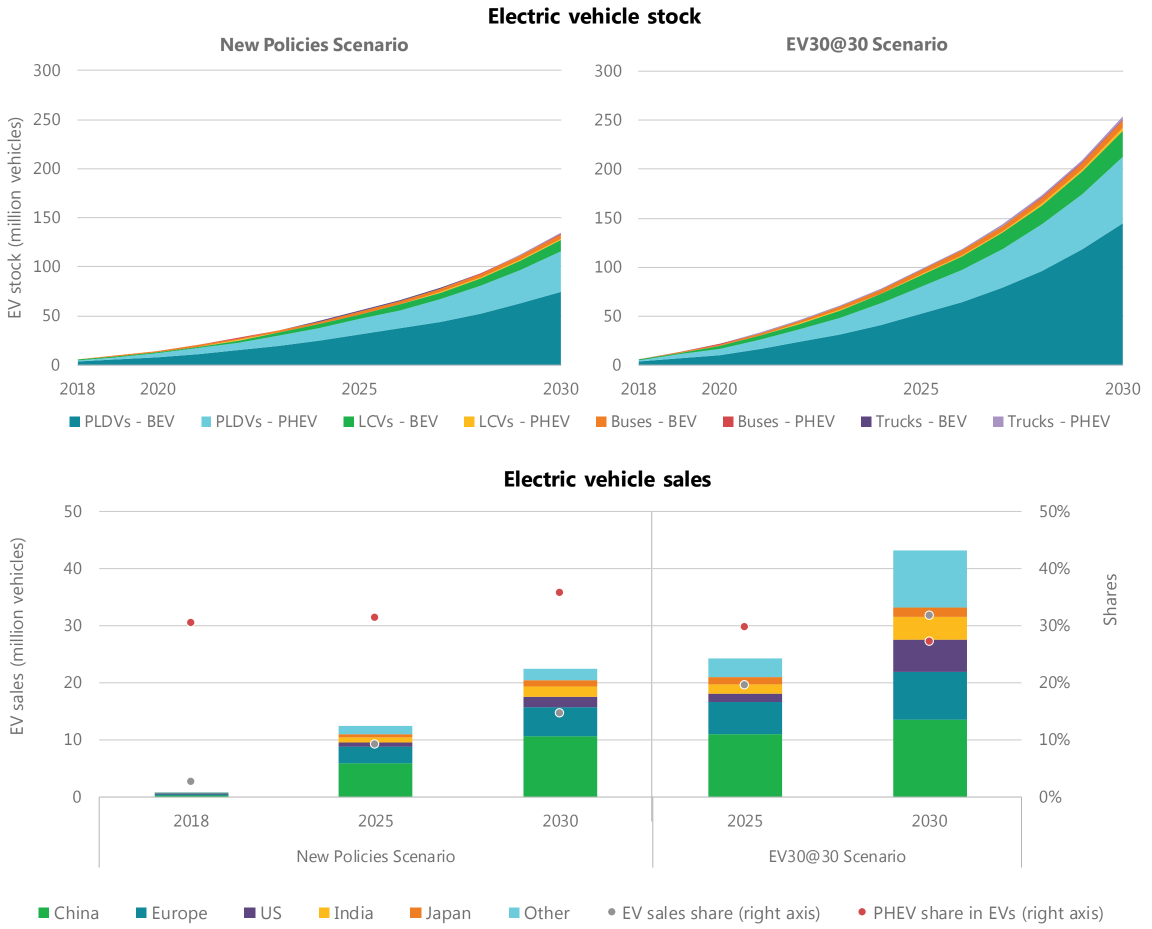
Global results

In the New Policies Scenario, the global EV *stock* (excluding two/three-wheelers) exceeds 55 million vehicles in 2025 and reaches about 135 million vehicles in 2030 (Figure 3.2), with an average year-on-year compound annual growth rate of 30% over the projection period. Global EV *sales* (excluding two/three-wheelers) reach 12 million in 2025 and nearly 23 million in 2030 in the New Policies Scenario, increasing on average by 21% per year. The projected EV sales correspond to 9% and 15% of all vehicle sales (excluding two/three-wheelers) in 2025 and 2030.

The EV30@30 Scenario projects global EV stock and sales that in 2030 are nearly double the projections in the New Policies Scenario. In the EV30@30 Scenario, the global EV *stock* exceeds

250 million vehicles in 2030 (Figure 3.2), when *sales* reach 43 million. In this scenario, it is assumed that all countries rapidly implement policy measures that promote the adoption of EVs such that by 2030 EVs slightly exceed a 30% EV share in the global vehicle market (excluding two/three-wheelers).

Figure 3.1. Global EV stock and sales by scenario, 2018-30



Note: PLDVs = passenger light-duty vehicles; LCVs = light-commercial vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2019a).

In 2030, global EV sales reach 23 million and EV stock exceeds 130 million vehicles in the New Policies Scenario (excluding two/three-wheelers). In the EV30@30 Scenario, EV sales and stock nearly double by 2030: sales reach 43 million and the stock is larger than 250 million.

Two/three-wheelers

Electric two/three-wheelers will continue to be the largest EV fleet among all modes. The size of the global electric two/three-wheelers fleet in the New Policies Scenario increases from about 300 million in 2018 to nearly 450 million in 2030, with a share of 39% in 2030 in the total stock. Sales of electric two/three-wheelers increase from about 26 million today to 46 million in 2030, when they account for more than half of all sales.

In the EV30@30 Scenario, the global electric two/three-wheelers stock is roughly a fourth higher than in the New Policies Scenario in 2030, at nearly 560 million units. Sales of electric two/three-wheelers approach 61 million in the same year.

The strong electrification of two-wheelers envisioned in both scenarios is expected to result from the combination of the following characteristics:

- Energy requirements per kilometre (km) are lower than in any other mode.
- Daily trip distances that are limited by the usage profile of two-wheelers (mostly for urban movements and short distances).
- Ease of charging with conventional level 1 plugs (especially for removable battery packs) and at off-peak times of power supply (e.g. overnight).
- Possibility to benefit from battery cost reductions that result from the increasing adoption of EVs in other modes.

The small size of two-wheeler battery packs also explains why there is very limited availability of PHEV powertrains in this mode. The large majority of the two-wheeler fleet continues to be concentrated in emerging economies, especially in the People's Republic of China (hereafter "China"), India and the Association of Southeast Asian Nations (ASEAN).

Light-duty vehicles

The fleet of electric LDVs (including passenger light-dulty vehicles [PLDVs] and light-commercial vehicles [LCVs]) is the second-largest after two/three-wheelers, accounting for more than 95% of the EV stock across all other modes (excluding two/three-wheelers) throughout the projection period in both scenarios. This does not depend only on the rate of electrification projected for LDVs, but also on the predominance of LDVs in the total vehicle fleet.

In the New Policies Scenario, the electric LDV fleet reaches nearly 52 million vehicles in 2025 129 million vehicles in 2030, up from 5.4 million in 2018. Globally, the stock shares of electric LDVs increase from below 1% in 2018 to 7% in 2030. Sales of electric LDVs rise from 2.1 million in 2018 to almost 12 million in 2025 (a market share of 9%) and 22 million in 2030 (15% market share). Over the period to 2030, EV sales in LDVs rise at an average year-on-year rate of 32%. Sales initially lean towards BEVs (about 70% in 2018), mostly due to the fact that China – the largest EV market worldwide – has remarkably high adoption of BEVs. In the longer term, the balance between BEVs and PHEVs shifts towards a slightly higher share of PHEVs, about 36% of all EV sales in 2030. This is due to the bigger popularity of PHEVs in the large vehicle segments, especially for consumers that have long driving range requirements. (Electric car models available in 2018 and announced models are shown in Chapter 2, Figure 2.1)

The evolution of BEV and PHEV shares is a challenging point. The policy environment certainly has strong capacity to influence consumer choices, as do marketing strategies. For example, BEVs are more popular in countries that use differentiated taxation measures related to zero tailpipe emissions (rather than both low- and zero-emissions vehicles), and the consumer appeal of a BEV can be maximised by optimising the balance between price and driving range, depending on travel habits. Regional differences are related to driving behaviour (for example, higher average mileage for LDVs in North America relative to Asia and Europe) and the availability of electric vehicle supply equipment (EVSE), especially for long-distance trips.

In the EV30@30 Scenario, around 110 million more electric LDVs are projected to be on the road in 2030 relative to the New Policies Scenario. This corresponds to a stock share of 15% in

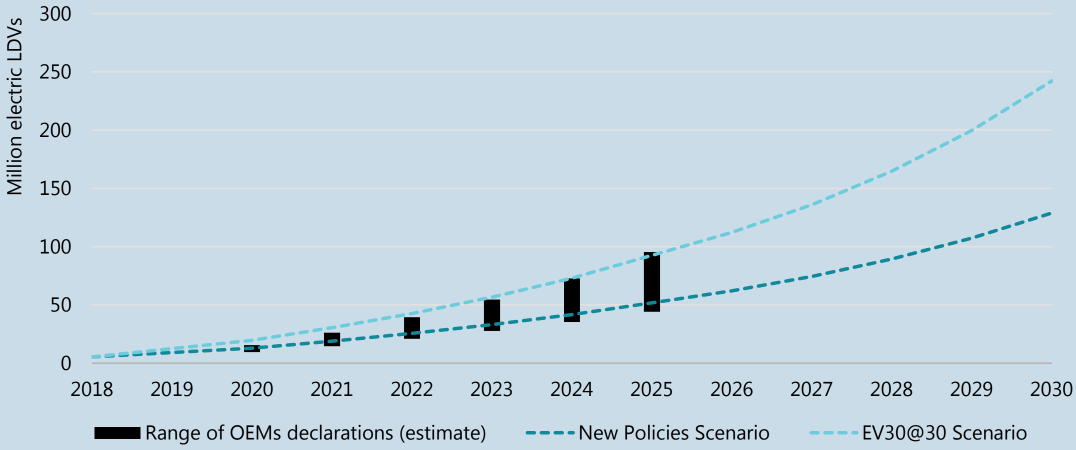
2030. This is the result of faster EV deployment that achieves and slightly exceeds the EV30@30 Campaign ambition to reach a 30% market share by 2030, combined with policies that help manage travel demand, reduce trip distance and shift part of the passenger mobility to more efficient modes of transport,[4] with the consequence of reducing the growth of LDV stocks.[5]

In the EV30@30 Scenario, electric LDV sales exceed 41 million in 2030 (a 33% market share, needed to compensate for a lower than 30% EV market share in buses and trucks). BEVs have a larger presence in the electric LDV fleet reflecting the emphasis on energy efficiency, energy diversification, and pollutant and GHG emissions reductions in this scenario. For the same reasons, PHEVs rely more on their electric powertrain than in the New Policies Scenario.

Box 3.1. Electric LDV sales projections compared with manufacturer announcements

The cumulative EV sales estimated from original equipment manufacturers (OEMs) announcements range from 10-15 million in 2020 and 44-95 million in 2025. These estimates are based on the OEMs declarations on absolute sales, announced percentage targets and models roll out (summarised in Chapter 2, Table 2.11). The estimates reflect more specificity in the next five years and blend into a range of values in the period to 2025 related to interpretations of the OEM announcements for the longer term. As illustrated, the estimated cumulative sales align closely with the stock projections of the New Policies Scenario in 2020 and lie between the projections of the New Polices Scenario and the EV30@30 Scenario in the 2025 time frame.

Projected global EV stock compared with OEM targets (2020-25)



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Notes: The cumulative sales shown in this figure are based on the OEMs announcements (Chapter 2, Table 2.11), interpolating between current sales and the OEM estimated targets. This assessment has been developed estimating first a number of EVs deployed by OEM in a target year and then extrapolating these values for the following years using a range of assumptions.

The number of electric vehicles deployed by each OEM in the target year is calculated taking into account three possible inputs: i) an absolute target value of EV sales given by an OEM; ii) a target value expressed in terms of models deployed in a given year; or iii) a

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[4] How the role of rail in global transport might be elevated as a means to reduce the energy use and environmental impacts of transport services is explored in *The Future of Rail* (IEA, 2019b).

[5] In the EV30@30, the LDV stock is 7% lower than in the New Policies Scenario in 2030.

targeted percentage of the OEM sales in a given year. In the first case, the value is used directly. In the second case, the number of EVs corresponding to the announcement is estimated as the product of the number of models by a range of values of EV sales per model. In 2020, this range falls between 10 000 and 30 000 units in a low and high bound, respectively. For 2025, EV sales per model range between 30 000 and 50 000 units. The increase is consistent with a widening range of models available, increased consumer awareness and improving cost competitiveness. By mean of comparison, 30 000 vehicles per model is a value that is broadly consistent with the vehicle to model ratio announced for 2025 by Volkswagen. Use of 10 000 is a conservative estimate, compatible with the magnitude of the ratio announced by Daimler for 2025. The 50 000 estimate reflects the vehicles to model ratio of successful EV models such as the Nissan Leaf and the Tesla Model S after four/five years on the market. In the third case, the number of EVs is evaluated calculating the market share of the OEM that made the announcement in 2018 and multiplying it by the total PLDV market size projected in the New Policies Scenario. Market shares by each OEM are calculated using data from Marklines (2019) and the share is kept constant over time.

EV sales in years preceding the year targeted by an announcement are determined using an exponential growth that achieves the number of EVs announced (or estimated as outlined above) for the target year. Sales occurring after the year targeted by an announcement are evaluated using both conservative and optimistic development paths. In the conservative case, EV sales by OEM are kept constant. In the optimistic case, the sales follow the rate of growth of the overall EV sales in the New Policies Scenario. For Chinese OEMs, sales in the upper bound case are capped at 6.3 million units per year from 2020 onwards, i.e. at a value that corresponds to 66% of a production capacity of 9.4 million vehicles. This is a rather conservative estimate, based on the collection of information on expected production capacities developed for the *Global EV Outlook 2018* (IEA, 2018a), if compared with recent announcements of production capacities of 20 million units by 2020 (Ren, 2019). In the lower bound case, sales of EVs from Chinese OEMs are limited at 2 million from 2020 onwards.

Sources: IEA analysis developed with the IEA Mobility Model (IEA, 2019a) based on the OEM announcements included in Chapter 2 (Table 2.11) and Marklines (2019).

Buses

The electric bus fleet attains 3.2 million in 2025 and 4.8 million in 2030 in the New Policies Scenario, hitting 7% and 10% stock shares respectively. The electrification of the bus fleet occurs primarily for urban buses, given their lower range requirements relative to intercity buses. PHEV (or range extender hybrid) buses also become part of the fleet thanks to their capacity to delivery energy efficiency improvements in regions that regulate fuel economy in heavy-duty vehicles, but their penetration is limited in comparison with urban buses (PHEVs/range extender hybrids account for slightly more than 10% of the electric bus fleet in the New Policies Scenario).

In the EV30@30 Scenario, the deployment of EVs in the bus sector accelerates, reaching 8.2 million in 2030, corresponding to 15% of the stock, primarily in urban buses. This is consistent with stronger commitments from municipalities and public transport operators, and could be enabled by policy instruments such as minimum requirements in public procurement processes, tightening of fuel economy standards for heavy-duty vehicles and their extension to buses.

Trucks

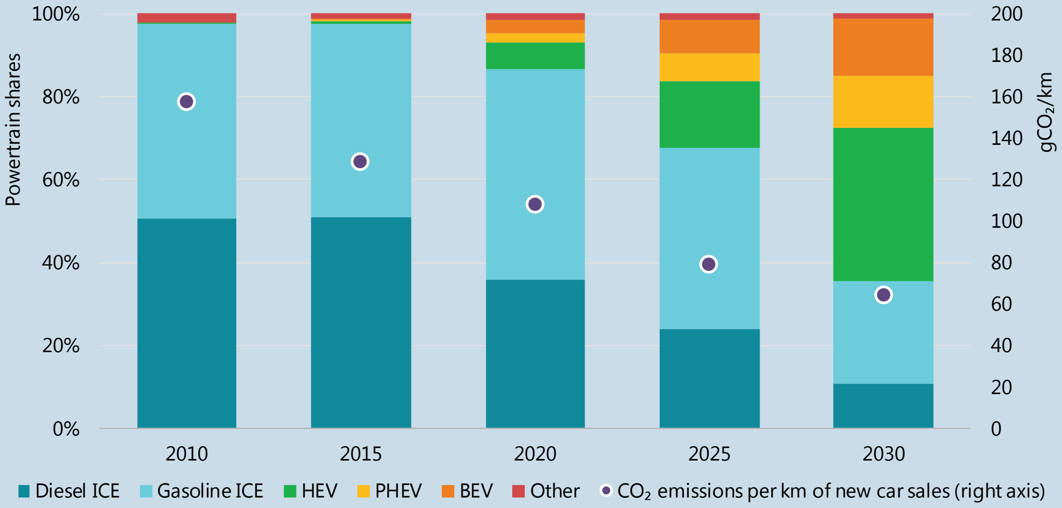
Electric trucks reach 0.9 million units in 2030 in the New Policies Scenario and 3.3 million in the EV30@30 Scenario, corresponding to 1% and 3% of the total truck stock. The penetration of electric heavy trucks is higher in medium size than in heavy truck segments. This is because medium trucks have more applications in urban areas, where vehicle usage profiles are inherently characterised by lower mileage (due to speed and travel time limitations), and regional deliveries, better suited for deliveries taking place with a hub-and-spoke type of operation than long-haul freight transport. Electric trucks are also fit to respond to announced intentions to restrict the circulation of ICE vehicles in major metropolitan areas.

Box 3.2. Implications of EU fuel economy standards on electrification of the car fleet

The European Council and the European Parliament recently agreed to tighten the fuel economy standards for the new car fleet in 2030. This is expected to provide a significant boost to the deployment of electric mobility (EC, 2017b). This development is seen as crucial to curb GHG emissions in the European Union, especially in light of the recent decline of diesel sales shares and a continuous tendency for consumers to purchase large and heavy vehicles (IEA, 2019c).

In this analysis the characterisation of the New Policies Scenario, which includes the new European Union regulation on grammes of carbon dioxide per kilometre (CO_2/km) for passenger cars, the share of electrified vehicles (including HEVs, PHEVs and BEVs) attains 31% of all sales in 2025 and 63% in 2030. Due to flexibility mechanisms embedded in the regulation (including multiplicative factors that allow increase in the weight of PHEVs in the final accounting mechanism required to meet the policy requirements), the relative shares of HEVs, PHEVs and BEVs are subject to some degree of variability (Transport & Environment, 2019). In our estimate for the New Policies Scenario, PHEVs and BEVs taken together account for almost half of the electrified vehicles in 2030, about evenly split between the two options.

Technology shares in the European Union car market, 2010-30



Notes: ICE = internal combustion engine; HEV = hybrid electric vehicle; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle; Other include compressed natural gas; liquefied petroleum gas and hydrogen fuelled vehicles. The carbon intensity per kilometre of new car sales is expressed in World Harmonised Light Vehicle Test Procedure (WLTP), converted from the New European Driving Cycle (NEDC) using (ICCT, 2019).

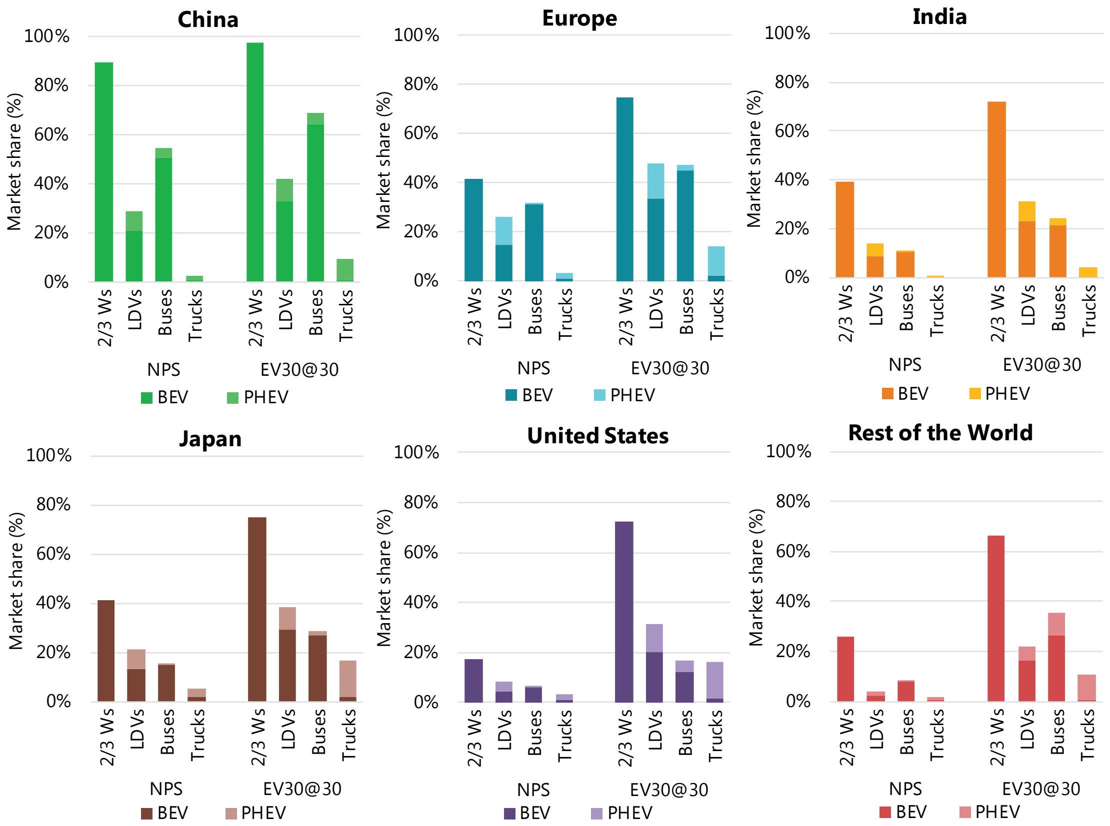
Source: IEA analysis developed with the IEA Mobility Model (IEA, 2019a).

Increasing shares of EVs are necessary to comply with the EU fuel economy standards in 2030. In our central estimate, PHEVs and BEVs account for 26% of the EU car market in 2030.

Regional insights

Figure 3.2 provides details on the EV uptake (in terms of market share) projected in the New Policies and EV30@30 scenarios on a regional basis. It illustrates various road transport modes in selected car markets.

Figure 3.2. Sale shares of EVs by mode and scenario in selected regions, 2030



Notes: NPS = New Policies Scenario; EV30@30 = EV30@30 Scenario; 2/3Ws = two/three-wheelers; LDVs = light-duty vehicles; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2019a).

China and Europe maintain leadership in the EV market in both the New Policies and the EV30@30 scenarios.

China

China is the region with the highest level of EV sales in all modes throughout the projection period to 2030. In the New Policies Scenario, EVs sales shares across all modes reach 57% in 2030 (28% excluding two/three-wheelers). The uptake of EVs in the LDV sector reflects several concurrent factors:

- In the near term (2019/2020), EV uptake is mainly driven by the NEV credit sales mandate (Government of China, 2017).
- In the medium term, the stringency of the corporate average fuel economy standard for cars (4 litres per 100 kilometres [L/100 km] NEDC in 2025) requires an acceleration of electric car sales (backed up by HEV sales) (Government of China, 2019).[6]

Additional factors supporting increasing EV uptake include: supportive industrial policy for battery producers; increasing number of restrictions in cities for registration of non-electrified

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[6] This is also confirmed in the roadmap of NEV sales target from 2020 to 2040 (Marklines, 2017).

vehicles; and scaling up the EV production capacity of Chinese OEMs in response to policy restrictions that would otherwise limit their opportunities for growth.

Electric LDV sales in China are characterised by the highest BEV penetration rate in all major global markets. This is in line with indications coming from the reorientation of subsidies to BEVs with longer ranges, and broadening of BEV technology deployment from the current concentration on small cars to a wider array of EV types (see Chapter 2, Figure 2.1).

Electric two-wheelers, already widely adopted in China, reach 90% sale shares in 2030. The uptake of electric buses in China, particularly in urban areas, is the fastest worldwide. This is in line with the strong dynamics that have characterised this industry in China, including expansion to international markets, and by several commitments by Chinese cities to electrify their bus fleets ((Beijing City Council, 2018); (Global mass transit, 2018)).

In the EV30@30 Scenario, the overall EV sales share across all modes of transport (including two/three-wheelers) attains 70% in 2030 (42% excluding two/three-wheelers), with increases in all modes of transport that capitalise on stronger policy support and the boost in commercial opportunities in areas where EVs are most competitive. In this scenario, in 2030, EVs account for 42% of all LDV sales, 69% of bus sales (mostly for urban and suburban services) and 9% of trucks (mostly used for urban deliveries and regional hub-and-spoke operations).

Europe

Europe accompanies China in the transition towards electric mobility. In the New Policies Scenario, the EVs sales share in Europe reach 26% in 2030 for all modes (excluding two/three-wheelers). The sales shares are very similar for LDVs. Buses attain 32% sales share in 2030, which is consistent with the Clean Vehicles Directive targets for procurement of electric urban buses (see Table 3.2). Two/three-wheelers in Europe start from a much lower level than China and thus only reach 41% sales share in 2030. These projections reflect:

- The need to comply with policies enforced across the whole European Economic Area (EEA),[7] including tightened fuel economy standards for LDVs and heavy-duty vehicles, as well as minimum thresholds for zero- and low-emissions vehicles for public procurements. The importance of electrification for the fulfilment of fuel economy targets is strengthened by the contraction of diesel vehicle sales in the LDV market (IEA, 2019b).
- Recent declarations by several European Union member states to ban the sales and imports of ICE vehicles. (See Chapter 2, Table 2.1)
- EV sales targets set by several EU members and pro-active action related to access restrictions in specified areas by a number of major European cities (C40, 2017) have relevance for the electrification of passenger cars, as well as urban buses, LCVs and trucks used for urban deliveries.
- The strategic relevance that European institutions place on battery storage and the development of a European battery industry, coupled with several announcements on new manufacturing capacity.
- The dynamic actions undertaken by European OEMs, starting with German car manufacturers, to accelerate the transition to electric mobility as a response to the clear policy signals.

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[7] The EEA consists of European Union member states and Iceland, Liechtenstein and Norway.

- Spill-over effects of the transition to electric cars and buses for the two-wheeler market, thanks to cost reductions induced by scale and technology shifts in battery cell manufacturing.

In the EV30@30 Scenario, European leadership in the electrification of transport is strengthened by: strong policy support; capturing commercial opportunities in areas where EVs are most competitive; and high fuel price regimes with fuel taxation rates that exceed those of any other major global market. In this scenario, EVs account for almost half of all vehicles sold in 2030.

India

EVs share of sales across all modes in India reach nearly 30% in 2030 in the New Policies Scenario, almost in line with its target (Government of India, 2018). Vehicle electrification is primarily in the two-wheeler segment with BEVs accounting for four-out-of-ten new units in 2030. EVs also penetrate the LDV and urban bus markets, reaching 14% of all passenger cars and LCVs, and 11% of all bus sales.

The deployment of EVs in India was spurred by the aim in 2017 of a full transition to electric vehicles by 2030. In 2018, a 30% target was established and is being supported by a number of policy measures such as standardisation, public fleet procurements and targeted economic incentives, both for vehicle uptake and charging infrastructure deployment.

In the EV30@30 Scenario, as a global frontrunner in the transition to electric mobility, India reaches EV sales shares across all modes (except two/three-wheelers) of 29% in 2030 (54% including two/three-wheelers). In 2030, in India 72% of two-wheelers, 31% of cars and 24% of buses are electric.

Japan

EVs sales shares for all modes (excluding two/three-wheelers) in Japan reach 21% in 2030 in the New Policies Scenario, mostly LDVs and, to a lesser extent, buses, which achieve a lower market penetration than in Europe and China.

Japan is one of the global leaders in the transition to electric mobility and is in line with the targets for the sale of "Next Generation Vehicles" (including EVs) outlined in the interim report by the Ministry of Economy, Trade and Industry (METI) Strategic Commission for the New Era of Automobiles (Government of Japan, 2018) and recent updates of fuel economy standards. Japan makes concrete progress towards the long-term goal for its automakers to cut GHG emissions per vehicle by 80%. The relevant uptake of BEVs and PHEVs matches the global leadership of Japanese manufacturers on vehicle electrification technologies from HEVs to BEVs, and growing engagement in the development of solid state batteries.

In the EV30@30 Scenario, EV market shares in Japan scale up rapidly to 37% in 2030 across all modes of transport. This is close to the market shares projected for China and Europe.

United States and Canada

In the New Policies Scenario, by 2030 EVs sales across all modes (excluding two/three-wheelers) in the United Sates are 8% of the market. In Canada, they attain a 29% market share, in line with other front running countries in the electrification of transport (Government of Canada, 2019). This also reflects an evolution in the development of electric mobility that occurs at two speeds in Canada and the United States:

- The 20 US states led by California that intend to legally challenge the federal government proposal to freeze fuel economy improvements from 2020 onwards (Shephardson, U.S. automakers push for deal on fuel efficiency rules efficiency rules, 2019). Ten states have implemented a zero-emissions vehicle (ZEV) mandate and together with Canada, are assumed to see faster deployment of electric vehicles (ZEV Task Force, 2019; Hanley, 2019).
- Other than the ten US states with the ZEV target, EV sales in the United States are projected to evolve at a slower rate than in other major vehicle markets. This reflects the different policy environment and a narrower scope for the economic competitiveness of BEVs and PHEVs due to low fuel taxes, despite higher average annual distance driven. (See Chapter 5, *Vehicle and battery costs*).

In the EV30@30 Scenario, the United States catches up with the global leaders in deployment of electric mobility across all modes, but does not achieve the same EV penetration observed in China, Europe and Japan due to its fuel price regime and vehicle sizes that place higher cost competitiveness barriers to transport electrification. By 2030, 31% of all LDV sales and 17% of all bus sales are electric in the United States. The uptake of electric trucks in the EV30@30 Scenario is slightly higher in the United States than in other regions. This is grounded in the increased consolidation of the logistics sector and more opportunities for uptake in large fleets, where EVs can be tailored to match vehicle usage profiles.

Other countries

While this category includes some countries that have strong initiatives to promote electric mobility (e.g. Chile, Costa Rica, Israel and New Zealand), EV sales shares for most countries in this grouping are lower than those for the major global markets. This reflects the limited size of their car markets and a lower degree of ambition as demonstrated via targets and policy measures in the context of the New Policies Scenario.

While the "other countries" grouping has an overall low level of EV deployment in the New Policies Scenario, some countries are projected to have a flourishing EV market over the period. For instance, EV sales shares in Chile and Israel are projected to grow significantly, mirroring their recently announced electrification ambitions and thus together achieving 32% in 2030 (Table 3.1).

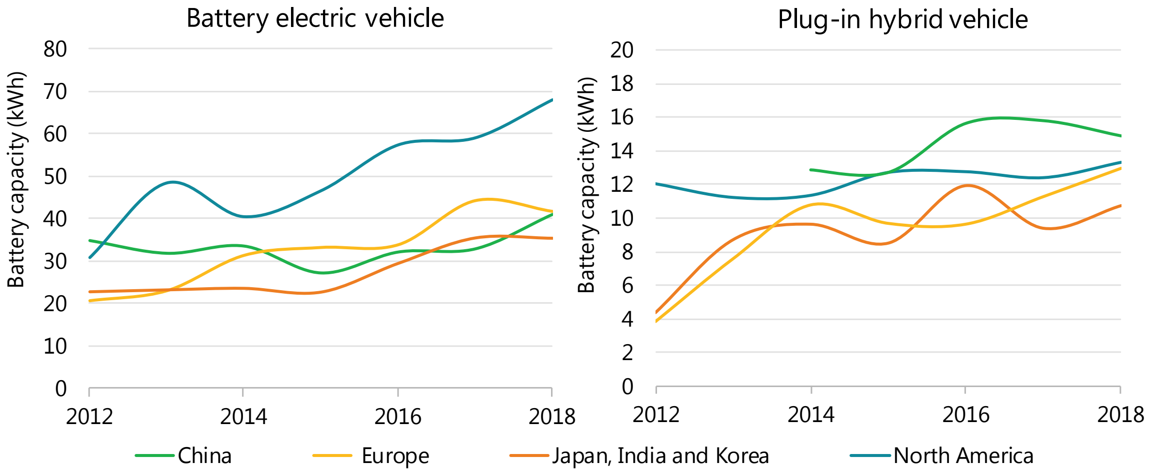
In the EV30@30 Scenario, electric LDVs shares in other countries reach 22% in 2030, thus contributing to achieve the EVI EV30@30 target at the global level.

Implications for automotive batteries

Capacity of automotive batteries

The EV deployment described in the Outlook section of this chapter is facilitated by increases in battery capacity. The extent to which this increase materialises does not only depend on the magnitude of future EV sales, but also on the balance between various electric powertrains, given that they are equipped with different battery capacities and on the future size of the batteries. Today battery pack sizes differ across regions and vehicle models.[8] In all main markets, battery pack capacity in BEVs has been increasing in recent years, from 20-30 kilowatt-hours (kWh) in 2012 to 35-70 kWh in 2018 (Figure 3.3). The upward trend is most pronounced in the United States, where a rapid shift to cars with large batteries (mostly Teslas) is additional to the broader increase of battery capacity in other models. Battery size for PHEVs is approximately 10-13 kWh in most regions, a value compatible with roughly 50-65 km of all-electric driving range. This all-electric range is capable to cover a large fraction of trips made by cars (60-70%, according to the most conservative regional estimate used in the worldwide harmonised light vehicle test procedure) (UNECE, 2018).[9]

Figure 3.3. Battery pack capacities of BEVs and PHEVs in key regions, 2012-18



Sources: Data for 2012-15 are based on IHS Markit (2019), 2016-17 on Marklines (2019) and 2018 on EV Volumes (2019).

Average battery pack size has increased in all major markets in recent years. Battery packs for BEVs in the United States are roughly twice the size of those in China and Europe, while battery packs for PHEVs are relatively uniform sizes across regions.

The capacities of batteries have increased to provide longer driving distances. In the future, the observed trend towards larger battery pack sizes is expected to continue until most BEVs have a driving range of at least 350-400 km.[10] This means battery capacities of 70-80 kWh for

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[8] For battery electric PLDVs, battery pack sizes range from 15 kWh for a small Chinese "city car" to 100 kWh for a sport-utility vehicle in the United States (EV Volumes, 2019). On average, the battery pack capacity ranges between 30-40 kWh in China. In Europe and other Asian markets (India, Japan and Korea), battery pack capacity is close to 40 kWh, while in the United States battery packs are significantly larger.

[9] The actual share of ell-electric driving of PHEVs will not only depend on the capacity of the battery, but also on the frequency of charging events (and therefore on user behaviour). Ensuring that the all-electric driving can be maximised may require the use of targeted policies. Geofencing (i.e. the requirement for all-electric PHEV use in particular geographic areas) may be necessary. It could be facilitated by the availability of in vehicle data recorders (which may become mandatory in Europe (European Parliament, 2019b)) and/or increased connectivity of vehicles.

[10] The actual size of battery packs will depend on a number of variables, e.g. driving range, battery price, availability of charging infrastructure (particularly of fast chargers), capability of automotive batteries to charge at a high power rate.

BEVs, while PHEVs are expected to have battery capacities of about 10-15 kWh in 2030.[11] Similar factors may drive battery capacities for LCVs to increase from the current range of 35-90 kWh to around 100 kWh, and for BEVs and from about 10 kWh to around 20 kWh for PHEVs in 2030.[12]

Based on these considerations and projections of future EV sales and BEV/PHEV shares (Figure 3.1), our central assumption for the New Policies Scenario is that the global EV battery capacity (for all transport modes combined) is estimated to increase from around 100 gigawatt-hours (GWh) per year today to 1.3 terawatt-hours (TWh) per year in 2030 (Figure 3.4). The future global EV battery capacity estimate is especially sensitive to the share of BEVs in the total of all EVs, given that batteries for PHEVs are far smaller than those for BEVs. Assuming that the share of BEVs in LDVs sales is 50% higher than the projections in the New Policies Scenario implies a global battery capacity of about 1.7 TWh/year in 2030 (+26%). On the other hand, assuming a share of BEVs in electric LDVs sales 50% lower than the central estimate implies about 0.9 TWh/year of battery capacity.

The increase of storage capacity is largely driven by LDVs (particularly BEVs), which will account for about 1.1 TWh/year (85% of the total) in 2030 in our central estimate.[13] Two/three-wheelers, which have the largest EV stock, only account for 7% of the total battery capacity in 2030.

Figure 3.4 suggests that the expansion of battery manufacturing capacity will largely depend on the evolution of electrification in the car market. This means that the electrification of cars will be a crucial pillar of the reduction of the unit cost of automotive battery packs.

In the EV30@30 Scenario, the surge of global battery capacity is faster and reaches a higher level in 2030, around 2.8 TWh/year. This is attributable both to the higher EV sales projected for this scenario and the higher share of BEVs. As in the New Policies Scenario, LDVs represent almost 90% of the total battery capacity in 2030, with battery electric cars alone accounting for 82% of the total.

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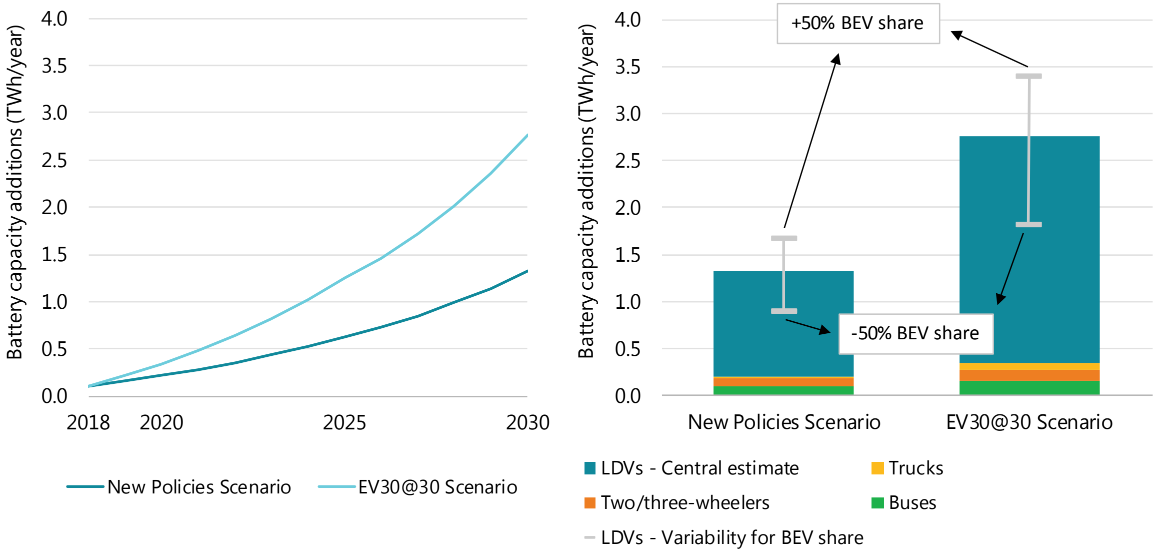
[11] In some countries, policies promote the adoption of PHEVs with large all-electric driving range (and therefore large batteries. For example, the United Kingdom is planning to set a minimum all-electric mileage range of around 80 km from 2040 (corresponding to a battery capacity of around 16 kWh) (Campbell and Pickard, 2018).

[12] The size of the battery packs used in heavy-duty vehicles can range from capacities similar to cars (20-40 kWh) and buses that use opportunity charging and PHEV trucks that can travel in all-electric modes for short ranges (e.g. 10 km) to 250 kWh for buses adopting the depot charging model, and possibly more for heavy-duty trucks used for regional deliveries (200 km of daily mileage for a heavy-duty truck would require roughly 300-350 kWh of battery capacity).

[13] The assumptions used for battery capacity in heavy-duty vehicles can have significant impacts on the battery capacities that will be installed, but the sensitivity of the results of cumulative automotive battery capacity additions is mitigated by the much lower stock numbers for electric heavy-duty vehicles in comparison with LDVs.

Figure 3.4. Annual global battery capacity addition for EV sales by scenario, 2018-30



Notes: The range indicates the variability in battery capacity resulting from an increase (or a decrease) of BEV sales shares in total LDVs by 50% compared with the New Policies Scenario projections. In some regions, the 50% increase of BEV shares leads to 100% BEV sales shares (especially in the EV30@30 Scenario, where BEV shares in LDVs are higher). This explains why the variability of battery capacity to BEV shares is not the same in both directions.

Battery capacity projections are based on estimated EV sales and region-specific EV battery capacity. For cars, battery capacity ranges progress to 70-80 kWh in 2030 for BEV and to 10-15 kWh for PHEVs. For LCVs, battery capacity increases to 90-100 kWh in 2030 for BEVs and to 15-19 kWh for PHEVs. 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.

Source: IEA Mobility Model (IEA, 2019a).

Cars are the main driver for battery capacity in the EV market, with demand projected to grow from about 100 GWh in 2018 to 1.3 TWh in 2030 in the New Policies Scenario and to 2.8 TWh in the EV30@30 scenario.

Material demand for automotive batteries

The expansion of annual battery production projected in both the New Policies Scenario and the EV30@30 scenario leads to significantly higher demand for materials to manufacture batteries.

Bigger EV battery capacity implies increased demand for new materials in the automotive sector. The nature of the material demand will vary according to the development of battery chemistry.[14] The cathode chemistries of automotive lithium-ion battery packs are transitioning towards higher nickel content to provide higher energy density. Information on

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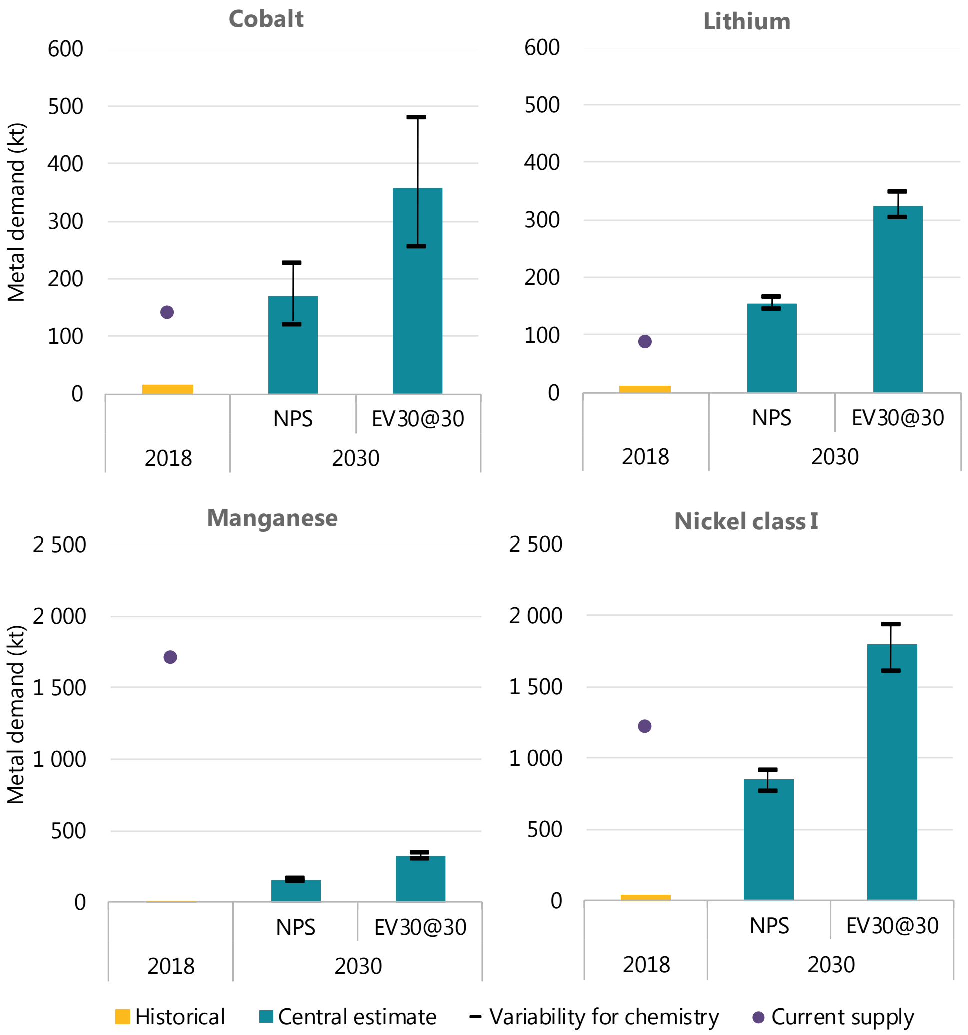
[14] Battery cells are currently composed of a graphite anode, liquid electrolyte and a cathode. The cathode is a characterising element of the batteries. There are three main families of cathode chemistry: ferrophosphate ($FePO_4$), nickel manganese cobalt oxide (NMC), and nickel cobalt aluminium oxide (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 433, NMC 532, NMC 622 and NMC 811, where the numerical component represents the various ratios. The $FePO_4$ is only used by Chinese OEMs in lithium iron phosphate batteries (LFP) and, 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 $N_{0.8}C_{0.15}A_{0.05}$ and $N_{0.9}C_{0.05}A_{0.05}$ (IEA, 2018a).

the current mix of chemistries is not fully consistent across various data providers, but there is broad consensus that the main chemistries currently in use are LFP, NCA and NMC, with the latter being subject to a transition from NMC 111 to chemistries with lower cobalt content (mainly NMC 433 and NMC 532, and to a much less extent, NMC 622 and NMC 811), to manage the risks associated with cobalt supply and to increase energy density (Heppel, 2018; McKerracher, 2019). According to our estimates, the material demand for the batteries of the EVs sold in 2018 was about 15 kilotonnes (kt) for cobalt, 11 kt for lithium, 11 kt for manganese and 34 kt for nickel (Figure 3.5). The comparison of material demand for automotive batteries with the current levels of supply suggests that in the years ahead that the supply of cobalt and lithium needs to expand to avoid shortages that may hinder the transition to electric mobility envisioned in the scenarios.

It is expected that by 2025, batteries will increasingly use chemistries that are less dependent on cobalt, such as NMC 622 or NMC 532 cathodes in the NMC family or advanced NCA batteries in the NCA family (IEA, 2018a). For NMC, cathodes with even lower nickel to cobalt ratios (NMC 811) are also likely to penetrate the market and contribute to the decrease of battery costs, despite some delays in industrialisation plans (Newspim, 2018). In terms of anode technology, silicon-graphite chemistries, which enable higher power densities, are expected to become available soon (Nationale Plattform Elektromobilität, 2018).

The demand for materials for battery manufacturing is projected to increase in both in the New Policies and EV30@30 scenarios. Considering a battery chemistry mix composed of 10% of NCA, 40% NMC 622 and 50% NMC 811 for 2030 (our central estimate), in the New Policies Scenario, cobalt demand expands to about 170 kt/year in 2030, lithium demand to around 155 kt/year, manganese to 155 kt/year and class I nickel (>99% nickel content) to 850 kt/year (Figure 3.5). In the EV30@30 Scenario, higher EV uptake leads to 2030 material demand values more than twice as high as the New Policies Scenario. For cobalt and lithium, these values mean that demand in the New Policies Scenario exceeds current supply. For class I nickel, this is the case in the EV30@30 Scenario. The choice of the cathode chemistry significantly affects the demand for metals, particularly cobalt. This is because the transition to higher content of nickel has larger implications for the reduction of cobalt than on the change in the amount of nickel in the battery.

Figure 3.5. Increased annual demand for materials for batteries from deployment of electric vehicles by scenario, 2018-30



Notes: Future demand for materials for battery manufacturing relative to the scenario projections is based on the global battery capacity shown in Figure 3.4 and the following assumptions of the shares for cathode chemistries in LDVs. For the central estimate: 10% NCA, 40% NMC 622 and 50% NMC 811. For the high cobalt chemistry (upper range in the figure): 10% NCA and 90% NMC 622. For the low cobalt chemistry (lower range in the figure): 10% NCA and 90% NMC811. The share of cathode chemistries for heavy-duty vehicles is assumed to be 20% NMC 622 and 80% NMC 811. The share of metals in the battery for the types of chemistries 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.

Sources: IEA analysis developed with the IEA Mobility Model (IEA, 2019a). Current material supply for cobalt and lithium is based on USGS (2019), manganese supply is from International Manganese Institute (2018) and class I nickel demand in 2018 is from BNEF (2019)

The demand for cobalt and lithium are expected to significantly rise in the period to 2030 in both scenarios. Cobalt demand has the largest variation to the type of cathode chemistry. Cobalt and lithium supply needs to scale up to enable the projected EV uptake.

Charging infrastructure

The deployment of EV supply equipment (including both private and publicly accessible chargers) needs to proceed in parallel, and sometimes (i.e. highway chargers) anticipate that of the EV stock.

This section projects the private and public charging infrastructure needs to power LDVs and public buses over the outlook period, taking into account structural drivers and policy objectives.[15]

- Structural drivers typically reflect consumer preferences and technical requirements. For example, charging practices for passenger car owners are largely reliant on slow charging at home or workplace; buses tend to have access to fast chargers at privately owned facilities; LCVs may rely largely on private slow or fast charging infrastructure; trucks need high power charging; and most vehicles need some degree of access to publicly available chargers.
- The key policies and targets related to deployment of EV charging infrastructure for China and the European Union – leaders in the transition to electric mobility – are summarised in Table 3.3. The target ratios for the number of chargers per vehicle of both China and the European Union are assumed to be stable in both scenarios (based on available information).

Table 3.3. Key government policy measures and targets for development of charging infrastructure

Country/region	**Key policy measures and targets**	**Announced** (year)	**Source**
Asia			
China	Target of 4.3 million private chargers (0.9 chargers per EV), 500 000 publicly accessible chargers (0.1 chargers per EV) and 12 000 battery-swapping stations for 5 million EVs by 2020.	2015	Government of China (2015)
Europe			
European Union	Requires governments to deploy an appropriate number of publicly accessible chargers by 2020 and includes an indicative number of 1 publicly accessible charger per 10 electric cars.	2014	European Commission (2014)

Notes: There are also charging infrastructure targets in California (State of California, 2018), New York (New York State, 2019), India (Government of India, 2019), New Zealand (Government of New Zealand, 2017), Japan and Korea (APEC, 2017). Due to structural differences of how targets are set (e.g. only a specific type of charger or only targets for specific distances) and limited geographical scope, these targets are not explicitly included in the scenario projections.

Box 3.3 considers the implications for deployment of charging infrastructure due to the transition to a higher reliance on electricity in trucks, despite a significant amount of

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[15] From a methodological perspective, it is worth noting that countries with high urban density (e.g. China and Japan) are subject to different assumptions in this assessment compared to the rest of the main global economies (having comparatively lower urban density). This analysis also includes estimates of installed capacity per charging type to improve the assessment of charging services based on recharging times.

uncertainty. These include: the mission profiles of truck usage that are electrified, which impact mileage and therefore energy use; the average power capacity of the chargers trucks use; and the capacity factor of the chargers.

Private chargers

Light-duty vehicles

The number of private LDV chargers is projected to expand from nearly 5 million today to about 127 million in 2030 in the New Policy Scenario (Figure 3.6). This corresponds to an average annual growth rate over the projection period of 31%, which is slightly faster than the uptake of EVs due to the expected growth in the ratio of private chargers per EV in China and Japan.[16]

The LDV private charging infrastructure accounts for 0.9 TW of installed charging capacity in 2030 in the New Policies Scenario, with an average annual growth rate of 39%. This is larger than that of the number of chargers, as most home chargers and part of the workplace chargers are upgraded from level 1 to level 2 in order to enable a wider uptake of smart charging options (Cambridge Econometrics, 2018).[17,18] The low capacity factors for home and workplace chargers lead to a total electricity demand of about 310 TWh in the New Policies Scenario.[19]

In the EV30@30 Scenario, the number of private LDV chargers is about 245 million in 2030, which entails a total capacity of installed chargers of 1.7 TW and leads to an electricity demand of almost 600 TWh.

Buses

Private chargers for buses are 550 000 units in 2030 in the New Policies Scenario, up from 192 000 today. The deployment of private chargers dedicated to electric buses occurs at a slower pace than the growth in the electric bus stock. This is the result of the combination of a number of drivers that justify a reduction of the charger to bus ratio over time, including:

- A tendency to increase the average power output per charger, related to a gradual switch from the current reliance on conventional DC fast charging at 50 kW to more use of ultra-fast charging.[20] Based on this, the average power of each bus charger increases from 50 kW in 2018 to 190 kW in 2030 in both scenarios.
- A tendency towards a reduction in the number of chargers per bus. For chargers having a power capacity of 50 kW, experience in the city of Shenzhen – the first big city to move to

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[16] Private LDV chargers in China and Japan, which currently have a higher reliance on fast chargers, are expected to be aligned with the Chinese target of 0.93 chargers per EV (Government of China, 2015). Countries in the rest of the world have not set specific targets and therefore keep a stable ratio of approximately 1.1 chargers per EV in the New Policies Scenario, aligned with historical developments.

[17] Examples of smart charging options include power management systems enabling the optimisation of the use of available power capacity (talking into account network-related constraints), load shifting, the provision of system flexibility services and the use of bidirectional power flows in vehicle-to-X applications.

[18] Globally, the power rate of private LDV charging is assumed to increase from 3.5 kW in 2018 (EVI country submissions) to 6.5 kW in 2030 due to increased battery size and consumer demand for quicker charging times. The charger per EV ratio used for this assessment has been explored in-depth in the *Global EV Outlook 2018* (IEA, 2018a).

[19] The capacity factor for private chargers is the ratio of the energy they deliver and what they could deliver if used at full capacity. The energy delivered is essentially dictated by the distances driven by electric cars and the energy they use per km. For a car driven 12 000 km a year, six days a week and 51 weeks per year, the average daily distance is 40 km. Multiplied by 0.2 kWh/km gives 8 kWh/day. This is 11% of the electricity that can be delivered by a 3 kW charger at full capacity and 5% for a 7 kW charger.

[20] Both opportunity charging and depot charging are compatible which ultra-fast power (Zero Emission Urban Bus System, 2017).

large-scale deployment of electric buses based on depot charging and which has achieved a fully electrified bus fleet – indicates that one charger is shared by three buses (Lu et al., 2018).[21] For chargers having larger power capacity, the same time allocation allowed by the case of Shenzhen to charging activities would allow for a higher number of buses to be coupled with a single charging unit (eventually equipped with multiple connectors). If the average charging power increases to 165 kW, applying the same time constraint of Shenzhen (reduced by 20% to reflect the increased complexity of sharing chargers across a rising number of buses) leads to the possibility to share the same charging unit by eight buses.[22]

Taking into account of these considerations in combination with the projections for electric bus deployment in the New Policies Scenario, indicates a cumulative power capacity for private bus chargers of 0.1 TW in 2030 and total electricity draw of nearly 170 TWh. In the EV30@30 Scenario, private bus chargers and charging power almost double relative to the New Policies Scenario, and electricity demand overpasses 220 TWh, reflecting the wider increase in electric bus deployment.

Private charging infrastructure for LDVs and buses

The total number of private charging points (excluding those for two/three-wheelers) is projected to reach 128 million in 2030 in the New Policies Scenario, up from about 5 million private charging points today (Figure 3.6). About 99% are slow chargers serving LDVs, installed at home and/or workplace. The hypotheses on the evolution of home and workplace charging towards level 2 and the average power of the bus chargers going to 190 kW mean that the overall installed capacity for private charging infrastructure for LDVs and buses reach nearly 1 TW in 2030 in the New Policies Scenario. Comparing this with the global installed capacity of air conditioning units in 2016 – 15 TW – helps to understand the relatively limited magnitude of this value (IEA, 2018b). Total electricity demand from private chargers for LDVs and buses is almost 480 TWh in 2030 in the New Policies Scenario.

Given the low capacity of home and workplace chargers, the share of private LDV chargers is lower when expressed in terms of terawatts than in terms of the number of chargers. By 2030, LDV chargers represent 90% of the power capacity of all private chargers installed for LDVs and buses. The comparatively low capacity factor of home and workplace chargers relative to bus chargers further reduces the weight of LDV slow chargers in the total of all LDV and bus chargers if they are compared on the basis of the energy they deliver. By 2030, LDV chargers account for about 65% of all energy delivered to LDVs and buses through private chargers.

The size of the private charger stock in the EV30@30 Scenario is almost double the size of the charger stock in the New Policies Scenario, reaching 245 million charging points in 2030. This situation corresponds to a total installed charging capacity of 1.8 TW in 2030 and consumption of 820 TWh of power.

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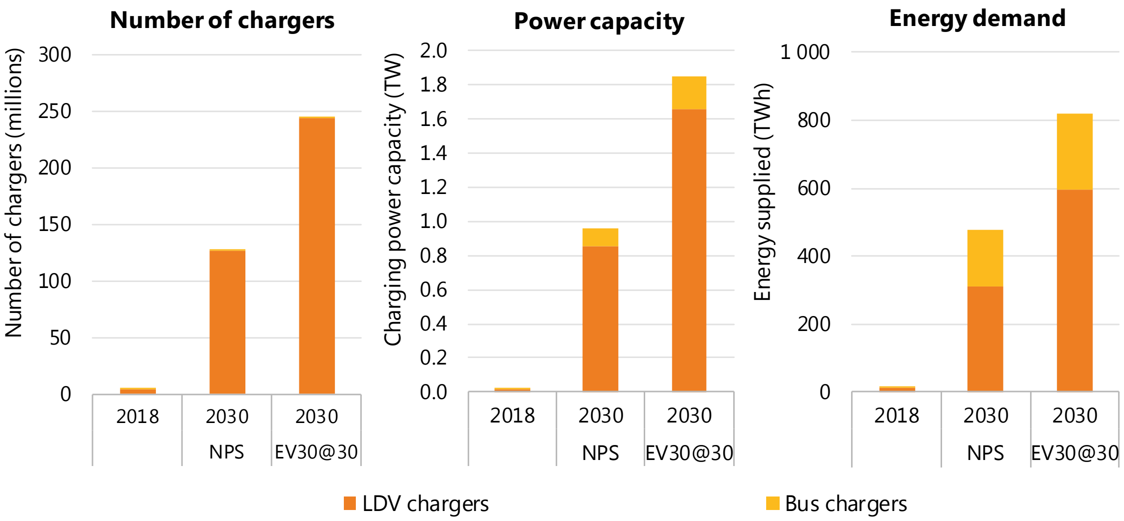
[21] This is consistent with an average energy use of 1.1 kWh/km and a usage profile of 200 km/day (compatible with an average speed of 20 km/h and a daily duration of use of 10 hours), since this would lead to a charging time slightly below 4.5 hours, allowing for three buses to charge in off-peak times of transport demand.

[22] A tendency to reduce the number of chargers per bus is also consistent with a certain degree of reliance on opportunity chargers, which are coupled with a lower charger to bus ratio than the one-to-one value characterising early depot charging developments in Europe.

Figure 3.6. Number of private chargers for LDVs and buses, relative power capacity and energy demand by scenario, 2018-30



Note: NPS = New Policies Scenario.
Source: IEA analysis developed with the IEA Mobility Model (IEA, 2019a).

Private chargers for LDVs and buses expand to 128 million in the New Policies Scenario and 245 million in the EV30@30 Scenario in 2030. In the New Policies Scenario, total power capacity reaches nearly 1 TW and the electricity consumption is about 480 TWh.

Box 3.3. Charging infrastructure for electric trucks

The electrification of trucks takes place at a slower pace than for other modes in both scenarios. Early adopters of electric trucks are likely to be logistics system operators that face constraints to deliver in areas (such as urban centres) that may be subject to increasing regulatory restrictions on ICE vehicles. Companies capable of managing their fleets in a way that can optimally pair technology choice and mission profiles are best placed to be early adopters. It provides opportunities to optimise electrification technologies with mission profiles, ensuring that electric driving can be maximised while minimising daily ranges and battery requirements (an aspect that has important cost implications, since battery electric trucks with ranges below 250 km are the most competitive in terms of ownership cost per kilometre, which requires close co-operation between OEMs and the users of their trucks).[23]

If the trucks entering the global fleet in the New Polices and the EV30@30 scenarios are primarily PHEVs operating in electric mode in urban areas and optimally managed BEVs, it is likely that the charging infrastructure they will use, at least in the early phases of the market uptake, will be

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[23] The "Pathways Coalition" announced in 2018 by Scania, E.On, H&M and Siemens is an interesting development in this respect (Scania, 2018).

privately owned. Given the large energy requirements of both medium- and heavy-freight trucks (roughly 1 and 1.4 kWh/km, respectively), it is also likely that, similar to buses, trucks will mostly rely on fast chargers.

Electricity demand estimated for trucks by 2030 is about 13 TWh in the New Policies Scenario and 72 TWh in the EV30@30 Scenario. The daily energy demand requirements depend on the all-electric range of the vehicles and the characteristics of their batteries. If PHEVs trucks have all-electric daily mileages of 30 km for medium-freight trucks and 15 km for heavy-freight trucks, and BEVs have a range of 150 km, a usage frequency of five days a week and 50 weeks a year would be compatible with all-electric mileages of 7 500 and 3 750 km/year for medium and heavy PHEV trucks, and a maximum of 37 500 km for BEV trucks. With a 50 kW charger, PHEVs would need less than one hour to charge, and BEVs would need two to three hours. With increasing charging power capacity, these times would reduce, allowing more opportunities to share charging infrastructure.

Assuming caps of 10 PHEV trucks and 10 BEV medium trucks (with a 165 kW average power by 2030) per charger and five BEV heavy trucks to be sharing chargers with a 450 kW power rate, and taking into account of the energy demand from the electric truck uptake considered in the scenarios would lead to 140 000 chargers deployed in the New Policies Scenario and 350 000 in the EV30@30 Scenario, mostly for medium trucks. The power capacity coupled with these chargers in 2030 would reach 27 GW in the New Policies Scenario and 67 GW in the EV30@30 Scenario.

Publicly accessible chargers for LDVs

Publicly accessible charging points for LDVs are complementary to private chargers. They are important enablers of the use of BEVs over long distances and by consumers that are interested in EVs but do not have the possibility to rely on private (home or workplace) chargers.

The projections for publicly accessible LDV chargers in both the New Policies and the EV30@30 scenarios build on the following considerations:

- Most countries are assumed to have a ratio of publicly accessible chargers converging towards one charger per ten electric LDVs in 2030, i.e. the value indicated by the targets in China and the European Union.
- The share of fast chargers per EV is stable and equal to a value of 10% of the distance driven by EVs in all global regions except China and Japan, where the same share is assumed equal to 20%. The 10% value is consistent with the much higher frequency of use of home and workplace chargers observed in the Nordic region (IEA, 2018c) and larger amounts of kWh per charge in the case of fast charging.[24] The higher value for China and Japan is based on higher reliance on fast charging that is observed today.
- Publicly accessible slow chargers are level 2 chargers with an average power rate increasing from about 3.7 kW today to 7.4 kW in 2030.
- DC fast chargers are subject to a progressive upgrade to ultra-fast and high power chargers, from an average of 50 kW in 2018 to almost 100 kW by 2030. If the capacity utilisation of

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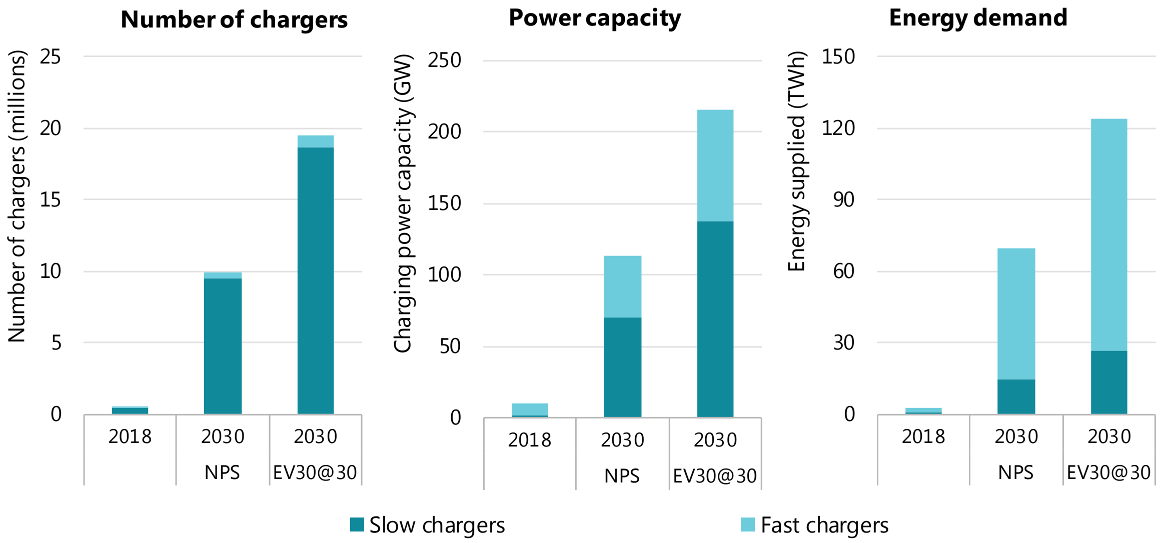
[24] The 10% value is also used in a recent study developed for the European Commission (Cambridge Econometrics, 2018).

fast chargers remains unchanged, this leads to a significant reduction in the number of publicly accessible fast charging points. This also brings down the share of fast chargers in the total of all publicly accessible chargers.[25]

In the New Policies Scenario, the number of publicly accessible chargers for LDVs resulting from these considerations increases from about 560 000 today to 10 million in 2030 (Figure 3.7). Slow chargers account for about 95% of the total publicly accessible charging infrastructure in 2030, up from 70% today. The power capacity of LDV public charging infrastructure reaches 113 GW in 2030, with fast chargers accounting for almost 40% of the total. The total energy consumed by publicly accessible chargers for LDVs is 70 TWh in 2030, with fast chargers delivering about 80% of it.

Figure 3.7. Number of publicly accessible chargers for LDVs, relative power capacity and energy demand by scenario, 2018-30



Notes: NPS = New Policies Scenario. The assumptions used for the development of these projections are included in the main text.
Source: IEA analysis developed with the IEA Mobility Model (IEA, 2019a).

The number of public LDV chargers reaches 10 million in the New Policies Scenario and almost 20 million in the EV30@30 Scenario in 2030, of which most are slow chargers. The power capacity is more evenly distributed among the two types of publicly accessible chargers. Fast chargers serve the bulk of electricity demand.

In 2030, the number of publicly accessible LDV chargers is 7% of the total number of LDV chargers (public and private). The power capacity of publicly accessible LDV chargers accounts for 12% of the total and about 18% of the total electricity consumed by EVs.

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[25] With a constant share of electricity delivered through fast chargers, an increase in power rating for fast chargers translates into a reduction of the amount of publicly accessible fast chargers that serve the EV fleet, if compared with a situation where the increase in the average power rating of the fast chargers does not take place. With a 10% occupancy rate for a fast charger, a 10% share of the distance driven by one EV in Europe could be satisfied by either one 50 kW fast charger for 150 cars, one 175 kW fast charger for 500 cars or one 350 kW fast charger for 1 000 cars. Similar results are indicated in the analysis developed for the European Commission (Cambridge Econometrics, 2018).

In the EV30@30 Scenario, the number of publicly accessible chargers rises faster than in the New Policies Scenario, in parallel with a larger uptake of EVs. Publicly accessible chargers account for almost 20 million units in 2030, coupled with a power capacity of 215 GW and consumption of 1 240 TWh of electricity. In the EV30@30 Scenario, the number of publicly accessible fast chargers reach 0.8 million, corresponding to a total power capacity of 78 GW and consuming nearly 100 TWh in 2030.

Impacts of electric mobility on energy demand

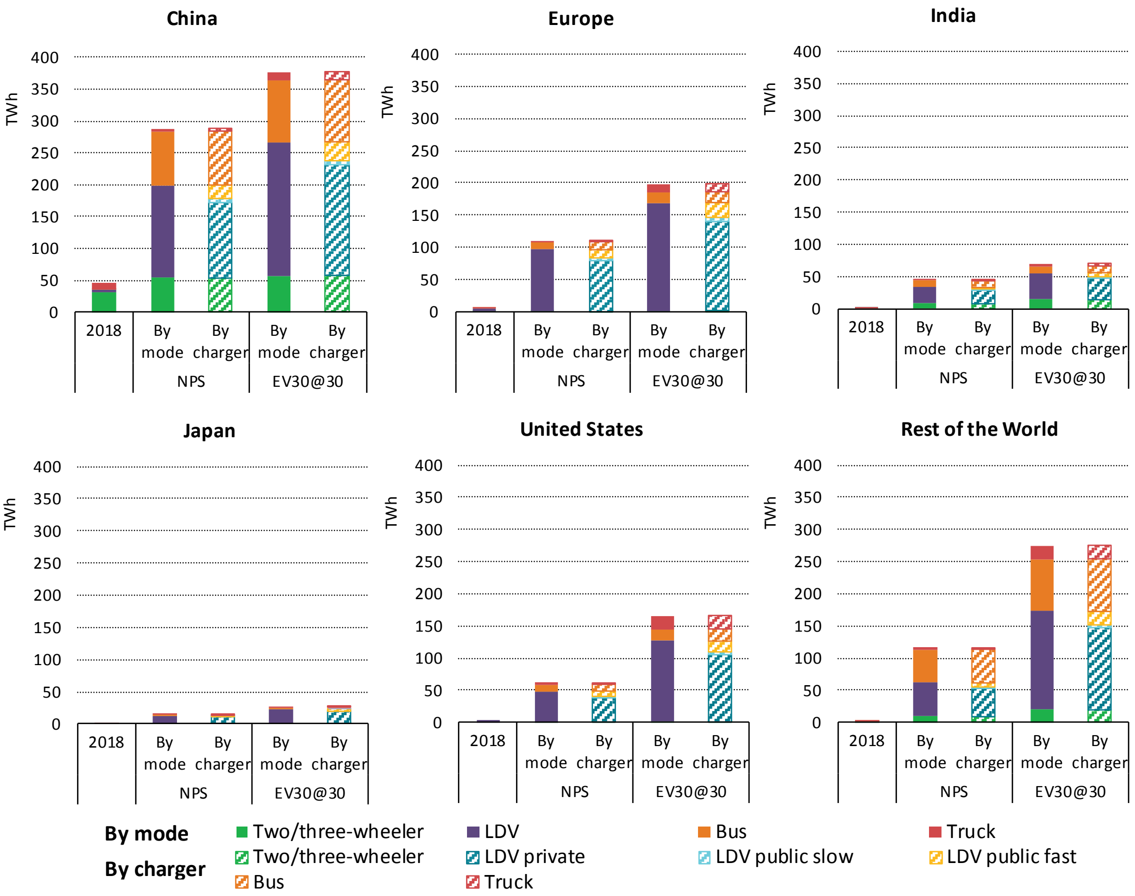
Electricity demand from EVs

As the stock of electric vehicles and their use expands, more electricity will be needed. In the New Policies Scenario, power demand from the global EV fleet is projected to reach almost 640 TWh in 2030, about equivalent to the total final electricity consumption in Germany and the Netherlands in 2017 (IEA, 2019d) (Figure 3.8). This is a tenfold increase from the 2018 level of 58 TWh. In the EV30@30 Scenario, the larger volume of EVs demands slightly more than 1 100 TWh of electricity in 2030, almost double the amount of the New Policies Scenario.

Projected electricity consumed by EVs in both scenarios suggests that EVs are going to be far more significant for power systems than they have been in the past and that they will be a driver of increments in peak power generation and transmission capacity. Assessing the extent to which power systems can be impacted must consider the additional power needed for EVs on an annual basis as well as the daily EV charging profiles, the power rate for chargers and locational considerations.

Figure 3.8 indicates that slow chargers (particularly private LDV chargers) account for about 60% of total electricity demand to charge EVs in 2030 (shares differ by region reflecting the extent of EV uptake across different transport modes). This helps power system management as slow charging provides opportunities for EVs to enhance flexibility. As fast charging demand is highest for buses, concentrating these charging events at night with depot charging, when both transport and electricity demand are lower, could help flatten the overall shape of the power demand curve. Opportunity charging requires high power draws during the day, so depot charging is likely to have lower impacts on the power system.

Figure 3.8. EV electricity demand by region, mode, charger* and scenario, 2018 and 2030



* In the data by type of charger, green and blue colours correspond to slow chargers; red, yellow and orange colours correspond to fast chargers.

Notes: NPS = New Policies Scenario; EV30@30 = EV30@30 Scenario; LDV = light-duty vehicle. The assumptions used to estimate electricity demand from EVs in the scenarios have changed from the assumptions used in the 2018 edition of the *Global EV Outlook* (IEA, 2018a). These results project overall higher power demand in the period to 2030. The main difference in assumptions is a 20% increase in annual mileage for EVs than conventional ICE vehicles (CBS, 2016). The following assumptions for EVs have been used for 2030 (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 IEA Mobility Model (IEA, 2019a).

Global electricity demand from EVs is close to 640 TWh in 2030, concentrated in China and Europe in the New Policies Scenario and more widespread in the EV30@30 Scenario. Slow charging accounts for the largest share of electricity consumed by EVs.

Structure of electricity demand for EVs in the New Policies Scenario

In the New Policies Scenario, LDVs are the largest electricity consumer among all EVs in 2030, surpassing two/three-wheelers in 2020. LDVs account for about 60% of the total EV power demand in 2030 (PLDVs account for 81% of total LDVs), followed by buses (26%), two/three-wheelers (12%) and trucks (2%).

The geographical distribution of power consumption from EVs does not change significantly from today's patterns. China has the highest power demand from EVs throughout the projection period in both scenarios, though its share of total global power demand declines from more than 80% in 2018 to 45% in 2030. China also has the most signifcant diversifcation of power demand across modes. In the New Policies Scenario, electricity consumed by EVs in China is about 290 TWh in 2030. Europe at 110 TWh and the United States at 62 TWh follow China in terms of power demand from the EV stock in 2030, corresponding to 17% and 10% of total power demand from EVs. The EV fleets in China and Europe together account for about 62% of total power demand from EVs in 2030. The rest of the world category has the largest increase in power demand from the EV fleet, accounting for 18% of global power demand from EVs in 2030. ASEAN, Canada, Brazil and Korea are responsible for about 45% of the total power demand from the rest of the world category in 2030.

EV fleets make an important contribution to reduce oil use. Globally, the projected EV stock avoids the consumption of 127 million tonnes of oil equivalent (Mtoe) (around 2.5 million barrels/day [mb/d]) of diesel and gasoline in 2030.

Structure of electricity demand for EVs in the EV30@30 Scenario

LDVs account for about 65% and buses for 20% of power demand from EVs in 2030 in the EV30@30 Scenario. This scenario is also characterised by a significant increase in the power demand from trucks (7%), which is almost equivalent to two/three-wheelers (8%) in 2030.

China remains the largest electricity consumer for EVs, despite a further reduction of its share in the global total to 34% in 2030. Europe (18%) of power demand for EVs follows China in this scenario, but the gap with the Unites States (15%) is narrower than in the New Policies Scenario because of the stronger difference in EV uptake between the scenarios in the case of the United States.

In the EV30@30 Scenario, the EV stock displaces 215 Mtoe (4.3 mb/d) of diesel and gasoline in 2030.

Implications of electric mobility for GHG emissions

The evolution of well-to-wheel (WTW) greenhouse has (GHG) emissions from the EV fleet is determined by the combined evolution of the energy used by EVs and the carbon intensity of electricity generation. Figure 3.9 indicates that in 2030 WTW emissions from EVs are lower, with the current and projected carbon intensities of the grid, than those that would result from the continued reliance of ICEs powered by liquid and gaseous fuel blends. The net reduction in WTW emissions from EVs increase, in percentage terms, over time. This reflects expectations in both the New Policies and EV30@30 scenarios of a more rapid decrease in the carbon intensity of electricity generation than in the case of liquid and gaseous fuel blends.[26]

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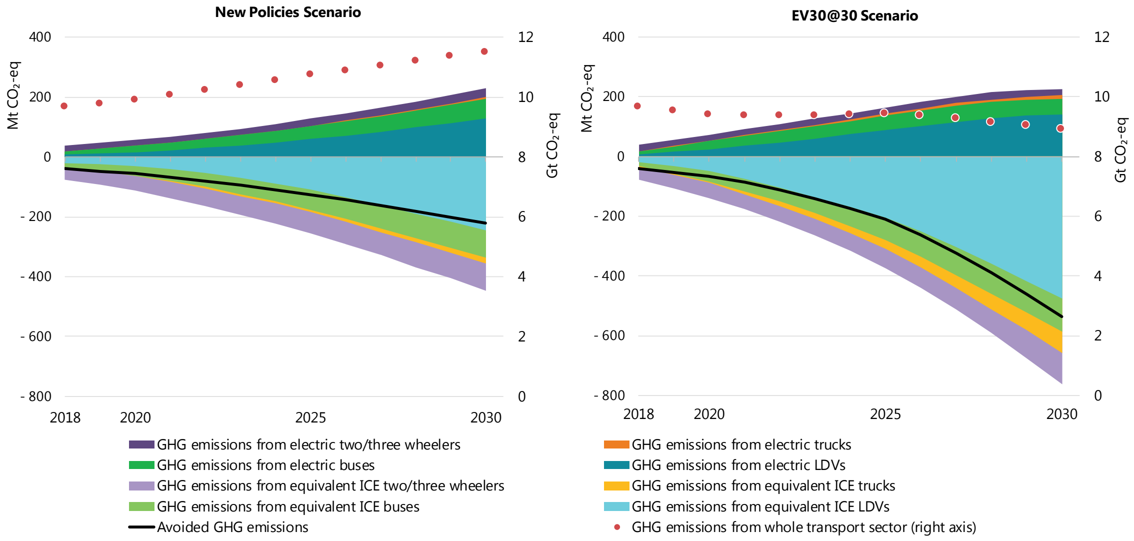
[26] Note that, in the New Policies Scenario, fossil fuel blends remain largely reliant on oil and are only substituted by limited shares of alternative fuels. The latter includes conventional biofuels to the extent already used in 2018, in addition to limited amounts of advanced and low-carbon sustainable biofuels. Electro-fuels are excluded from the liquid and gaseous fuel blends used in road transport in this scenario. In the EV30@30 Scenario, low-carbon fuels used in gasoline, diesel and gaseous fuel blends combined reach a share of 7% by 2030. The carbon intensities of all energy sources in the New Policies Scenario are in line with the analysis developed for the *World Energy Outlook 2018* (IEA, 2018d). Those of the EV30@30 are aligned with the developments considered in the Sustainable Development Scenario of that report. ICE vehicles replacing EVs in this analysis are assumed to have the same efficiency of the remaining ICE vehicles sold in the market in any given year.

Figure 3.9. Well-to-wheel net and avoided GHG emissions from EV fleets by mode and total GHG emissions from the transport sector, 2018-30



Notes: 2/3Ws = two/three-wheelers. Positive emissions are the net emissions from the global EV fleet. Negative emissions are avoided emissions due to the global EV fleet, which are calculated as the difference between the emissions from an equivalent ICE fleet and an EV fleet. The WTW GHG emissions from the projected EV stock are determined in each scenario by multiplying the future electricity consumption from the EVs times the carbon intensity of each power system from the IEA *World Energy Outlook* for the New Policies Scenario and its Sustainable Development Scenario for the EV30@30 Scenario. The WTW GHG emissions for the equivalent ICE fleet are those that would have been emitted if the projected EV fleet was 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 to Figure 3.8.

Sources: IEA analysis developed with the IEA Mobility Model (IEA, 2019a); carbon intensities from (IEA, 2018d).

Electric vehicles reduce WTW GHG emissions by half from an equivalent ICE fleet in 2030, offsetting 220 Mt CO$_2$-eq in the New Policies Scenario and 540 Mt CO$_2$-eq in the EV30@30 Scenario.

In the New Policies Scenario, the GHG emissions by the EV fleet reach about 230 million tonnes of carbon-dioxide equivalent (Mt CO$_2$-eq) in 2030. If the projected EVs were driven by ICE powertrains, WTW GHG emissions would almost double (450 Mt CO$_2$-eq). The global EV fleet in 2030 avoids emissions of about 220 Mt CO$_2$-eq. In the EV30@30 Scenario, in which the accelerated deployment of EVs is assumed to be coupled with a trajectory for power grid decarbonisation consistent with the IEA Sustainable Development Scenario, the projected EV fleet emits almost 230 Mt CO$_2$-eq in 2030, while the equivalent ICE powered fleet would emit about 770 Mt CO$_2$-eq. The rapid decarbonisation of power systems envisioned in the EV30@30 Scenario is important to limit the increase of GHG emissions from the rapid growth in the EV stock. Without the decarbonisation of electricity supply, WTW GHG emissions from the EV fleet in the EV30@30 Scenario would be about 340 Mt CO$_2$-eq by 2030. In the New Policies Scenario, WTW emissions increase 5% while the EV stock increases 93% in 2030. Moreover, Figure 3.9 shows that in the EV30@30 Scenario after 2020, total WTW emissions from the transport sector stabilise at around 9.4 Gt CO$_2$-eq and then decrease to 9 Gt CO$_2$-eq in 2030, which is more than 20% lower than in the New Policies Scenario.[27]

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[27] The reduction of GHG emissions in the EV30@30 Scenario with respect to the New Polices Scenario reflects stronger EV uptake, as well as modal shifts, fuel switching and additional energy efficiency.

Despite the comparative advantage of EVs in terms of GHG emissions identified, it is clear that the benefits of transport electrification on climate change mitigation will be greater if EV deployment is parallel with decarbonisation of power systems. This is shown in particular in chapter 4, which includes an in-depth look at the GHG emissions resulting from car (and battery) manufacturing.

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4. Electric vehicle life-cycle GHG emissions

Context

With zero-tailpipe emissions, the positive impact of electric vehicles (EVs) on the reduction of local pollutant emissions in high exposure areas like urban centres is widely accepted. Regarding their overall environmental impact and greenhouse gas (GHG) emissions, EVs are regularly subject to debate.

Assessing whether or not EVs bring about overall net reductions in greenhouse gas (GHG) emissions with respect to other powertrain options requires a life-cycle analysis (LCA).[1] This section explores the relative importance of GHG emissions along various stages of the vehicle life cycle and identifies drivers of emissions reduction for different vehicle technologies relative to each other.

In their use phase, EVs have net GHG emissions reductions when compared with fossil-fuelled internal combustion engine (ICE) vehicles (discussed in Chapter 3, *Implications of electric mobility for GHG emissions*). The well-to-wheel approach to evaluate GHG emissions, does not account for the emissions that occur during the full life of the vehicle, in particular in manufacturing.

One reason for questions related to the GHG emissions impacts of EVs across their life cycle may be attributed to the variability of the results shown by LCA assessments, and in particular to assumptions used to assess the carbon intensity of battery pack manufacturing. Figure 4.1 illustrates the variability of assumptions and results from a selection of recent assessments.

Lithium-ion NMC batteries are the most common EV battery technology in use today. In the studies compared in Figure 4.1, the GHG intensity (expressed as kg CO_{2}-eq/kWh) of battery manufacturing varies on the basis of the assumed energy use for battery manufacturing and assumed battery energy density. Higher energy intensity reported in these studies may be attributed to smaller plant sizes and/or lower manufacturing capacity factors.

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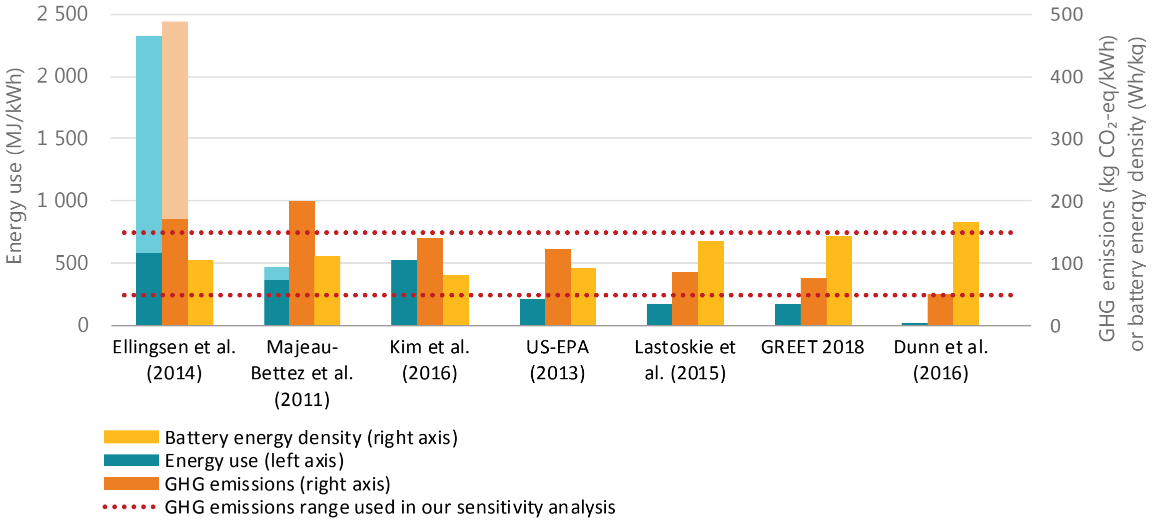
[1] LCA accounts for emissions that take place in the two main components of a vehicle life cycle: i) the vehicle cycle, from manufacturing to disposal (including materials extraction, processing, assembly, as well as disposal and recycling of the vehicle parts, e.g. chassis, engine and battery); ii) the fuel cycle, including well-to-tank (WTT) emissions, comprising emissions due to fuel (e.g. liquid fossil fuel, biofuel, electricity, hydrogen) production, refining and transport to the vehicle; and tank-to-wheel (TTW) emissions, i.e. emissions directly due to vehicle use (on this aspect, battery electric vehicles and fuel cell electric vehicles are zero-emissions for GHGs).

Figure 4.1. Battery energy density for lithium-ion NMC batteries, energy use and GHG emissions intensity from manufacturing by various analyses



Notes: MJ/kWh = megajoules per kilowatt-hour; kg CO_2-eq/kWh = kilogrammes of carbon-dioxide equivalent per kilowatt-hour; Wh/kg = Watt hour per kilogramme.

Sources: Dunn et al. (2016); Ellingsen et al. (2014), Kim et al. (2016); Majeau-Bettez et al. (2011); ANL (2018); US Government (US Government, 2013); (Latoskie and Dai, 2015); Personal communications with M. Wang, J. Kelly and Q. Dai of Argonne National Laboratory.

The GHG emission intensity of battery manufacturing per kWh tends to decline as assumptions on battery energy density, plant size and plant capacity utilisation increase.

Among these studies, the Greenhouse Gases, Regulated Emissions and Energy use in Transportation (GREET) model's battery manufacturing GHG emissions intensity (75 kg CO_2-eq/kWh) reflects the current status of battery technology deployment, with a battery energy density of 143 kilowatt-hours per kilogramme (kWh/kg), a manufacturing facility running at 75% capacity for a plant size of 2 gigawatt-hours (GWh) and relying mostly on natural gas for the supply of heat. The GREET model assumptions are in line with average sizes of production lines and capacity utilisation of current battery manufacturers.[2] Based on these considerations, the GREET results are used in this analysis as the central estimate for the assessment of vehicle manufacturing, assembly, disposal and recycling in the comparative review of vehicles with different powertrains. As Figure 4.1 illustrates, however, there is a degree of uncertainty about the exact level of GHG emissions from battery manufacturing, not least because they can be location specific. In order to account for the variability of different estimates, some of the results reported in the following sections also account for a range of possible battery GHG emission intensities per kWh, using the upper and lower bounds shown in Figure 4.1.

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[2] Personal communications with M. Wang, J. Kelly and Q. Dai of Argonne National Laboratory.

Methodology

For the analysis of the emissions over the vehicle life cycle, the GREET model of the Argonne National Lab (ANL, 2018) (version 2018)[3,4] was used and combined with the GHG emissions estimates for the phase of fuel use as deduced from the IEA's Mobility Model. Assumptions regarding vehicle size and attributes such as battery capacity used by the GREET model were made consistent with the rest of the information included in this report, as well as with the latest assessment of typical vehicle attributes (fuel consumption by powertrain, vehicle power, vehicle size and vehicle weight) from IEA (2019a).

The analysis additionally applies GHG emissions intensity of battery manufacturing from the GREET model (Figure 4.1), and therefore is calibrated in a context that assumes a significant degree of scale-up of battery manufacturing facilities compared to other studies. (Sensitivity analysis are discussed below) This is in line with the expectations of significant EV uptake outlined in the scenario projections in Chapter 3, *Electric vehicle projections*. Battery lifetime was assumed to be equal to the vehicle lifetime (i.e. ten years and 150 000 kilometres (km) in most cases in this analysis, unless stated otherwise).[5]

This assessment is centred on a mid-size passenger car with a power rating of 110 kilowatts (kW) for the following powertrain types: internal combustion engine (ICE), hybrid electric vehicle (HEV), plug-in hybrid vehicle (PHEV), battery electric vehicle (BEV) and fuel cell electric vehicle (FCEV). The assumed driving range of the PHEV is 55 km (11 kWh battery). Two BEV ranges are considered: driving ranges of 200 km (38 kWh battery) and 400 km (78 kWh battery).[6] Fuel economy values are consistent with the Worldwide Harmonised Light-duty Test Procedure (WLTP) values and included a 5% penalty for charging losses in the case of electric powertrains. Variations of key parameters, such as vehicle size, total mileage and carbon intensity of power generation are also explored.

The vehicle drive range is a key assumption. It reflects on vehicle models currently available to the market. Today BEVs in particular are generally designed to be sufficient to meet typical daily driving needs of most car owners, but have a more limited driving range than conventional ICE vehicles. For comparison, a conventional ICE vehicle assumed for the purpose of this analysis has an average driving range of 600-800 km without refuelling, depending on the size of the fuel tank.

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[3] GREET is a bottom-up model assessing emissions at each step of the vehicle cycle (material production, processing, vehicle manufacturing, assembly, disposal and material recycling) for a number of powertrains and vehicle types. GREET also provides an assessment of fuel cycle emissions (i.e. reflecting vehicle emissions during the use phase), however this capability was not used in this assessment. The model is available at no cost at: https://greet.es.anl.gov/.

[4] The GREET model was developed with a main focus on the Unites States, i.e. considering materials sourcing based on typical supply chains of the US vehicle manufacturing industry and assuming that vehicle production and assembly is also located in the United States. The global application of the vehicle cycle results used in this report accounts for differences in key vehicle attributes such as size and weight, but it excludes effects related to regional differences in manufacturing processes and supply chains of materials such as steel, aluminium and battery materials. This simplification has been addressed in the remainder of the analysis by considering uncertainty ranges with regards to emissions from battery manufacturing to reflect variability in emissions according to different literature sources (Figure 4.1). This variability may be due to different assumptions regarding sizes of battery manufcaturing plants, plant capacity utilisation rates, the energy densities of the batteries and a range of different assumptions on region-specific characteristics of material supply chains and battery assembly plants.

[5] Battery durability is discussed in the *Global EV Outlook 2018* (IEA, 2018a).

[6] Most BEV models in 2018 had a battery size below 40 kWh.

Key insights

Based on a battery electric vehicle with a GHG emissions intensity of the electricity mix that is representative of the global average (i.e. with a CO_2 emissions intensity of 518 g CO_2/kWh when including transmissions and distribution losses) and accounting for a 5% penalty for charging losses, the key findings are:

- HEVs, PHEVs, BEVs display similar emissions on a life-cycle basis. (Figure 4.1).
- The largest contribution to life-cycle emissions from BEVs are from electricity generation today.
- The extent to which an average BEV on today's market emits less GHG emissions than an average ICE vehicle depends on the carbon intensity of the electricity generation mix in the use phase.
- The main GHG emissions reduction potential over the vehicle life cycle is in the decarbonisation of the power system. The extent to which this could reduce emissions is beyond what ICEs and HEVs are likely to be able to achieve without direct or indirect CO_2 sequestration (i.e. without the use of biomass-based fuels, electro-fuels or on-board carbon capture technologies).
- Avoided GHG emissions are higher in a BEV of large size and high mileage in comparison to conventional powertrains with similar characteristics. (In absolute terms, low mileage and small vehicle size emit less GHGs for all powertrains).
- A BEV will have a proportionally higher vehicle cycle GHG emissions impact if the power system in the country of use decarbonises. As the carbon intensity of power supply improves, it will become increasingly important to address GHG emissions from vehicle manufacturing to fully decarbonise the vehicle over its life cycle.
- Minimising the vehicle cycle GHG emissions requires minimising GHG emissions from battery manufacturing. Key instruments include increasing battery energy densities; scaling up battery manufacturing production capacities; maximising capacity utilisation; and reducing the GHG intensity embedded in the materials used for battery production.

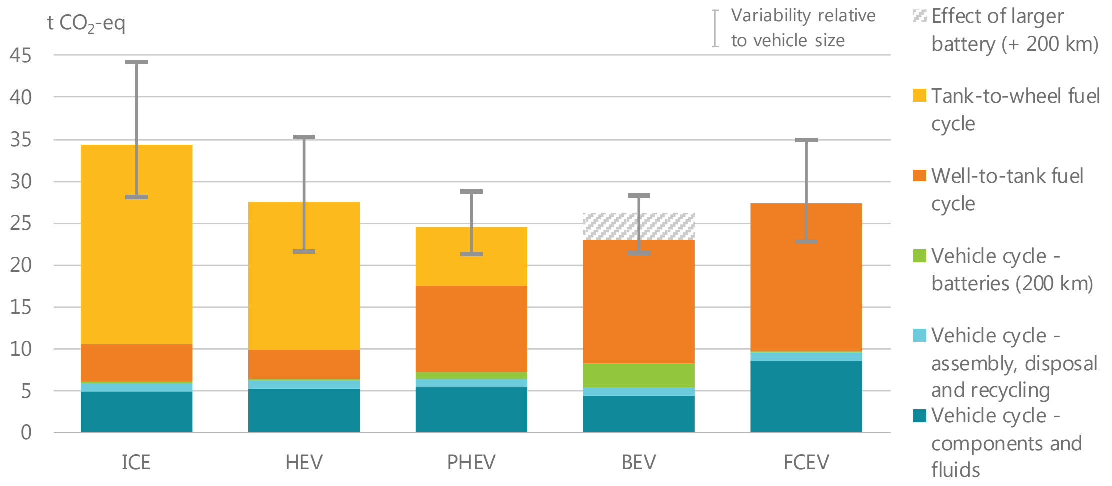
This analysis was designed to represent current average vehicle characteristics and technologies, as well as to consider the likely evolution of these elements over the next decade. We do this by looking at specific sensitivities on parameters such as battery size, battery chemistry and decarbonisation of power systems. As such, the analysis is based on a framework of assumptions that uses the best available data and evidence. Nonetheless, some assumptions may be challenged by other approaches or with unforeseeable developments in the sector. Among these are significant changes in assumptions related to total vehicle mileage and lifetime, battery lifetime including second-life uses, or energy use and emissions associated with the production of the battery, vehicle materials and fuel processing, which may entail significant differences with the conclusions of this analysis. Additionally, the effects of a potentially more systematic recycling of some vehicle components in the future – primarily the battery – are not assessed. This needs to be the subject of further research.

Detailed assessment

Life-cycle GHG emissions: drivers and potential for emissions reduction

The balance of GHG emissions due to vehicle manufacturing and fuel production and use varies depending on the powertrain. Typically, GHG emissions in the vehicle cycle, i.e. components manufacturing, assembly, disposal and recycling,[7] of electric powertrains are higher in EVs than for ICE vehicles. The fuel cycle GHG performance of ICE vehicles versus electric powertrains can vary widely based on the carbon intensity of the supplied electricity. Additionally, these observations vary depending on battery size, location of battery plants (due to the characteristics of battery assembly and the supply chains of battery materials), vehicle size and mileage driven. This section discusses results based on variations of these parameters. Figure 4.2 shows the comparative assessment of five powertrains for a mid-size car with the characteristics set out in the Methodology section. It also reflects on variability of results that comes with comparisons of different car sizes.

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



Notes: All ICE powertrains (i.e. including in the HEV and the PHEV categories) are assumed to be powered by gasoline.
Vehicle assumptions: vehicle power 110 kW, battery size 38 kWh (BEV with a range of 200 km) or 10.5 kWh (PHEV with a range of 55 km); battery chemistry NMC111; annual mileage 15 000 km; vehicle lifetime ten years. (Assumptions applicable to all powertrains unless otherwise stated).
Fuel economy assumptions (WLTP values): ICE - 6.8 litres of gasoline equivalent per 100 kilometres (Lge/100 km); HEV - 5.1 Lge/100 km; BEV - (200 km range) 19.0 kWh/100 km (2.1 Lge/100 m), BEV (400 km range) 19.4 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) include a 5% penalty for charging losses.
Power supply CO_2 intensity in the fuel cycle is 518 g CO_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 of large cars (upper bound) – for BEVs, the lower bound of the sensitivity bar represents a small car with a 200 km range, and the upper bound represents a large car with a 400 km range. All parameters relative to small and large cars are detailed in the notes to Figure 4.4.
Sources: IEA analysis based on ANL (2018); IEA (2019a),(2019b).

The fuel cycle is today the largest component of life-cycle GHG emissions of all powertrains; with a GHG intensity of electricity generation equal to the global average, EVs, FCEVs and HEVs all exhibit similar performance.

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[7] In this assessment, recycling of a number of materials is accounted for directly in each material production process, based on their global average recycling rates, according to the GREET model methodology. There is no specific accounting for lithium-ion battery recycling.

Figure 4.2 provides several key insights:

- For all powertrains, the fuel cycle GHG emissions (orange and yellow in the figure) over the vehicle lifetime outweigh vehicle cycle GHG emissions (dark blue, light blue and green in the figure): vehicle manufacturing, disposal and recycling ranges between 18% (ICE) and 36% (BEV 200 km and FCEV) of the vehicle life-cycle emissions. For a BEV with 400 km range though, this share goes up to 43%.
- BEVs and PHEVs emit the least life-cycle GHG emissions (around 25 tonnes of carbon-dioxide equivalent [t CO_{2}-eq]) given the assumptions of this analysis, although those of BEVs can be slightly higher with longer drive range. Results may also vary depending on the location of the battery production given differences in the characteristics of battery assembly and the supply chains of battery materials. The GHG emissions performance of FCEVs and HEVs is slightly higher at 27.5 t CO_{2}-eq, with global average ICE vehicles emissions at 35 t CO_{2}-eq.
- In a BEV with 200 km range, lithium-ion (Li-ion) batteries (38 kWh size) with currently available cathode chemistries (NMC 111) account for a third of vehicle cycle emissions and 12% of vehicle and fuel cycle emissions combined. If one assumes a doubling of the range, and thus brings battery capacity to 78 kWh, Li-ion batteries account for slightly half of vehicle cycle emissions and 23% of vehicle and fuel cycle emissions combined.

The relative importance of each life-cycle stage (represented by a different colour in Figure 4.2) can vary widely by powertrain type. As do the areas with the largest potential for CO_2 emissions reduction for each type of powertrain.

For ICE vehicles and HEVs, the tank-to-wheel fuel stage accounts for the majority of life-cycle GHG emissions. They can only be reduced by efficiency improvements (provided that they overcome eventual increases in vehicle manufacturing emissions) and indirect measures, such as on-board carbon capture or fuel switching that compensates for tank-to-wheel CO_2 emissions (e.g. sustainable biofuels or electro-fuels). The vehicle cycle (components manufacturing, vehicle assembly, disposal and recycling) is the second-largest contributor to ICE and HEV life-cycle emissions.

For BEVs and FCEVs, which are zero-emissions at the tailpipe and for which with 2018 global average carbon intensity of power generation, the wheel-to-well aspect of life-cycle emissions accounts for 56-64%. So reducing the amount of CO_2 emissions due to fuel use is the area with the largest GHG mitigation potential. This can be achieved through vehicle efficiency improvements[8] and CO_2 emissions reduction in electricity or hydrogen production.[9] In addition, a reduction in the carbon intensity of electricity generation could also provide GHG emissions

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[8] Electric powertrains are currently three-to-five-times more efficient than internal combustion engines, depending on vehicle weight. Auxiliaries, such as air conditioning can significantly affect the vehicle electricity use. Better vehicle insulation or heat pumps can help in that regard. For example, upcoming model SEAT El-Born is fitted with a heat pump that can, according to the manufacturer, save 60 km of range (SEAT, 2019) and the Audi Q4 e-tron model uses a body paint specifically designed to reflect certain light waves to help keep the interior cool and minimise needs for air conditioning (Audi, 2019). Both models are expected to start production in 2020.

[9] The variability of the carbon intensity of electricity generation across countries (as low as 9 g CO_{2}-eq/kWh in Norway in 2017) suggests that there is a demonstrated capacity and a viable margin to do so. Carbon capture, utilisation and storage (CCUS) may also make this viable for power generation from fossil fuels. For hydrogen, lowering emissions requires the use of electrolysis and renewable electricity, or the use of steam methane reforming (SMR) coupled with CCUS. However, hydrogen produced by electrolysis requires a significantly higher amount of electricity compared with battery storage, and SMR with CCUS only allows for partial GHG emission reductions.

reductions in the vehicle cycle (as processes would be using lower carbon electricity), if the region of use of the vehicle and of manufacturing are the same, or if the emissions reduction from electricity production are global.

Plug-in hybrids can tap the GHG emissions reduction potential areas as for HEVs and BEVs, plus the additional lever of increasing the share of electric driving.

As stated, an important aspect of the analysis of life-cycle emissions is the difference in driving ranges provided by the various vehicle types. A comparison of FCEVs and BEVs illustrates this well. It shows that doubling the drive range of the BEV to the same level of the FCEV diminishes the life-cycle emissions benefit of the BEV relative to the FCEV at the current global average carbon intensity of electricity generation.[10] This also holds for a similar comparison with a conventional ICE vehicle. Boosting the BEV to a hypothetical 600-800 km drive range, which likely can be achieved by a benchmark global average ICE vehicle, would significantly cut into the current life-cycle emissions benefit of BEVs, as the required larger battery size would increase the life-cycle emissions associated with the battery roughly proportionally. In practice, such drive ranges are not currently considered among BEV manufacturers, not least to contain BEV costs. Nonetheless, this consideration underscores that rightsizing the drive range of BEVs is important not only for their cost competitiveness, but also from the point of view of their climate benefits. Addressing this while ensuring no loss in convenience for the customer (through e.g. optimised and fast charging infrastructure) will be important moving forward.

Effect of mileage on EV life-cycle GHG emissions

The vehicle cycle of BEVs results in higher GHG emissions than for an equivalent ICE vehicle. However, as BEVs emit less than ICE vehicles in the use stage, BEVs provide GHG emissions savings on a life-cycle basis after a period of use of the vehicle. Relative to an equivalent gasoline ICE vehicle, a mid-size BEV, with a 200 km drive range and assuming the global average CO_2 emissions intensity of electricity generation as well as average battery manufacturing GHG emissions of 75 kg CO_2-eq/kWh, starts saving CO_2 on a life-cycle basis when it has been driven more than 25 000 km (Figure 4.3). For a BEV with a longer range (400 km), the break-even mileage is 60 000 km under the same assumptions. For a vehicle driving 15 000 km annually, used as a central estimate in this analysis, a BEV provides net GHG emissions savings after 1.5 to 4 years of use, depending on the driving range.

With a carbon intensity of electricity generation equal to the 2018 global average, a BEV travelling 150 000 km over ten years (as per our central estimate) saves 23-33% of GHG emissions over its life cycle compared with an ICE vehicle. Savings are maximised for high mileage drivers, at around 32-38% less GHG emissions than an equivalent ICE vehicle at 250 000 km, provided that this does not require a battery replacement. At this mileage level, two-thirds to three-quarters of the vehicle's emissions are from the fuel, as opposed to vehicle manufacturing, disposal and recycling. This is particularly relevant for fleet vehicles or taxis which will cover higher-than-average distances over their lifetime. Moreover, CO_2 savings due to mileages that are higher than our central estimate go hand-in-hand with fuel cost savings and an early cost-parity, on a total cost of ownership basis. A lower CO_2 intensity

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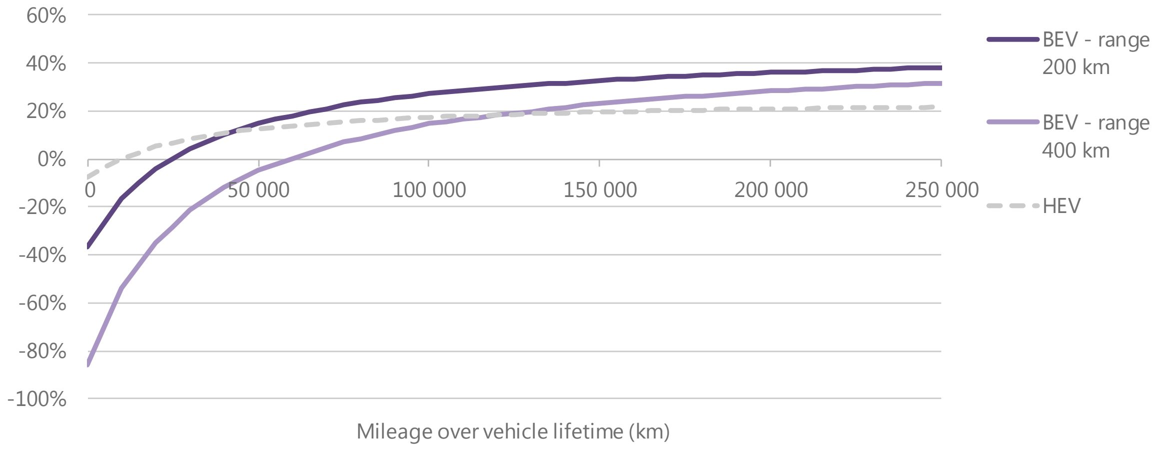
[10] The BEV being powered by electricity and the FCEV being powered by hydrogen stemming from steam methane reforming from natural gas.

of power generation would naturally shorten the time needed for a break-even with an ICE vehicle and it would boost savings at high mileages.[11]

A key difference from BEVs is that HEVs have vehicle cycle emissions (manufacturing, disposal and recycling) very similar to those of an ICE vehicle (Figure 4.2). HEVs start saving CO_2 in the first year of driving (i.e. under 15 000 km), but do not surpass 20% GHG savings compared to an equivalent ICE vehicle in the long-run.

Figure 4.3. Life-cycle GHG emissions savings of a mid-size BEV and HEV relative to a global average mid-size ICE vehicle by lifetime vehicle mileage, 2018



Notes: Assumptions are the same as for Figure 4.2, except for mileage which is a variable here. Average carbon intensity of electricity generation in the fuel cycle is 518 g CO_2-eq/kWh.

Sources: IEA analysis based on ANL (2018); IEA Mobility Model (2019b); IEA (2019a).

Life-cycle GHG emissions savings begin at 25 000 for a 200 km BEV and 60 000 km for a 400 km BEV. HEVs start saving GHG emissions compared with a global average mid-size ICE vehicle after 10 000 km. HEVs save about 20% of the lifetime GHG emissions; with the current global average carbon intensity of the electricity mix, BEVs can save up to 30-40%, relative to a global average mid-size ICE vehicle.

Effect of vehicle size and power on EV life-cycle emissions

For all powertrains, vehicle size has an impact on life-cycle GHG emissions.

- A large ICE car (200 kW) with 150 000 km total mileage emits 58% more than a small size, 70 kW ICE car over its lifetime (44 t CO_2-eq versus 28 t CO_2-eq).
- For BEVs, assuming a 39 kWh battery (for a range of 200 km) and 200 kW power for a large version, and a 36 kWh battery (for a range of 200 km) and 70 kW power for a small version, the difference is 17% (25 t CO_{2}-eq versus 21 t CO_{2}-eq) (Figure 4.4).

For ICE vehicles, the vehicle cycle (manufacturing, disposal and recycling) and the fuel cycle (use phase) are in roughly equal parts responsible for this difference in emissions, meaning that manufacturing a larger ICE (implying larger material quantities), and the greater amount

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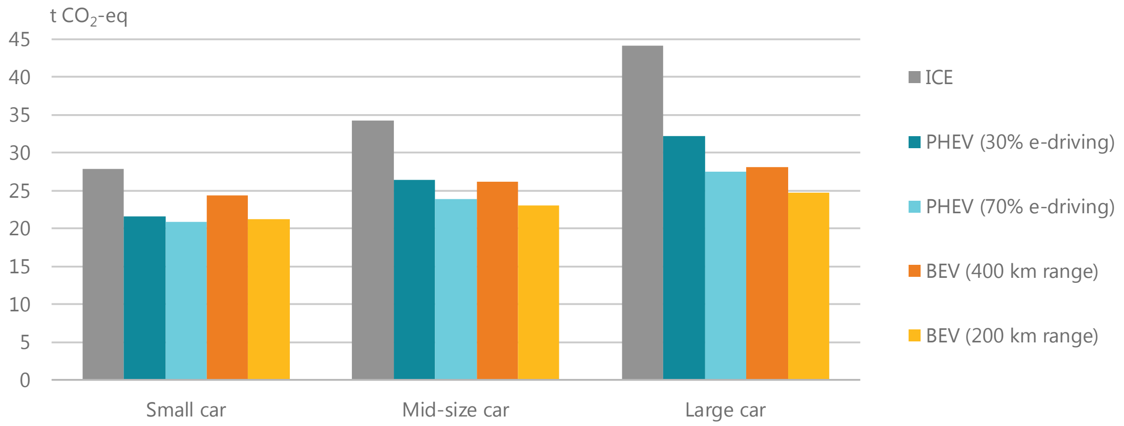
[11] The effect of power system CO_2 intensity on vehicle life-cycle emissions is shown in Figure 4.5 and Figure 4.6.

of energy needed to move it, drive emissions up to a similar extent. The picture is different for BEVs, for which larger vehicle manufacturing makes up for the large majority of additional emissions compared to a small BEV,[12] although the increase in emissions is smaller than for ICE vehicles.

Figure 4.4. Life-cycle GHG emissions of BEVs, PHEVs and ICEs by market segment, 2018



Notes: This figure is based on the life-cycle GHG emissions assessment of vehicles in small, mid-size and large market segments, coupled with three sizes and power ratings: 70 kW (1 100 kg), 110 kW (1 450 kg) and 200 kW (1 900 kg) (the relationship between vehicle size and power is shown in (IEA, 2019a)). For the mid-size BEV, PHEV and ICE vehicle, the assumptions are the same as in Figure 4.2. The vehicle specific assumptions for the small and the large vehicles are:

Small: battery size 36 kWh (BEV with a range of 200 km), or 75 kWh (BEV with a range of 400 km), or 10 kWh (PHEV with a range of 55 km); WLTP fuel economy 5.5 Lge/100 km (ICE); 18.2 kWh/100 km (2.0 Lge/100 km) (BEV 200 km range); 18.6 kWh/100 km (2.0 Lge/100 km) (BEV 400 km range). The fuel economy of BEVs and PHEVs (for the electric powertrain) include a 5% penalty for charging losses.

Large: battery size 39 kWh (BEV with a range of 200 km), or 80 kWh (BEV with a range of 400 km), or 11 kWh (PHEV with a range of 55 km); on-road fuel economy 8.9 Lge/100 km (ICE); 19.6 kWh/100 km (2.1 Lge/100 km) (BEV 200 km range); 20.0 kWh/100 km (2.2 Lge/100 km) (BEV 400 km range). The fuel economy of BEVs and PHEVs (for the electric powertrain) include a 5% penalty for charging losses.

For all segments, PHEV is a combination of ICE and BEV fuel economies, either with 70% total mileage driven on gasoline and 30% on electricity (30% e-driving) or 30% total mileage driven on gasoline and 70% on electricity (70% e-driving). Annual vehicle mileage is 15 00 km and vehicle lifetime is ten years. Carbon intensity of electricity generation in the fuel cycle is 518 g CO_2-eq/kWh.

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

GHG emissions savings from electric vehicles increase with size relative to equivalent ICE vehicles. In absolute terms, small vehicles emit less GHGs than large ones with the same powertrain.

Figure 4.4 shows that over a ten-year vehicle lifetime with 15 000 km annual mileage, the larger the vehicle size, the larger the difference in GHG emissions between an EV (BEV or PHEV) and an ICE car. In other words, in the large vehicle segment, EVs save more GHG emissions compared to ICE vehicles: at the 2018 global average carbon intensity of electricity generation, a small BEV saves 12-24% (depending on BEV range) of GHG emissions over its lifetime compared to a similar size ICE vehicle, and a large one saves around 40%. In the current context of rising sales of vehicles with large powertrains in all markets (IEA, 2019a), this observation suggests that increasing electrification of large vehicle models and targeted

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[12] The reason for this is the much lower sensitivity of BEV fuel use to changes in vehicle weight in comparison with ICE vehicles, as highlighted in Fuel *Economy in Major Car Markets* (IEA, 2019a). This is mostly due to the higher efficiency of electric powertrains and the effect of regenerative breaking.

actions for their adoption over similar size ICE vehicles can be a particularly effective CO_2 mitigation opportunity.

For PHEVs, a larger vehicle size induces larger GHG emissions savings compared to a similar size ICE vehicle in general. However, the share of electric driving is a determining factor in the scale of emissions that can be saved: for a large car that is driven 70% on electricity, a PHEV saves 38% in GHG emissions compared to a similar sized ICE vehicle. If only 30% of the mileage is electric, then these savings go down to 27% (Figure 4.4). Given that most large electric car models in the line-up of automakers are PHEVs, ensuring that the use of the electric powertrain is maximised appears crucial to reap the GHG (and air pollutant) emissions savings benefits of electrification and to rapidly compensate for the higher vehicle cycle emissions (+19%) of a large PHEV, compared with a large ICE vehicle.

It is important, however, to remember that rightsized vehicles (i.e. that are sufficient to fulfil consumer needs) in terms of power, vehicle weight and battery size, contribute the most to limiting GHG emissions. In fact, a small size, 200 km range BEV emits 21 t CO2-eq over its lifetime, which is 25% less than for both a similar size ICE vehicle and a large BEV with 400 km range. However, the absolute difference in life-cycle GHG emissions between a BEV with 200 km range and a BEV with 400 km range does not exceed 15% for the same vehicle size.[13]

Effect of power system and battery manufacturing emissions on EV life-cycle emissions

The GHG savings potential of BEVs for various carbon intensities of power generation are illustrated in Figure 4.5 and Figure 4.6. The results are sensitive to the GHG intensity of battery manufacturing and the size of the car. The ranges in Figure 4.5 and Figure 4.6 show how GHG emissions savings would vary with a GHG intensity of battery manufacturing ranging from 50 kg CO_2-eq/kWh (upper end of the areas) to 150 kg CO_2-eq/kWh (bottom end).[14] This sensitivity analysis illustrates the impacts of the variability of estimates of carbon intensity per kWh of automotive battery packs shown in Figure 4.1.

The result is, as discussed earlier, that emissions savings are highest where emissions from battery manufacturing are low and a large ICE vehicle or HEV is being replaced by a BEV of similar size with 200 km drive range. They are smallest (and can be negative in countries with a carbon-intensive electricity mix) where emissions from battery manufacturing are high and a small ICE vehicle or HEV is being replaced by a BEV of similar size and a drive range of 400 km. In countries where CO_2 emissions of the electricity generation mix are low already today, emissions savings of BEVs are significant regardless the case in question. A zero-carbon electricity supply in the country of use of the BEV maximises emissions savings[15] compared with an ICE vehicle. This underscores the fundamental role of power sector decarbonisation to unleash the climate benefits of BEVs moving forward, especially in the longer-term.

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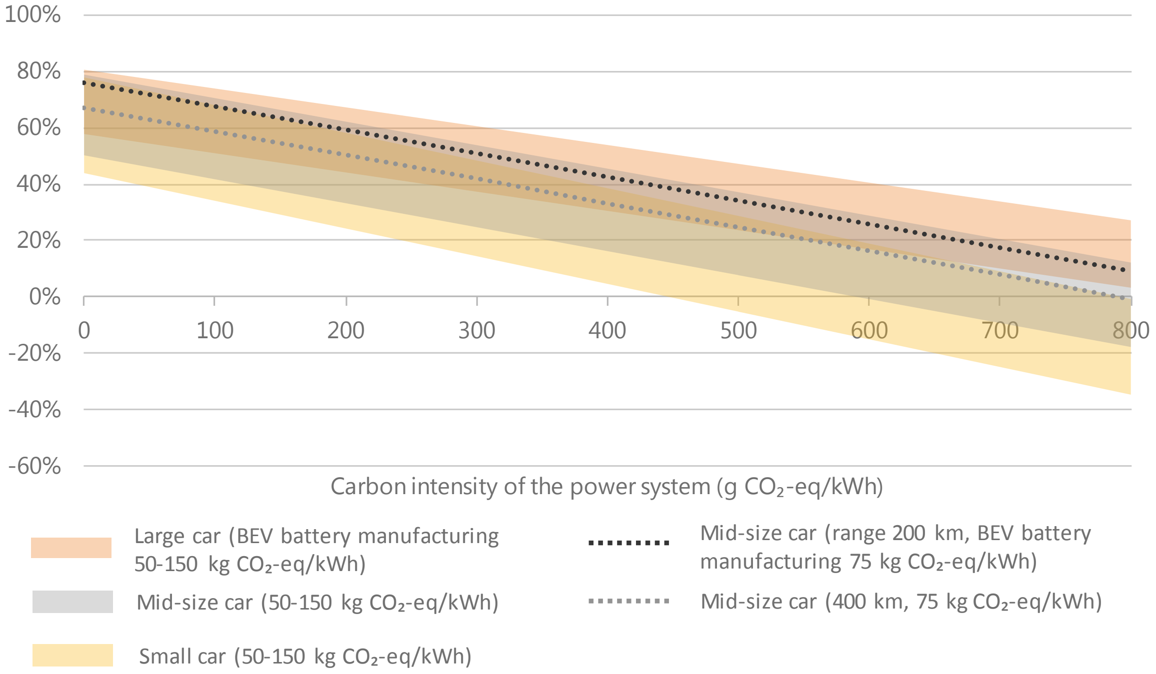
[13] Since larger batteries provide longer driving ranges, they may also facilitate faster EV adoption. The current environment, where battery size is still dictated by affordability considerations, may evolve (as battery prices continue to decline) to where consumers have an increasingly wider choice of ranges for a single vehicle model.

[14] In the central estimates (lines shown for mid-size cars in Figure 4.5 and Figure 4.6), the GHG emissions intensity of battery pack manufacturing is 75 kg CO_2-eq/kWh, which is the value from the GREET model.

[15] 67% for a BEV with 200 km range and 76% for a BEV with 400 km range.

Figure 4.5. Life-cycle GHG emissions savings of a BEV relative to an average ICE vehicle of the same size under various power system carbon intensities

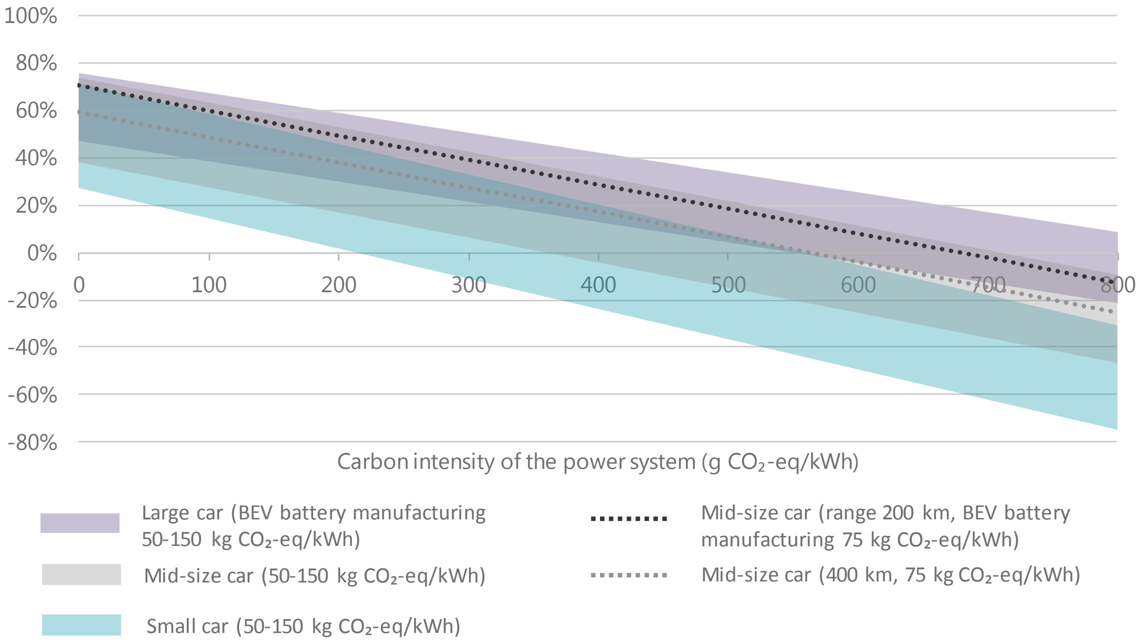


Notes: In this figure, the upper bound of each area is relative to a BEV with 200 km range and a battery manufacturing GHG intensity of 50 kg CO_2-eq/kWh, while the lower bound is relative to a BEV with 400 km range and a battery manufacturing GHG intensity of 150 kg CO_2-eq/kWh. The intermediate lines in the area relative to the mid-size car refer to BEVs with battery manufacturing GHG intensities of 75 kg CO_2-eq/kWh. The carbon intensity of electricity generation varies only for the electricity used as a vehicle fuel; the power system GHG intensity for electricity used in vehicle cycle-related processes (i.e. manufacturing, disposal and recycling) is based on the GREET model and is constant.. The fuel consumption per km of small, mid-size and large cars is the same as in Figure 4.4. All other assumptions are the same as in Figure 4.2.

Sources: IEA analysis based on ANL (2018); IEA (2019a), (2019b), (2019c), (2019d).

Over their life cycle, the extent of GHG emissions savings of BEVs relative to ICE vehicles depends on the carbon intensity of electricity generation for final use and the size of the car.

Figure 4.6. Life-cycle GHG emissions savings of a BEV relative to an HEV of the same size under various power system carbon intensities



Notes: See Figure 4.5.

Sources: IEA analysis based on ANL (2018); IEA (2019a), (2019b), (2019c), (2019d).

In order for life-cycle GHG emissions of BEVs to break even with HEVs, the carbon intensity of the electricity consumed in the use phase must be lower than when comparing BEVs with ICE vehicles.

Box 4.1. Battery chemistry and GHG emissions

In this analysis, the battery technology is lithium-ion with NMC 111 cathode chemistry. The figure here shows the GREET model results for a mid-size BEV with 110 kW power and a lifetime mileage of 150 000 km and explores the effect of other battery chemistries on BEV life-cycle emissions.[16] It provides two main insights:

- Regardless of battery chemistry, a 38 kWh battery (corresponding to a mid-size car with a range of 200 km) is responsible for less than 12% of BEV GHG emissions over its life cycle, if the power mix carbon intensity for fuelling the vehicle corresponds to the 2018 global average of 518 g CO_2-eq/kWh. For a 78 kWh battery (corresponding to a mid-size car with a range of 400 km), this share can go up to 22%, depending on the battery chemistry.

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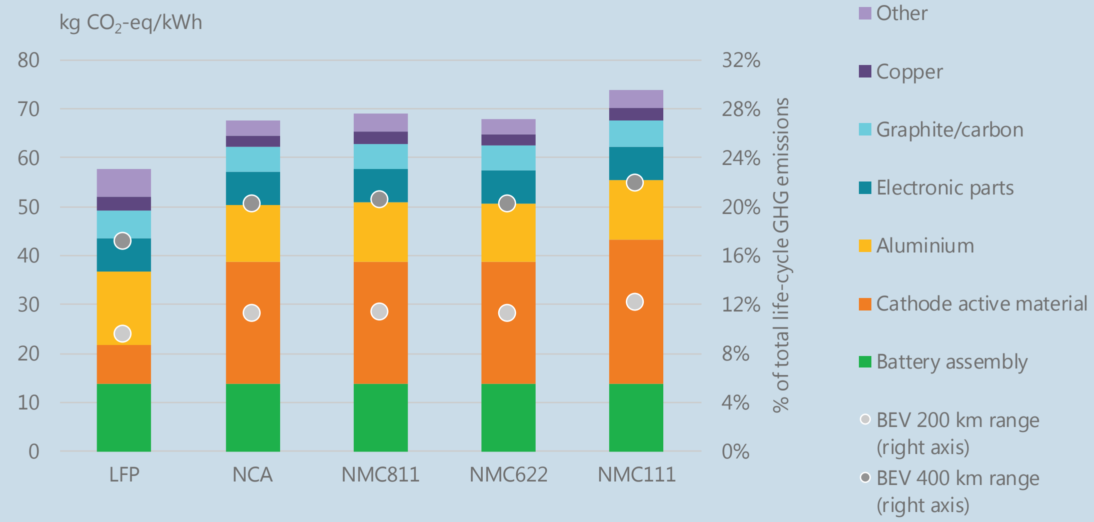
[16] Within the lithium-ion battery technology, various cathode chemistries exist at commercial level or are estimated to rise in importance in the coming years. These include nickel-manganese-cobalt (NMC) 622 and NMC 811 (the numbers 622, 811 and 111 represent the proportions of nickel, manganese and cobalt, in this order, in the cathode active material). In electric cars today, the NMC 111 chemistry is the most widely used, while nickel-cobalt-aluminium (NCA) cathodes are currently used in Telsa vehicles. Lithium iron phosphate (LFP) batteries were in use in cars China, but this chemistry is now mostly used in electric buses.

- The mix of active materials in the cathode (e.g. nickel, manganese and cobalt), is the main determinant of battery manufacturing emissions. The NMC 111 chemistry is the most GHG-intensive of the five chemistries shown and LFP is the lowest.

Life-cycle GHG emissions of different battery chemistries for automotive batteries



Sources: IEA analysis based on GREET (ANL, 2018).

At similar battery capacity (in kWh), the NMC 111 chemistry emits 28% more than the LFP chemistry. As the NMC 622, NMC 811 and NCA chemistries have broadly equivalent GHG emissions per kWh, future development towards nickel-rich chemistries in automotive batteries (which exclude LFP, currently used in buses) are not expected to result in substantial increases in GHG emissions from battery manufacturing processes.

In the future, the relative impact of battery manufacturing on the vehicle life-cycle emissions is also likely to rise as the electricity consumed in the use phase decarbonises. Minimising this impact will require the reduction of the carbon intensity of the energy mix used in processes related to battery manufacturing (and a reduction of carbon intensity in electricity generation across the world will also lead to a reduction in manufacturing emissions, additional to EV emissions in the use stage). Reduction of GHG emissions in the battery assembly per unit will also be facilitated by the scale-up of battery manufacturing facilities and capacity factor maximisation: i.e. by factors that also reduce unit costs. [17]

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[17] In this analysis, changes due to evolution in battery chemistries are assumed to have a net-zero impact on emissions from the battery assembly process. Even if there is an intention to refine this assumption, currently embedded in the GREET model, it is reasonable to estimate that battery assembly energy intensity will not drastically change in the next decade with an NMC 111 chemistry towards NMC 622 and NMC 811. This is because higher energy requirements from stricter monitoring of humidity required in the assembly rooms for nickel-intensive chemistries (Dunn et al., 2012; Dai et al., 2017) are compensated by the increase in energy density per unit volume.

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5. Challenges and solutions for EV deployment

Vehicle and battery costs

Challenge

EV purchase prices are not yet competitive with ICE vehicles

Indications from the total cost of ownership analysis

The high purchase price of an electric vehicle (EV) (absent purchase incentives) is regarded by consumers as the main barrier when buying a new car. The price difference compared with an internal combustion engine (ICE) vehicle is substantial. Purchasing a standard medium size EV is approximately 40% more expensive[1] than a conventional ICE vehicle of similar size (IEA, 2019a).

The purchase price, however, does not give the full picture of the total cost for the consumer. The total cost of ownership (TCO) is a useful means to compare the cost of driving vehicles with different characteristics by taking account of the combined effects of purchase price and operational costs. The *Global EV Outlook 2018* took a close look at comparing the TCO between electric and ICE vehicles for various categories (IEA, 2018a). The key findings are: [2]

- From a first-owner perspective (assumed to keep the car on average 3.5 years), even with higher prices for fuel than for electricity on a per kilometre (km) basis, the TCO for a battery electric vehicle (BEV) is higher than for an ICE vehicle.
- With battery prices to auto manufacturers of USD 260 (United States dollars) per kilowatt-hour (kWh) (comparable with battery production costs close to USD 215/kWh, i.e. accounting for a 20% profit margin for battery suppliers), scaling up the consumer adoption of BEVs in cars continues to require policy support.
- With battery prices close to USD 330/kWh,[3] plug-in hybrid vehicles (PHEVs) show lower first-owner TCOs than ICE cars only in regions with high fuel prices.
- Electric two-wheelers are cost competitive with ICE versions in countries with high fuel taxes when the mileage exceeds 4 500 km/year and with a battery pack price of USD 400/kWh.[4]

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[1] An EV costs around USD 35 600 and a standard ICE vehicle costs around USD 25 000 (IEA, 2019b).

[2] The TCO analysis parameters include: vehicle purchase price; mileage; fuel consumption; fuel price; maintenance costs; duration of ownership; residual value of the vehicle at the end of its life, as well as a discount factor. The TCO analysis developed for the Global EV Outlook 2018 looked at the mid-size car category and did not take into account time and discomfort costs possibly posed by BEVs, e.g. for long-distance trips.

[3] This value (which applies to PHEVs) is compatible with USD 260/kWh for BEVs, given that PHEV batteries have a stronger focus on power density, rather than energy density (IEA, 2018a).

- Electric buses travelling 40 000-50 000 km/year are competitive in regions with high diesel taxation regimes for battery prices below USD 260/kWh.
- Electric trucks are only cost competitive as medium trucks with an all-electric driving range below 200 km and as heavy trucks with a range of 400 km with battery pack cost of USD 260/kWh and diesel price of USD 1.4 per litre (L).

A significant overall conclusion of the TCO analysis is that, given the battery production costs, battery prices and fuel prices considered in the *Global EV Outlook 2018* analysis, the economic advantages of vehicle electrification currently are limited to a relatively narrow range of cases.

Effect of recent battery cost reductions on the cost gap

A recent survey indicates that prices of automotive battery packs were around USD 175/kWh by the end of 2018 (Goldie-Scot, 2019). The significant price drop in comparison with the USD 215/kWh used for the central estimate of the TCO analysis in 2018 reflects changes in the key determinants of battery pack costs. These include moving towards increasing shares of nickel-rich chemistries in nickel manganese cobalt oxide (NMC, i.e. moving from NMC 111 to 422 and 532, and to a lesser extent up to 622 and 811)[5] and nickel cobalt aluminium oxide (NCA, moving from $N_{0.8}C_{0.15}A_{0.05}$ to $N_{0.9}C_{0.05}A_{0.05}$) batteries and the increasing size of battery production plants, which reduces the production costs per kWh of automotive battery packs.

Simulations made with the BatPac Model developed by the Argonne National Laboratory indicate that the battery pack cost of USD 215/kWh used in the 2018 TOC analysis is consistent with an average battery pack of 30 kWh, a plant capacity of 3.5 gigawatt-hours per year (GWh/year) and an NMC 111 cathode composition (IEA, 2018a).[6] The same BatPac Model indicates that a cost value of USD 175/kWh is compatible with a change in battery chemistry to a 80/20% NMC 111 and NMC 622 mix, if the pack size is 30 kWh and the plant size is 3.5 GWh/year.[7]

Impacts of developments in 2018 on the total cost of ownership

The TCO for all-electric vehicles is strongly correlated with the price of batteries (IEA, 2018a). As battery prices continue to decrease and energy densities increase, EVs are set to become increasingly attractive from the perspective of cost and performance. Figure 5.1 illustrates the cost competitiveness of different powertrain technologies for a car as a function of battery prices. It considers a first-owner perspective and looks at two fuel price conditions: USD 0.8/L and USD 1.5/L, respectively coupled with average annual mileage of 12 000 km/year and 18 000 km/year.[8] Conditions compatible with the 2018 TCO analysis (i.e. battery price of USD 260/kWh) are shown on the extreme right of the graphs. The figure also covers battery price estimates closer to the USD 175/kWh indicated in Goldie-Scot (2019).

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[4] The smaller the battery pack, the larger the relative fixed costs associated with it (e.g. battery management system, casing). This explains the higher pack cost per kWh for small battery capacities (e.g. two-wheelers) compared to larger capacities (in cars and heavier vehicles) for the same battery technology and chemistry.

[5] The numbers correspond to the ratios of nickel, manganese and cobalt in the cathode.

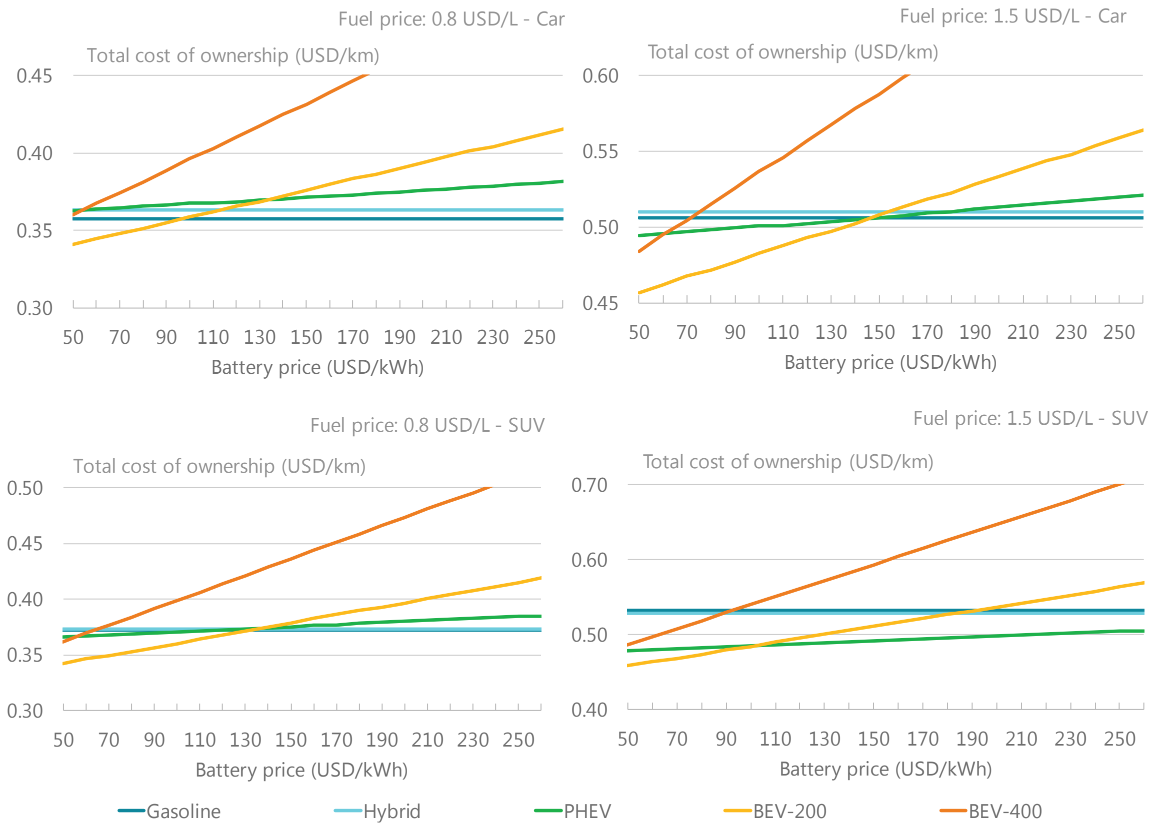
[6] As discussed in 2. Prospects for electric mobility development, NMC chemistries account for roughly half of the automotive battery market, while NCA accounts for almost a third of the total. While the focus of the discussion here is on NMC chemistries, similar considerations can also be developed for NCA and advanced NCA chemistries.

[7] Other ways to achieve the same cost include a stronger shift towards NMC 622 battery chemistry, but in plants having less than 3.5 GWh/year capacity or an upward adjustment of either the pack size or the plant capacity with a higher NMC 111 chemistry share.

[8] The 12 000 km/year mileage for a USD 1.5/L price environment is consistent with the average magnitude of mileage and fuel prices seen in Europe; 18 000 km/year and USD 0.8/L are closer to values observed in the United States.

Figure 5.1 shows that a mid-size BEV car with a 36 kWh battery pack (allowing an all-electric range of 200 km) will have a lower TCO than conventional gasoline ICE or hybrid electric (HEV) cars with a fuel price of USD 1.5/L and 12 000 km/year mileage when battery prices fall below USD 150/kWh. If the all-electric range is 400 km, the battery cost threshold for a costs competitive TCO against a gasoline ICE car would be close to USD 70/kWh.

Figure 5.1. Total cost of ownership as a function of battery and fuel prices for a mid-size car and a SUV



Notes: The total cost of ownership is calculated from a first-owner perspective, i.e. within a period of four years and using a discount rate of 10%. Annual mileage is 12 000 km for the high fuel price scenario and 18 000 km for the low fuel price scenario. For cars, the gasoline vehicle and the hybrid vehicle are assumed to have fuel consumption of 6.8 litres of gasoline equivalent per 100 kilometres (Lge/100 km) for the ICE vehicle and 5.1 Lge/100 km for the hybrid vehicle. The BEV is assumed to consume 0.19 kilowatt-hours per kilometre (kWh/km) (1.9 Lge/100 km) for 200 km range (36-kWh battery), 0.195 kWh/km for 400 km range (73-kWh battery). For SUVs, the gasoline consumption is 8.9 L/100 km and the hybrid consumption is 6.5 L/100 km. BEV consumption is 0.195 kWh/km for a 200-km SUV and 0.2 kWh/km for a 400-km SUV. PHEVs have the same consumption as the hybrid vehicles for ICE operation and the same as the BEVs when in electric mode, their all-electric range is assumed to be 50 km and the share of electric driving is assumed to be 60%. The price for electricity is USD 0.13/kWh and USD 0.04/kWh is added to account for charging infrastructure costs.

As battery prices decline, BEVs become cheaper to operate than ICE vehicles. PHEVs already have lower TCO than ICE vehicles where fuel prices are high, even with high battery costs.

Battery prices of around USD 100/kWh are necessary for BEV cars with 200 km range to be cost competitive with a conventional ICE vehicle at a fuel price of USD 0.8/L and 18 000 km/year mileage. The cost parity threshold falls to USD 50/kWh for BEVs with 400 km range, in the same mileage and fuel price conditions. HEV competitiveness is achieved already at slightly higher battery prices.[9]

Figure 5.1 also shows that with fuel prices of USD 1.5/L plug-in hybrid cars with a 50 km all-electric range (and a 60% share of all-electric driving)[10] are a cheaper alternative to gasoline ICE vehicles or HEVs at a battery price of USD 150/kWh.[11] In low fuel price regions, plug-in hybrid cars are close to cost competitiveness at battery prices below USD 70/kWh.[12] The cost thresholds that allow BEVs to compete on a first-owner TCO basis with hybrids are almost the same as those seen for gasoline engines given these price and average mileage parameters.

Cost competitiveness is reached at higher battery prices for larger vehicles (e.g. sport-utility vehicles [SUVs]) than cars, due to the increased relative benefits of electrification for heavier vehicles (Figure 5.1).[13] For SUVs in countries where the fuel price is USD 1.5 /L, BEVs are cost competitive with hybrids at battery prices of USD 190/kWh if they have 200 km range, and USD 100/kWh for a 400 km range, while large PHEVs with a 50 km all-electric range are already cost competitive with battery prices well above USD 250/kWh. In regions with a gasoline price of USD 0.8/L, large BEVs with a 200 km range and PHEVs are both cost competitive with battery prices at USD 140/kWh, while they need to fall to USD 70/kWh to enable cost competitiveness for large BEVs with a 400 km range.

Solutions

Three areas are of particular importance to deliver significant structural cost reductions in electric vehicle prices[14]:

- Achieve cost reductions in battery manufacturing.
- Achieve cost savings from vehicle design and manufacturing.
- Take advantage of the opportunities from digital technologies to adapt battery capacity size to user needs.

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[9] Cost competitiveness of electric powertrains can also be reached at higher battery costs in light-duty vehicles having higher mileage and lower discount rates (both conditions are possible, in particular in the case of fleets), or with higher fossil fuel taxes.

[10] This is in line with the lower range of values indicated for the utility factor (i.e. the ratio, based on driving statistics, defining the range achieved in charge-depleting condition for PHEVs) in the Worldwide Harmonised Light Vehicle Test Procedure (UNECE, 2018).

[11] Note that the cost per kWh of PHEV battery packs tend to be higher (about 25%) than for BEVs because PHEV battery packs have lower energy storage capacity and because PHEV batteries require cells which need to comply with higher power requirements than those of BEVs. This has a trade-off with energy storage capacity (per unit weight or volume, battery cells capable to deliver high power store less energy than battery cells delivering lower power). The cost per kWh of PHEV batteries therefore is not directly comparable with the cost per kWh of BEV batteries.

[12] The TCO for PHEVs is highly dependent on the chosen powertrain. The analysis shown in Figure 5.1 is conservative as it takes into account that PHEVs have a total installed power that is 40% higher than of an equivalent gasoline vehicle. PHEV designs with small powertrains are likely to reach cost parity for higher battery prices even in low fuel price environments.

[13] ICE vehicles are subject to stronger variations of fuel use per km due to weight increases than BEVs, as discussed in IEA (2019a).

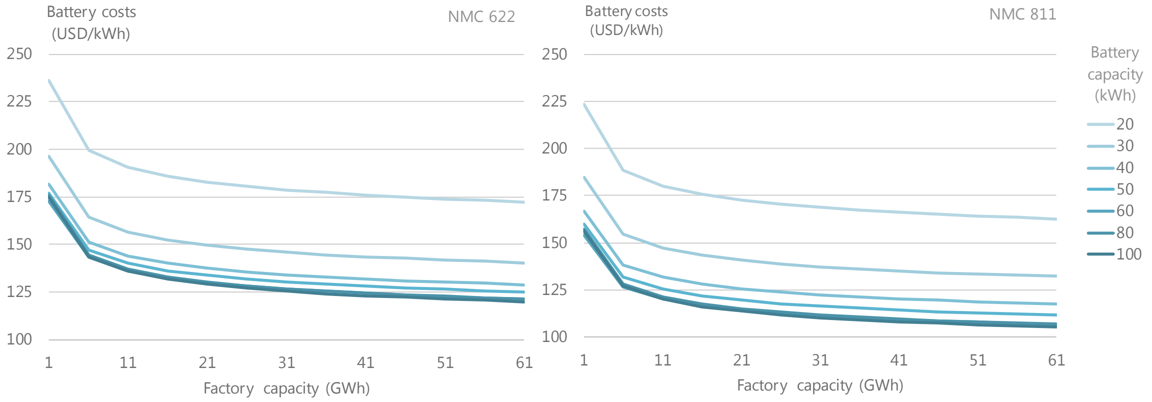
[14] Fuel taxation and vehicle taxation are also options to help deliver significant reductions in the price gaps between EVs and ICE or hybrid vehicles. Such options are beyond the scope of this section. The intention here is to focus on technological solutions that can deliver structural changes (either dependent on technology or vehicle design choices) in terms of cost competitiveness for BEVs and PHEVs, independent of the vehicle and fuel taxation regimes. The effects of an increased uptake of electric mobility on fuel, vehicle and other taxation instruments in transport are discussed in the Government revenue from taxation section.

Battery cost reductions

Analysis of the future development of the three main determinants of battery costs – battery pack size, production capacity of battery manufacturing plants and chemistry – suggests that battery costs declined during the course of 2018 and are expected to continue falling in the near term. (See Chapter 2, *Industry roll-out plans* and Chapter 3, *Implications for automotive batteries*).

Results from the BatPac Model with NMC 622 and NMC 811 cathode chemistries and a range of battery pack capacities and plant sizes are shown in Figure 5.2. Using NMC 811 cathodes, average battery sizes around 80 kWh and 30-50 GWh/year factory capacities, BatPac suggests that battery costs in the medium term can fall to between USD 105-120/kWh. This does not include additional medium-term cost reductions that are expected to come from improvements in areas such as anode materials, electrode thickness and cell voltage. In addition, the development of solid state cell technology has the potential to bring a step-change reduction in battery costs. These results are in line with the cost targets of most research and development plans globally, which range 80-120 USD/kWh by 2030 (IEA, 2018a).

Figure 5.2. Lithium-ion and NMC 622 battery cost relative to capacity and factory size



Notes: Costs represent a battery design for a BEV of varying capacities. Cells are modelled considering an NMC 662 cathode and a graphite anode.
Source: IEA analysis based on BatPac 3.17 (ANL, 2019).

There is scope for battery cost reductions through economies of scale and cell chemistry advances.

Significant developments are also being made for post lithium-ion technologies, in particular for solid state batteries. Large investments in solid state battery research are being made in Japan, where an alliance of Japanese manufacturers has joined forces (with public support from Japan's New Energy and Industrial Technology Development Organization) to develop solid state batteries (Tanaka et al., 2018). Recently, Toyota and Panasonic created a joint venture with the aim of developing solid state batteries in the first-half of the 2020s and intends to do so for various automakers (Toyota, 2019).[15]

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[15] This intention is coherent with the indications given in the interim report of Ministry of Economy, Trade and Industry's Strategic Commission for the new era of automobiles, which makes explicit references to a co-operative approach across industrial stakeholders (Tabeta, 2018).

If the cost reduction rates are sustained and battery costs continue to decrease, the economic case for BEVs and PHEVs will also be strengthened for vehicles that have an average daily mileage below 300 km. Battery technology is expected to continue to progress in terms of reduced charging times as well as increased capacity to handle high power charging. This, in combination with the use of PHEVs (and fuel cell range extenders – if fuel cell costs are reduced), is well suited to ensure that the attractiveness of electric mobility can expand to a broader range of applications.

Reducing EV costs with simpler and innovative design architectures

The TCO analysis assumes that electric cars have equal costs to ICE cars with the exception of the costs linked strictly to the powertrain and the energy storage system. However, as the experience with the manufacturing of EVs increases and scale increases, there are good reasons to believe that costs for EVs will decline also because of opportunities in other areas.

The possibility to fully redesign the vehicle manufacturing platforms, capitalising on the presence of much fewer moving parts than in ICE vehicles and taking advantage of compact dimensions of electric motors, can offer cost reduction opportunities. A statement by Volkswagen executives announcing the forthcoming launch of the "*ID*", the first electric car expected to sell for the price of a comparable Golf diesel (Diess, 2019), suggests that the achievement of price parity between BEVs and an equivalent ICE car can be (at least partly) underpinned by the development of a dedicated vehicle architecture. This suggests that cost reductions are not only limited to powertrain and energy storage system developments. In the specific case of Volkswagen, the statement on cost parity made direct references to the development of a new vehicle manufacturing platform, the Modular Electric Toolkit (MEB) dedicated to the production of over 100 million BEVs and inspired by the ones already in use by the company to manufacture a variety of its models at a large scale (Diess, 2019).[16]

Adapting battery sizes to travel needs

Since the battery is the major cost driver of EVs, matching the range of vehicles to owners travel habits is critical to avoid costly "oversizing" of batteries in vehicles. A better adaptation of the battery size will also have benefits for material efficiency and reducing life-cycle greenhouse gas (GHG) emissions. Examples of adaptation of battery size that have already been put into practice include:

- Electric bus designs using the opportunity charging concept (i.e. placing chargers at the end of urban bus lines, rather than at the bus depots) are based on the optimisation of the battery capacity of vehicles to fit the required route.
- Car manufacturers offering EV models with different battery sizes to consumers to match their travelling habits.[17]

Decreasing the need for very high range BEV cars can also be facilitated by the offer of rentals of ICE vehicles to owners of BEVs when planning a long-distance trip. This solution is currently being proposed by several brands.

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[16] To accelerate this process and allow the new platform to establish itself as the standard for electric mobility, Volkswagen also announced its intention to open it to other carmakers (Volvo Trucks, 2019).

[17] Two examples include the Nissan Leaf and Tesla models, even if this is an option not yet offered in every market.

Further battery size optimisation can be achieved through widespread use of digitalisation and information and communication technology (ICT). As consumers and business opt into real-time monitoring and data on vehicle utilisation patterns become more available, it will be increasingly possible for original equipment manufacturers (OEMs) to suggest vehicles with a range that is appropriate to specific consumer driving patterns. This is likely to have its greatest potential for freight vehicles, where the calibration of battery capacity to the mission profiles of the vehicles can have a large impact in terms of cost optimisation, especially in well-managed fleets.

Instruments such as Scania's connected service web portal, allow real-time tracking of truck positioning and usage profiles (Scania, 2019).These are extremely well suited to give insights into the status and performance of the fleet and individual vehicles to the customers of truck and bus manufacturers, as well as to provide useful information on usage patterns of customers to the OEMs. This can enable the offer of vehicles that are optimised to their needs and even the use of modular battery packs, capable of mission-specific requirements), speeding up the adoption of PHEV and BEV technologies.

A clear example is the case of fleet vehicles that operate in urban areas. Even today, battery electric vehicles with battery capacities and charging profiles in such fleets are very well suited to deliver net TCO savings in comparison with ICE and hybrid vehicles. Other examples include vehicles that have mixed use with significant portions of urban driving, which could fully transition to electrified operations for the urban operations via PHEV technologies, optimising PHEV battery capacities to enable all urban operations in all-electric driving.

Co-operative arrangements such as the coalition formed by E.ON, H&M group, Scania and Siemens to accelerate decarbonisation of heavy transport can be useful to build knowledge in this innovative area of technology development (Scania, 2018). They can help design, pilot and demonstrate new solutions that can be scaled up or adopted by other private sector stakeholders to foster the clean energy transition in transport.

Supply and value chain sustainability of battery materials

Challenges

The growth of a new major industrial sector inevitably leads to consequences for the material and supply chains. For the automotive sector, a transition from ICE vehicles to batteries and electric motors as the main components of the powertrain leads to structural change in the materials used. Challenges surrounding the supply chain of these materials will also gain in importance.

It is important that governments and the auto manufacturing industry develop the needed capacity to anticipate the risks associated with these changes and design strategies to manage them.

The main risks of raw or refined material supply are:

- Production-related (e.g. lack of reserves or resources,[18] under-investment in production capacity, lead times for new capacity).
- Economic (demand/supply balance, including demand fluctuations and sudden disruptions, stockpiling, policies affecting production or import/export options).
- Geopolitical (highly dependent on national policies and strategies, and often exacerbated in cases of geographical concentration of extraction and/or refining).
- Social (impact on the well-being of communities at all scales, local, regional, national and transnational).
- Environmental (e.g. local pollution, supply chain related carbon dioxide (CO_2) emissions, impact on local ecosystems and water resources, landscape destruction).

The importance of these risks often defines the *criticality* of a material and varies substantially from different stakeholder perspectives and in time (Hache et al., 2019). For instance, lithium is considered as critical in the United States (Bradley et al., 2017) whereas the European Commission does not assess it as such (EC, 2017a). [19]

The future demand for materials for automotive sector will depend on the speed of the transition to electric mobility, as well advances in battery technology and chemistry.[20] The materials needed in the largest quantities for battery packs using the most common battery chemistries are aluminium, graphite/carbon, copper, nickel, cobalt and manganese.[21] An electric car contains about five-times more copper than an equivalent ICE car (ANL, 2018), as it is present in the battery, electric motor and wiring. Copper will also be needed in large quantities for power grid upgrades and infrastructure extensions for electric vehicle charging.

An issue that makes the sustainability of material supply chains difficult to ensure is the lack of identification and traceability of each stakeholder along the material value chains, from the mine to the end-product manufacturer, the OEM in the case of electric vehicles (IEA, 2018a). Their international nature and the diversity of local regulations and minimum reporting standards do not help to gain a clear view of the overall value chain. Gaps in the supply chain traceability lead to under-awareness of the social, environmental, corruption and conflict-related risks and hazards associated with each step of the value chain. The limited information for product manufacturers and their customers that results from these gaps in traceability of supply chain does not encourage action.

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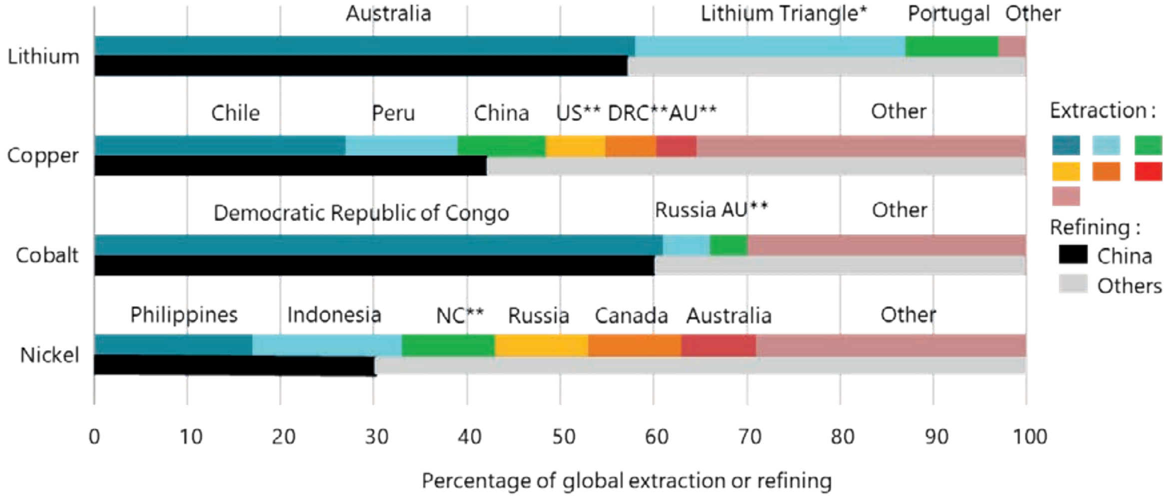
[18] A mineral resource is a concentration of material naturally found on Earth, in a quantity and concentration that could allow economically feasible extraction. Resources are classified as known or estimated. Reserves are the part of resources for which economically viable production has been proven (New Pacific Metals Corp, 2018).

[19] On both the European Union and United States lists, critical raw materials related to EVs are cobalt, graphite and rare earth elements (the latter are mostly used in electric motors). In addition, lithium, aluminium and manganese are also considered critical in the United States (USGS, 2018) (EC, 2017a).

[20] Ranges of estimated future demand for some of these materials, according to the electric vehicle uptake scenarios developed in this report, are presented in Chapter 3, *Material demand for automotive batteries*.

[21] Note that there is no cobalt or nickel in lithium iron phosphate (LFP) battery chemistry.

Figure 5.3. Main extraction and refining locations of key materials for automotive batteries



* Lithium Triangle = Argentina, Bolivia and Chile.

** US= United States; AU= Australia; DRC= Democratic Republic of Congo; NC= New Caledonia.

Notes: For extraction, all countries are reported based on 2017 data. For refining, data are based on 2015, 2016 or 2017 depending on the source. Each of the countries aggregated under other have lower material extraction or refining rates than the countries individually presented.

Nickel extraction and refining sites are shown here regardless of the class of the nickel. Nickel is supplied from sulphide ores and laterite deposits. The former are mainly used to produce class I nickel (>99% Ni content). Class II nickel (<99% Ni content) is mostly derived from laterite and currently driven by demand for stainless steel production. The choice to include all nickel supplies in the figure is due to the fact that a growth in nickel demand for EV batteries may lead to growing production of class I nickel from laterite deposits. On the refining side, the figure also shows shares for both class I and class II nickel. In 2016, class I nickel metal products accounted for 49% of the global nickel output and class II nickel (ferronickel, nickel pig iron and oxide) for 51 % and the main class I nickel producers were the Russian Federation (20%), China (19%), Canada (18%) and Australia (12%).[22]

Sources: USGS (2019a), (2019b), (2019c), (2019d), CDI (2016); Sun et al. (2017)

Extraction of lithium and cobalt is particularly concentrated geographically. China is the main refiner of lithium, copper, cobalt and nickel.

Figure 5.3 highlights the main locations of extraction for a selection of materials used in vehicle battery production that are subject to higher criticality than others. It also provides the percentage of the current production which is refined in the People's Republic of China (hereafter "China"), the main refiner for the materials studied.

Table 5.1 summarises, from a high-level perspective, the specific risks associated with a number of materials used in vehicle battery production.

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[22] These data are based on a personal communication of the authors with Mark Mistry from the Nickel Institute.

Table 5.1. Main features and known risks associated with primary material supply for automotive batteries

	Lithium	Cobalt(1)	Nickel	Copper
Known material resources(2)	61.8 Mt	27 Mt	300 Mt (onshore)	2.1 Gt
Cum. demand from EVs by 2030 in the NPS(3)	0.97 Mt	1.1 Mt	5.3	6.4 Mt
Cum. demand in the EV30@30	1.9 Mt	2.1 Mt (50% of global demand was from battery market in 2016)	11 Mt	12 Mt (battery only)
Supply and capacity ramp-up challenges	Large geological availability. Current overcapacity of mines supply regarding the demand but production struggles to keep up with demand. Up to ten years lead time from suitable deposit identification to production.	Current production surplus, but stockpiling issues. Lead time for new capacity (up to ten years). Market highly dependent on by-product extraction.	Geologically abundant, but variety of end-product grades. Challenge is in ramping up capacity for the production of EV battery-suitable grade (Class I >99% Ni content (4)).	Large resources, with long time needed to convert resources into reserves (17 years on average).
Environmental challenges(5)	Significant for local ecosystems and water resources (Lithium Triangle).	Significant for local ecosystems: soil and water pollution if poor waste management, use of acid in processing.	Air pollution. Water/soil pollution and toxic tailings. Acid leaching processes.	Significant for water resources, local water and soil pollution.

	Lithium	Cobalt(1)	Nickel	Copper
Social challenges	In Lithium Triangle: water-related conflicts, local (indigenous) community's under-benefitting from the activity, corruption.	20% of mining in DRC is artisanal, which is associated with health and safety concerns for miners, plus child labour. Cases of corruption in both artisanal and large-scale mining.	Conflicts with local (indigenous) communities due to environmental issues.	Same social problems as for cobalt in the DRC and some local communities oppose new mining activities (water shortage concerns) (Peru, Chile).

Notes: Mt = million tonnes; Gt = gigatonnes.

(1) Even though the trend for battery chemistry is to significantly reduce the amount of cobalt used, this transition will take some time and, even with relatively low cobalt content in batteries in the longer term, global cobalt demand is expected to soar with the growth of e-mobility as this sector will be one of the main drivers of cobalt use (see Chapter 3, *Implications for automotive batteries*).

(2) The most recent resource assessments for each mineral are considered relative to demand in the two scenarios. It is important to keep in mind that resources cannot necessarily be converted into reserves.

(3) These figures are based on a mix of 10% NCA, 10% NMC 433, 15% NMC 532 batteries, 25% NMC 622 and 40% NMC 811 by 2030 and associated mineral content (IEA, 2018a) and on EV uptake in the New Policies Scenario presented in Chapter 3.

(4) Today, most of the class I nickel comes from nickel sulphide ores mainly located in the Russian Federation and Canada (USGS, 2015) while laterite deposits (mainly located in Philippines and Indonesia) are mainly used to produce class II nickel (<99% Ni content). The latter is mostly driven by demand for stainless steel production. However, the growth of class I nickel demand for EV batteries may lead to growing production of class I nickel from laterite deposits.

(5) Additional to the environmental challenges outlined, material refining is often an energy-intensive process, with potentially significant associated CO_2 emissions depending on the power generation mix. For example, refining is responsible for about 60% of the life-cycle global GHG emissions from cobalt today (CDI, 2016).

Sources: USGS (2019a) (2019b); Mudd et al (2013); Mudd and Jowitt (2014); Yaksic and Tilton (2009), Speirs et al (2014), Hache, Seck and Simoenl (2018); Cyclope (2018); Home (2018); Schodde (2014); Drive Sustainability; The RMI; The Dragonfly Initiative (2018); Church and Crawford (2018), Kavanagh et al (2018); Amnesty International (2016); RCS GLOBAL (2016); BBC News (2014)

Solutions

Some of the challenges identified in Table 5.1 have already led to the development of a number of regulations that frame the activities of the mining sector (e.g. on workplace health and safety, water withdrawals, waste and effluent management, air emissions). These regulations, developed at national, regional and international levels, enable major mining companies to frame the development of their operations in a way that complies with safety, environmental and social requirements. They also help in the development of monitoring practices that are instrumental to identify and replicate good practices. The engagement of major mining companies to deal with the challenges extends beyond regulatory frameworks, through their participation in processes under the framework of the United Nations and other international fora. Overall, this is helpful to ensure that large-scale mining activities develop not only in a way that acknowledges the relevance of existing challenges, but also to have a proactive role to find solutions, including those that can help ensure that long-term supply for electric vehicle materials occurs with minimum adverse effects.

This section provides an overview of the response from various stakeholders, both public and private, along the EV material supply/value chains. This overview builds on existing high-level guidelines and best practices that target a traceable and sustainable approach of raw material supply chains. However, because of the significant geological, physical, economic and geographical diversity of the materials and their origin, plus their associated risks, detailed scrutiny and tailor-made solutions are needed to mitigate risks all along the chain down to the individual mine.

Towards sustainable minerals sourcing via due diligence principles

A number of stakeholders, from government, international organisations, non-governmental organisations (NGOs) and the private sector have looked and/or are increasingly looking into solutions to improve transparency of material supply chains and to mitigate risks associated with materials production. Action was initiated through the creation of guidance on due diligence in supply chains. One of the first major governmental actions on due diligence was the 2010 Dodd-Frank Act in the United States, requiring due diligence for conflict mineral sourcing. It focused on tin, tantalum, tungsten and gold (3TsG) (GlobalWitness, 2015a), all well known for being conflict minerals. They are used in electronic devices such as mobile phones. Several African countries with significant extractive activities such as the Democratic Republic of Congo (DRC) and Rwanda passed laws requiring companies to monitor their supply chain (GlobalWitness, 2015b). The Dodd-Frank Act contributed to the development of the Organisation of Economic Co-operation and Development (OECD) Due Diligence Guidance for Responsible Mineral Supply Chains (OECD, 2019a). It is the leading international standard on the topic (currently in its third edition[23]), and provides detailed recommendations for enhancing supply chain transparency and mitigating risks mainly related to human rights (Box 5.1). In 2021, the European Union will enforce a regulation called the Conflict Minerals Regulation for 3TsG to ensure that importers from EU countries will reach the standards set by the OECD Due Diligence Guidance (EC, 2017b).

Box 5.1. OECD Due Diligence Guidance for Responsible Mineral Supply Chains

The guidance aims to help companies to assess the risks related to mineral sourcing in the conflicted mineral supply chain by providing a five step protocol.[24] The five step framework is applicable to all minerals, with the guidance featuring more detailed supplements for the 3Ts and gold. The supplements are considered the first point of reference for other supply chains with similar characteristics.

Summary of the five step framework:

- Step 1: Companies should strengthen their management systems to adapt their engagement with materials suppliers as outlined in the next steps.
- Step 2: Companies should map the factual circumstances of their supply chain (according to their position along the supply chain), and identify and assess the risks of adverse impacts. Refiners and all companies further upstream are expected to map to the mine of origin of the raw material, and all companies downstream of the refiner are expected to map to the refiner.

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[23] The first edition was adopted in 2011 (OECD, 2019b).

[24] Conflict minerals are defined as those for which companies involved in their supply chain risk to directly or indirectly contribute to violent conflict or human rights abuses (EC, 2017b). A definition given by the French Economics, Social and Environmental Council extends it to risks linked to the environment and to conflicts with local communities due to water resources and corruption (Saint-Aubin, 2019).

- Step 3: Companies should set up a”risk management plan” to prevent or mitigate the risks identified and monitor impacts along the supply chain.
- Step 4: Companies should audit their due diligence practices in the supply chain.[25]
- Step 5: Companies should make their due diligence standards and practices available to the public.

Besides these high-level principles, the guidance also provides best practice advice in its annexes. In particular, it provides a model of a supply chain policy for companies, which addresses the major impact areas from material sourcing to export, including for actions to avoid non-state armed groups being involved in extractive activities or human rights abuses. Annex III, titled ”Suggested measures for risk mitigation and Indicators for measuring improvement”, offers concrete measures for upstream companies to tackle several common risks, such as working closely with international organisations and encouraging efforts from governments to improve work and safety conditions in artisanal mines.

Although the focus until now has mainly been on the 3TsG, due diligence principles can be applied to any material. Additionally, increased scrutiny is now being placed on battery materials after the consumer electronics boom of the past decade. This has been particularly the case for cobalt, linked to calls from NGOs such as Amnesty International (Amnesty International, 2016). The risks of child labour and corruption have been widely communicated in the press (CBS News, 2018).

With the expected growth of EVs, it is essential that the automotive sector and its supply chains get increasingly familiar with the diverse challenges of battery material supply. In this context, a number of automotive battery manufacturers and OEMs have joined the Global Battery Alliance, formed by international organisations, governments, companies and NGOs as a public-private partnership and collaboration platform to catalyse, connect and scale up efforts with the goal that batteries power sustainable development, across the full battery value chain (GBA, 2019). Additionally, ten OEMS co-operate in the *Drive Sustainability* framework, founded to support actions to better supply chain sustainability.[26] Its *Material Change* report identifies risks for several EV-related materials. The Alliance also provides a self-assessment questionnaire available on the website for companies to assess their sustainability performance, and training that covers topics such as social and environmental sustainability, business conduct and compliance (Drive Sustainability; The RMI; The Dragonfly Initiative, 2018). The expected size of the automotive battery market (1.3 terawatt-hours [TWh] of battery capacity by 2030 in the New Policies Scenario and 2.8 TWh in the EV30@30 Scenario, compared with 0.1 TWh of

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[25] Only certain “control points” in the supply chain are required to undergo a third-party audit of their due diligence practices. Control points are key points of transformation of the materials in the supply chain where there is a risk to lose the traceability or to break the chain of custody information and such lost could be pursued further into the supply chain. For most mineral supply chains, this is the smelter/refining stage.

[26] BMW Group, Daimler AG, Ford, Honda, Jaguar Land Rover, Scania CV AB, Toyota Motor Europe, Volkswagen Group, Volvo Cars and Volvo Group. (Drive Sustainability, 2019).

battery capacity demand for EVs in 2018)[27] strengthens the case for accompanying this large-scale transition by better practices and regulations surrounding supply chains transparency, and human and environmental sustainability.

In this context, in 2018 the European Commission adopted the Strategic Action Plan for Batteries developed by the European Battery Alliance (EBA) to develop a sustainable and competitive battery industry.[28] One of its objectives is to secure access to raw materials for batteries. To do so, the two key actions are to encourage research on EU-based suitable extraction sites for critical materials and the use of trade policy instruments to reach sustainable procurement of raw materials from third countries and to promote responsible sourcing (EC, 2017a). The London Metal Exchange (LME), the main global trading platform for industrial metals, is also working on responsible sourcing standards building on the OECD Due Diligence Guidance for responsible sourcing of minerals. LME-listed brands will have to meet these standards to continue trading their product on this platform (LME, 2019). Given the relevance of the LME for the international trade of metals this could have a significant impact on responsible sourcing practices. Indeed, if extractive activities scale up significantly without an appropriate set of basic principles, it is likely that the risks outlined in Table 5.1 and their effects will be exacerbated, to the detriment of local communities, society and the environment. Very recently, the World Bank has also launched the Climate-Smart Mining Facility, the first fund dedicated to making mining for minerals climate-smart and sustainable. It aims to support the sustainable extraction and processing of minerals and metals used in clean energy technologies, including electric vehicles (World Bank, 2019).

Initiatives for better battery supply chain transparency and sustainable extractive activities

A number of automotive and battery companies seem to be placing increased attention on limiting risks associated with the production of automotive batteries feeding their existing and upcoming EV models This is key to provide vehicle customers with the insurance of a responsible product and is in the interest of the automotive industry for its corporate image.

A number of private sector companies have joined corporate initiatives such as the Responsible Mineral Initiatives (RMI) which helps companies to make choices to ensure a responsible supply chain. The RMI was initially formed by electronic companies that provide tools to identify and assess risks in supply chains. This is mainly based on the OECD Due Diligence Guidance and includes a database of validated material refiners based on their performance with regards to due diligence principles.[29] Additionally, the RMI has worked with the China Chamber of Commerce of Metals Minerals & Chemicals Importers & Exporters (CCCMC) on writing the Cobalt Refiner Supply Chain Due Diligence Standard based on the OECD Guidance (CCCMC, The RCI, The RMI, 2018)[30] This is particularly relevant, as most of the cobalt refined in China was shipped from the DRC (Mining Technology, 2018).

Some automotive companies, in co-operation with other stakeholders, are taking concrete action against negative impacts of extractive activities, including to the level of the mine (Box 5.2). Most of these cases are at the pilot stage.

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[27] See Chapter 3, *Material demand for automotive batteries*.

[28] The EBA, launched in 2017, is a co-operative platform of private and public sector stakeholders, including the European Commission, to develop a competitive battery manufacturing industry in Europe.

[29] This work was initiated for the 3TsG, but a database of cobalt refiners is under preparation.

[30] The Cobalt Institute is currently developing a cobalt-specific framework called CIRAF (Cobalt Industry Responsible Assessment Framework) which will help companies identify, assess and mitigate risks in accordance with the leading standards such as the OECD Due Diligence Guidance. (CDI, 2017).

Box 5.2. Examples of local actions to mitigate negative impacts of extractive activities

Cobalt

The main issues with cobalt[31] sourcing come from artisanal mining, closely related to child labour and safety risks of mining operations. The majority of cobalt is produced by industrial scale mining of copper and nickel; and the artisanal mining issue should be seen in this context, given it is largely a subsistence activity in the Democratic Republic of Congo (DRC). The analysis from the Dodd-Frank Act in the United States of the impact on local communities of 3TsG extraction led to the conclusion that boycotting artisanal mining has more adverse effects than benefits on local communities (Montejano and Matthysen, 2013). Products from artisanal mines enter the battery supply chain. Therefore, cross-industry projects in collaboration with NGOs develop onsite actions. For example, Trafigura,[32] CHEMAF[33] and PACT[34] look at enhancing operation safety and efficiency in the DRC region of Mutoshi. They provide working clothing and helmets, as well as mechanised machinery to artisanal miners. Fences surround the site and each worker is registered, with identity and age checks at the site's entrance. Actions are also being developed with local communities outside the mine, providing training for workers, adequate medical support and better education opportunities for children. (Trafigura, 2019).

Lithium

Sustainable Lithium for a Responsible Energy Transition (LiFT) is a voluntary supply chain sustainability project, aimed at catalysing and accelerating action towards socially responsible, environmentally sustainable and innovative battery value chain. LiFT, a project of the NGO RESOLVE, seeks to optimise the contribution of sustainable lithium for a responsible global energy transition.[35] The project is being initiated with lithium producers in Argentina, in partnership with the Cámera Argentina de Empresarios Mineros (CAEM) and with the support of the Mining Association of Canada (MAC). LiFT is designed to link existing mine site responsibility initiatives such as Towards Sustainable Mining (an insurance programme developed by MAC and adopted by CAEM), ICMM Performance Expectations and RMI, with the sustainability requirements of downstream manufacturers, and facilitate a multi-stakeholder dialogue that brings together lithium producers, downstream users, communities, regional governments and civil society. The project is now in a pilot stage of identifying risks, benefits and community concerns related to lithium production in the Lithium Triangle. (RESOLVE, 2019).

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[31] The initiatives on cobalt and lithium are recognised by the Global Battery Alliance as contributing to the GBA's goal.

[32] Trafigura is a multinational commodity trading company. They trade metals and minerals, among others. (Trafigura, 2019).

[33] CHEMAF is a mining and processing company that operates in the DRC (Trafigura, 2019).

[34] PACT is a NGO that tries to improve living conditions for poverty-stricken communities. Through this project, they support CHEMAF in the maintenance of the mine to meet the goal of a responsible mining site. (PACT, 2019).

[35] RESOLVE is an organisation that helps its partners to find solutions on natural resource conflicts, environmental and social challenges.

Bridging the gap between due diligence principles and on-the-ground actions

For the past few years, civil society was alerted through NGOs and media coverage of the adverse effects of some mining practices directly affecting the social and environmental sustainability of consumer goods, first consumer electronics and now (and increasingly in the future) electric vehicles.

Due diligence guidance has existed for about a decade, and high-level principles related to supply chain traceability and risk identification and mitigation have been brought into national and EU laws.[36] These principles, in theory, are applicable to any supply chain, but there is a trend to increasingly adapt them to a specific value chain structures, such as the risks of battery materials, such as cobalt. Japan, for example, included cobalt as a strategic resource for the future battery industry in its "Well-to-wheel Zero Emissions" long-term plan to 2050 (Government of Japan, 2018).[37]

Currently, due diligence frameworks are only voluntary in the case of battery materials. Despite an increasing pool of private sector stakeholders abiding by the voluntary guidance principles, via the RMI for example, a gap clearly needs to be bridged between the level of requirements set by due diligence guidance and concrete requirements to reach full supply chain transparency and the proper identification of the various stakeholders along the chain to take concrete risk mitigation actions locally. In the specific case of cobalt, the DRC government developed a National Action Plan to improve working conditions at artisanal mining sites (LeCongolais, 2017) and the Congolese Mining Code was revised in March 2018 and it imposes an increase of the tax from 2% to 10% on metals considered as strategic by the government, including cobalt. (Government of the DRC, 2018; Delamarche, 2018). However, in the case of cobalt and other battery materials today, the implementation of many mitigation solutions at the mine level are only at pilot stage.

Overall, this suggests that some end-product manufacturers (battery producers and OEMs that are in direct contact with the EV customers) increasingly feel responsible for their supply chain to the mine level; increasing the sustainability of the supply chain requires this to be extended to a larger scale. Such actions could be supported and scaled up via binding regulatory frameworks that encourage international multi-stakeholder co-operation to address challenges related to the international span of mineral supply chains, so that effects are visible at the local community and local ecosystem levels.[38]

Battery end-of-life management

The fate of batteries at their end-of-life also has an impact on the sustainability of the material value chain. Different options (some of which can be combined) exist at the end-of-life of the battery as electricity storage on-board of the vehicle. They are broadly grounded on the reuse and recycle components of the wider 3R[39] framework on waste prevention, as key alternatives

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[36] As mentioned, these countries include the United States and a few African countries such as Rwanda and the DRC. The Conflict Minerals Regulation will be adopted in 2021 in the European Union and aims to ensure that EU companies import the 3TsG from responsible suppliers only (EC, 2017b).

[37] The plan states that the procurement of cobalt needs to be guaranteed and stabilised, referring notably to the need to address stockpiling issues.

[38] One example of such regulation is the *loi sur le devoir de vigilance* (duty of vigilance law) established in 2017 by the French government. It forces companies to establish and publish their strategies to identify and prevent environmental, human right abuses and corruption risks not only for their own work, but also on their suppliers and subsidiaries activities in France and abroad.

[39] Reduce, Reuse and Recycle. The 3R principles are guidance to help reducing the amount of waste generated.

to landfilling.[40] Such end-of-life treatments fall within the circular economy, which ensures that products are kept in use. In terms of battery materials, it enables limiting shortage risks and the dependency on primary raw materials that could be related to potential risks depicted in the Table 5.1.

Reuse: EV batteries degrade over time and with use.[41] Once the service they provide is no longer optimal for use in the vehicle sector, they can find useful purposes in other areas (Casals, et al, 2019). An often-mentioned solution is the use of an "old" EV battery as stationary storage (available capacity requirements are less of an issue than for a vehicle where it matters for driving range). A number of OEMs have announced efforts on such options, in order to maximise the economically viable lifetime of a single battery pack (the recovery of production costs therefore would be spread over the mobile battery lifetime and the stationary battery lifetime of the same pack) (Volvo Group, 2018a; FCA, 2017; Renault-Nissan-Mitsubishi Alliance, 2018).[42] In the European Union, the European Commission via the Innovation Deal developed a process to allow easier reuse of batteries for stationary purposes.[43] It includes the assessment of the national and EU laws to determine whether some of them hinder the reuse of EV batteries (EC, 2018). Indeed, it is crucial that legislation on end-of-life management enables the use of batteries for secondary purposes.

Recycle: Recycling allows materials to be reinjected into the economy, lifting pressure to exclusively resort to new raw material extraction. Although it is unlikely that recycled materials in the short and medium term will supply a large share of the metal demand regarding the expected growth of EV sales and the time it takes for EV batteries to reach their end-of-life. However recycling could limit risks of material shortages and reduce dependency of consumer regions on supply chains associated with transparency issues and risks. Table 5.2 summarises the main recycling processes possible for batteries and their advantages and disadvantages.

A relevant example of co-operation of battery/auto manufacturers with material producers to enable increased recycling rates as well as material traceability is the case of Umicore and Audi, which are working on a closed-loop battery cycle. The objective is to both improve the recycling rate of the battery and create a closed-loop for the recycled metals. Under this initiative, laboratory tests showed that under optimised recycling processes, 95% of the cobalt, nickel and copper in batteries could be recovered. The objective is to attain such rates at an industrial scale (UMICORE, 2018).

As recycling processes have specific advantages and challenges, developing a cost-effective, environmentally respectful recycling method requires the close co-operation of governments and the transport sector to provide appropriate regulations to incentivise companies to recycle when it makes sense and that makes recycling economically viable. A number of initiatives, some of which take inspiration from the "extended producer responsibility approach" have

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[40] Landfilling of non-recyclable materials or even of entire, non-recycled batteries, is the "last-resort" solution for batteries at end-of-life.

[41] The order of magnitude of a battery lifetime is eight to ten years [(Casals et al, (2019)].

[42] The battery packs, aggregated together into large stationary storage packs, would typically be used to absorb variable renewable energy to be able to redistribute it when called upon. Volvo, for instance, works with the City of Gothenburg in Sweden to reuse its batteries from electric buses for local energy storage for a building initiative called "Positive Footprint Housing". So far, it has been on one building as a pilot test. It aims to study the potential lifetime extension of the battery and its role in facilitating residential energy management before further large-scale applications (Volvo Group, 2018b). Such projects can expand the lifetime of the battery up to an estimated ten years for the project (Volvo Group, 2018b).

[43] Innovation Deals are voluntary agreements that help to overcome barriers to innovation (EC, 2018).

started to be developed in major economies.[44] They also generally address the upstream work on the battery design closely related to recycling as it facilitates the dismantling step of recycling.

Table 5.2. Advantages and drawbacks of the main recycling processes suitable for EV batteries

Name of recycling process	Description	Advantages	Drawbacks
Pyrometallurgy	Metals are recovered via high temperature smelting. Separation done by hydrometallurgy.	Easy implementation.	Energy-intensive smelting. Costly because of high energy use. Production of harmful gases. No recovery of aluminium or lithium.*
Hydrometallurgy	Acids dissolve ions out of the metallic battery parts (nickel, cobalt, lithium) into a solution from which each metal can be recovered by precipitation or solvent extraction.	Low energy process. High recovery rate of battery materials.	High consumption of harmful chemicals (waste acid sludge issues). Long process (chemical reactions).
Direct recycling	Use of physical processes such as gravity separation of shredded battery materials.	Low energy process.	Does not permit recovery of each cathode material separately.
Biometallurgy	Hydrometallurgy based on microbial activity to separate ions.	Low energy process. High recovery rate of battery materials. Easily manageable temperature and pressure requirements.	Long process (chemical reactions relying on microbial activity). Requires bacteria culture.

* Recovery of these metals is possible through hydrometallurgy, but it is not economically viable.

Notes: Before each process (excluding pyrometallurgy), the battery is disassembled. This first step allows recovery of some metals such as copper and aluminium. Then the battery (or the rest after dismantling) is shredded (can be included for pyrometallurgy). These processes can be combined to optimise recycling rates. The most widely used processes are currently pyrometallurgy and hydrometallurgy.

Sources: Gaines (2018); Zheng et al. (2018).

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[44] This is a policy approach under which producers are given significant responsibility, financial and/or physical, for the treatment or disposal of post-consumer products. Assigning such responsibility could in principle provide incentives to prevent waste at the source, promote product design for the environment and support the achievement of public recycling and material management goals.

In **China**, a programme called "Interim Measures for the Management of the Recycling and Utilization of Power Batteries for New Energy Vehicles" was established to reduce battery waste. It holds vehicle manufacturers responsible for the end-of-life treatment of the vehicle battery. Furthermore, battery manufacturers are encouraged to design batteries that are easy to dissemble since dismantling is the first major step for each recycling process. They also have to provide the technical details of the battery and its dismantling to the companies they supply. Some measures concern the improvement of the traceability system developed by various stakeholders along the supply chain (Government of China, 2018). [45]

In the **European Union**, the Battery Directive has set standards for industrial and automotive battery waste management since 2006 including the ban of landfilling and incineration (Article 14). It mandates companies to collect and recycle them. It fixes a minimum required recycling rate for different types of battery (EC, 2014).[46] Nevertheless, this policy was determined based on former battery technologies, when zinc-based batteries were dominant, and lithium-ion (Li-ion) batteries had not yet emerged. To adhere to this regulation, the focus is given to materials for which recycling is cheapest, regardless of its criticality or a view to minimise impacts due to extraction (Tytgat, 2013). However, the directive is being revised (EEA, 2018; Dahllöf and Romare, 2017). With the deployment of EVs, volumes of Li-ion batteries are expected to soar. The legal framework thus would benefit from being strengthened and adapted to take account of the new challenges of the EV transition and associated batteries. This could be applied, for example, via recovery mandates for each critical battery material separately, instead of a mandated recovery rate for the battery as a whole.

Implications of electric mobility for power systems

Challenges

The charging requirements of a growing EV fleet are a source of increased electricity demand on power systems, (See Chapter 3, *Impacts of electric mobility on energy demand*.)

High EV uptake, with uncoordinated charging, can pose a challenge for power systems if this demand coincides with peak demand periods and pushes the peak demand on a system, which could translate to the need for additional generation capacity. Clustering effects in the increased uptake of EVs can also lead to local overloading of distribution networks, resulting in the need to upgrade the distribution network. This includes the replacement of transformers and reinforcement of lines.

Solutions

Potential for controlled EV charging to deliver grid services and participate in electricity markets

Controlled EV charging enables access to a range of solutions for power systems through the provision of demand-side response (DSR) services. In particular:

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[45] The Ministry of Industry wants to develop a universal traceability information system that will store specific data about the batteries such as the owners of the after-sale car in which it is contained. Automobile manufacturer have to ensure that car sales are updated in the system to include the new data about the owner of the car (Government of China, 2018).

[46] 65% for lead-acid battery by average weight, 75% for nickel-cadmium battery and 50% for the other batteries (EC, 2014).

- EVs can minimise impacts on a power system by shaping the electricity demand pattern through changes in the timing of charging events to low-demand periods.
- EVs have the potential to provide energy into the power system when needed. The properties of EV batteries allow very fast and precise response to control signals, as well as the ability to shift demand across longer time periods. These capabilities enable EVs to provide DSR services to the system across a wide range of time scales and to participate in electricity markets (Table 5.3 and Box 5.3). This is a major advantage EVs have compared with other sources of DSR.
- EV batteries can store energy that may be used for other purposes than powering the vehicle, thanks to the opportunities offered by vehicle-to-grid (V2G) and similar technologies (V2X, for example vehicle-to-home). With V2X, EVs serve as battery storage capacity which can discharge energy to buildings and, more generally, the power grid to maintain system stability. This feature can have significant advantages to address challenges at a local level, avoiding overload on a distribution grid, as well as at the main network level.[47]

Table 5.3. Role of EVs for various types of flexibility services in power systems

Flexibility type	Ultra short-term flexibility	Very short-term flexibility	Short-term flexibility	Medium-term flexibility	Long-term flexibility
Time scale	Sub-seconds to seconds	Seconds to minutes	Minutes to days	Days to weeks	Months to years
Electricity market	Ancillary services		Ancillary services, balancing, energy markets	Balancing, energy markets	Balancing, energy markets
Power system issue	Ensure system stability (voltage, transient and frequency stability) at high shares of variable (non-synchronous) generation.		Meeting more frequent, rapid and less predictable changes in the supply/ demand balance.	Addressing longer periods of surplus or deficit of power generation, e.g. driven by presence of a specific weather system affecting VRE generation.	Balancing seasonal and inter-annual availability of variable generation with power demand; meeting capacity requirements when VRE generation is low.
Capability of EVs	Batteries can provide fast frequency response based		Ability to charge earlier or later across one day more, or at varying		Smart charging helps meet capacity needs by

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[47] Negative impacts on battery durability could be a possible downside of V2X and the related battery services provided to power system. This is an issue that is likely to depend on the depth and frequency of the discharge cycles and on technology advances. It requires the remuneration of negative impacts in terms of battery durability to EV owners. Ensuring that potential drawbacks in terms of durability are properly accounted for is important, especially in the presence of policy environments encouraging the emergence of aggregators to facilitate demand-side response (while taking into account rapid technological changes in batteries).

Flexibility type	Ultra short-term flexibility	Very short-term flexibility	Short-term flexibility	Medium-term flexibility	Long-term flexibility
	on a control signal. For smart charging, increase or decrease in demand can be offered. The full EV charging load can be somewhat reduced to provide frequency support.		charging speed to better suit the system. V2X could provide system services and help meet system requirements. Aggregated charging capacities of large EV fleets can be part of a virtual power plant (VPP), either through DSR or V2X.		shifting EV demand according to system requirements, and can impact long-term planning of capacity. Aggregated charging capacities of large EV fleets can be part of a VPP.

Notes: VRE = variable renewable energy. The capability of EVs to contribute to long-term flexibility is complemented by other actions that can take place across the whole power system, for example, including shifts in demand for other electrical devices.

Source: Adapted from IEA (2018b).

Box 5.3. Characteristics of various electricity markets

There are many electricity markets across the world and their configurations vary from one another. Electricity markets usually consist of a combination of wholesale markets, which trade for the bulk supply of energy, and a range of complementary markets that ensure secure and reliable system operation by supplying flexibility across various timescales

The need for and presence of these complementary markets is quite dependent on the configuration of the electricity market, and in particular how close to real time the energy market is settled (gate closure time). For energy markets settled close to real time, more flexibility procurement is effectively incorporated into the energy market, while for energy markets with longer gate closure time, more of the flexibility requirements need to be represented in additional explicit markets.

Ultra short-term and very short-term flexibility markets involve lower energy volumes than energy markets, but they provide both a payment for the availability of response mechanisms and a payment for supplied electricity when these mechanisms are called upon. They can typically be expected to give higher revenues per unit of energy. Energy markets such as the intra-day markets that may be used to enable load shifting are characterised by higher overall energy volumes, but may also be coupled with lower monetary value per kWh, depending on price differentials across the day. The participation in capacity markets involves an availability payment as well as additional compensation when activated.

Due to the variability and uncertainty of variable renewable energy (VRE) generation, electricity system operators are faced with challenges to reconcile supply and demand of electricity.[48] The

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[48] Countries enter various phases of system integration with the need for flexibility options at different points of VRE uptake. The transition depends not only on the share of VRE generation in the total electricity mix, but also on other factors such as the complementarity between VRE generation and demand profiles as well as the size of the power system, which are context specific. In systems where VRE generation and demand profiles are not well matched and where power systems are smaller (e.g. islands), they are faced with greater operational challenges and therefore enter higher phases of system integration earlier. As discussed in

capability of EVs to participate in DSR services enables them to contribute to enhanced system flexibility for the power sector, playing an important role to maintain the reliability of the system as shares of VREs increase.

The potential revenue available from electricity markets for the provision of grid services depend on multiple factors. Increased competition, including from a larger pool of EVs as well as increasing participation of batteries and other distributed resources, acts to reduce average market revenues as more flexibility providers participate. On the other hand, increasing flexibility needs (particularly with increasing shares of VRE) can be expected to increase the trading volumes of market products that supply flexibility. In general, it is likely that very short-term markets would provide greater benefits to EV owners and demand aggregators in the near term, but saturate earlier than energy markets as DSR (including from EVs) becomes more widespread over time.[49] Some studies indicate that the value of offering an EV battery for flexibility services will be greater when bi-directional charging control is available (V2G) , but significant flexibility benefits already could be available with unidirectional charging (with lower complexity and investment requirements).

Enabling flexibility from EVs

In the context of the growing electrification of end-uses (including transport) and their potential to contribute to flexibility services via DSR, the key is to ensure the necessary mechanisms are in place to unlock DSR from EVs. Fundamentally, to enable DSR the customer must be able to obtain a cost benefit from charging in a way that benefits the system. This can happen in three main ways:

- Direct load control, where the utility has the ability to directly control the electricity demand and has the right to discontinue it.
- Dynamic pricing arrangements that provide a price signal directly to customers so they can voluntarily react to the prices.
- Participation through an aggregator in electricity markets where price signals incentivise DSR activity.

The direct control is most relevant in industries with no electricity markets, and in this case the customer (traditionally a large-scale electricity consumer) obtains a lower tariff or some other incentive from the utility to participate. Dynamic tariffs require smart metering as a prerequisite and rely on the spontaneous response to price of many independently operating units which may be difficult to predict and control. DSR participation in markets through an aggregator comes with a benefit over dynamic tariffs in terms of the precision of control because the aggregator needs to estimate the response capability of the resource it controls at any point in time and take the responsibility for the DSR.[50] From a technology perspective, market participation through an aggregator can involve smart metering, but it could also be mediated through other communication channels, for example solutions embedded in the charging system controlled by software applications. An example of how price signals, smart charging of

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the *World Energy Outlook 2018*, it is expected that before 2030, many countries will have shares of VRE that require advanced flexibility services (IEA, 2018c).

[49] In practice, this is dependent on the specific market design and system requirements.

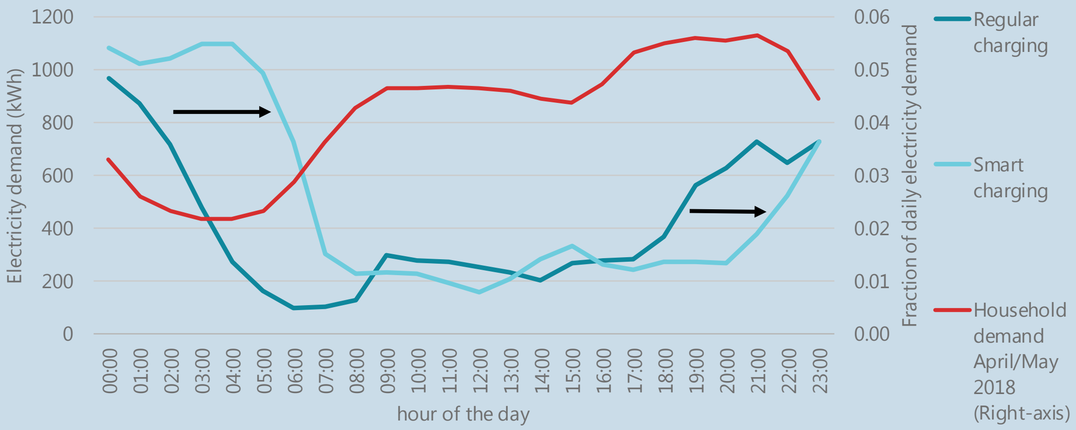
[50] From a system operations point of view, this is much simpler than trying to manage the load through a dynamic tariff only, relying on the consumer's willingness to individually react to the variable tariff signals. From an EV owner perspective, it is also much simpler as it takes away the effort of keeping track of price signals and adjusting the charging pattern accordingly. In addition, the time scale of control required for the very short-term services of which EVs are capable is much shorter than the communications intervals of many smart meters installed today.

EVs and platforms aggregating the supply of flexible charging capacity can enable changes in the load patterns of EVs that shift power demand away from the system demand peaks is given in Box 5.4.

Box 5.4. Fostering EV participation in electricity markets through aggregation: an example from the Netherlands

The potential for EVs to participate in electricity markets and being exposed to market prices is underway, with smart charging of EVs and platforms aggregating the supply of flexible charging capacity as a means to balance the grid in place in several countries. The figure in Box 5.4 shows an example where the charging capacity of 1 000 EV charging sessions in the Netherlands were pooled by an aggregator, Jedlix, and responded to price signals. This resulted in a significant change in the pattern of power draw to charge EVs to off-peak hours, in comparison with 1 000 charging sessions not subject to the price signals (ElaadNL and Jedlix, 2019). Relative to the average household electricity demand, smart charging shifts to hours with lower demand. On a national scale, 30-50% of charging sessions in the Netherlands occur in the evening peak hours (16:00-20:00), while cars are parked four-times longer than the required charging time, allowing for time to shift the charging sessions to off-peak times.

Regular and smart EV charging patterns from 1 000 simultaneous sessions compared with average hourly household demand in the Netherlands



Sources: ElaadNL and Jedlix (2019); NEDU (2018); Refa and Hubbers (2019).

Importance of policy actions to enable EV participation in markets

Despite the early participation of aggregated EVs in a small number of markets and smart meter deployment (a key prerequisite for DSR) that has grown rapidly in recent years, the situation is not homogeneous globally. In the majority of countries, power markets are not developed to a point that can optimally accommodate increased EV uptake, since demand-side resources are only able to participate in a small number of programmes (Smart Energy Demand Coalition, 2017). Achieving large-scale flexibility from EVs around the world will require that power markets evolve. Three prerequisites must be in place to enable participation:

- First, the market must include the presence of services (e.g. grid balancing) suitable for EV participation.
- Second, the market must allow the participation of small loads through aggregators. This includes the existence of legal frameworks that define the participation of EVs and other electrical devices into aggregated DSR.[51]
- Third, and perhaps most importantly, aggregators should not face high transaction costs to be able to pool large number of small loads to participate in demand response in an electricity market.

These are the three broad principles adopted by the European Union with the update of the directive on common rules for the internal market in electricity, adopted in March 2019 by the European Parliament as part of the Clean Energy for All Europeans package (European Parliament, 2019).[52]

Table 5.4 illustrates different levels of grid integration and links to the changes needed in the regulatory environment and electricity market reforms, outlining what they mean for EVs. Controlled single direction charging alone (level 2) is expected to unlock a major flexibility potential. Bi-directional (level 3/vehicle-to-home or level 4/vehicle-to-home) is expected to further increase the value of the flexibility services offered by EVs, as they increase the possibilities for EVs to access a wider pool of flexibility incentives.

Altogether, the opportunities offered by EVs and the potential to enhance power system flexibility to facilitate VRE integration suggests that EVs can help to accelerate the energy transition pathways that extend beyond the decarbonisation of the transport sector.

Table 5.4. Grid integration of EVs, and regulatory and market requirements

EV grid integration levels	Description	Regulatory and market requirements
Grid-compliant charging	Phase where EVs are connected to the grid for their charging needs, but smart charging is not yet applied.	EVs comply with the local requirements and regulations. The charging power is below the thresholds prescribed by grid operators.
Level 1 – Controlled charging	The charging power and timing of charging can be shifted remotely by the DSO, CPO, EV user, EV or home energy management system.	Dynamic electricity pricing levels needed to incentivise charging behaviour.
Level 2 – Aggregated controlled charging	A charging profile is negotiated based on various drivers (monetary drivers or grid constraints), and responses are controlled and bundled by aggregators	Aggregators need to be authorised as market players. The wholesale, balancing and capacity markets (where applicable) need to be open to

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[51] The presence of a legal framework to define the rules that apply to electricity market that rewards flexibility is crucial to clarify aspects such as the conditions that apply to consumers that opt for dynamic electricity price and conclude aggregation contracts.

[52] The directive urges member states, among others, to empower energy consumers to get access to electricity markets and perform DSR activities. Demand response is seen as pivotal to enable the smart charging of EVs and thereby enable the efficient integration of EVs into electricity grids. It also urges states to enable dynamic electricity price contracts and to allow more flexibility, including an appropriate electricity market design, to accommodate an increasing share of renewable energy in the grid. Member states must also ensure that participation of DSR through aggregation is allowed and fostered, and that all customers are free to purchase and sell electricity services, including aggregation.

	without direct individual user interaction.	incentivise aggregated demand-side resources.
Level 3 – Bi-directional charging	EVs can also feed electricity back to the grid and home. This allows for the use of EVs as a distributed electricity storage mechanism, and enhances the attractiveness for EVs as a frequency response measure.	Pricing of flexibility services needs to exceed the increased cost for the EV owner of bi-directional charging. Bi-directional charging requirements may be included in the standardisation of EVSE and EVs.
Level 4 – Aggregated bi-directional charging	The enhanced flexibility capacities of EVs are managed by aggregators to be able to compete in the flexibility market with larger capacities.	Aggregators need to be allowed as a market player, benefits from bi-directional flexibility should be rewarded through electricity market dynamics.

Note: EVSE = electric vehicle supply equipment; DSO = distribution system operator; CPO = charging point operator.
Sources: IEA analysis based on CharIN (2018) and SEDC (2017).

Government revenue from taxation

Challenges

Governments typically collect tax revenues from three tax bases: road use (most frequently through highway tolls, congestion charges[53] and cordon prices[54]), vehicle (most often through the registration and/or annual circulation taxes[55]) and energy use (typically through fuel taxes) Box 5.5).

Box 5.5. Fuel taxes in road transport

Fuel taxes are raised in most countries (approximately three-out-of-four) through the application of taxes added to the gasoline or diesel price. Other countries (around one-out-of-four) subsidise oil-based fuels (IEA, 2018d).[56] In 2017, the prices of gasoline and diesel ranged from less than USD 0.1/L of fuel in countries with high subsidies to almost USD 2/L in the countries that apply the highest tax rates. In 2017, oil products represented more than 90% of global transport energy consumption (IEA, 2019b). Gasoline and diesel accounted for roughly 80% of the total of all fossil fuels used in transport and nearly all of the transport tax revenue (IEA, 2019b).

Governments also tax electricity. In terms of global coverage, the share of countries that tax electricity (about 85% of all countries) exceeds those that subsidise it (IEA, 2018d). As a percentage

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[53] Congestion charges are road use charges that vary across different geographical areas and times of the day.

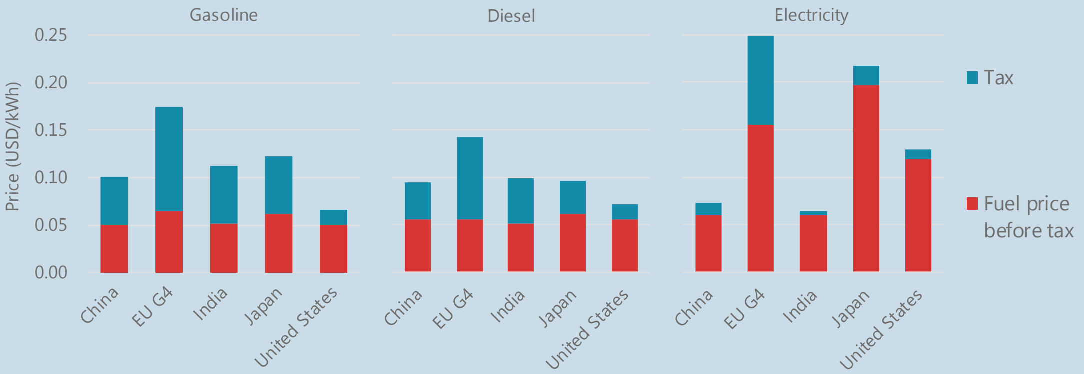
[54] One example of cordon pricing is the application of fees to regulate access to urban centres.

[55] Registration taxes often include a component (typically the value-added tax) that depends on the vehicle price and another component (often coupled with the vehicle environmental performance) that does not depend on it.

[56] The highest taxes per litre of fuel can generally be found in Europe, Japan and several small countries in Asia and Africa. In Europe, approximately 60% of the fuel price consists of taxes. Global regions hosting countries that subsidise transport fuels include Middle East, Africa, Latin America, Central Asia and the Association of Southeast Asian Nations (ASEAN) (IEA, 2018d).

of the total fuel price, electricity is taxed to an extent that is relatively similar to the one observed for gasoline and diesel (5% to 63% per unit of energy, depending on the country) (IEA, 2018e).[57] Including taxes, electricity prices range between less than USD 0.5 per kWh in Saudi Arabia up to USD 0.33 per kWh in Denmark (IEA, 2018e).

Gasoline, diesel and electricity fuel prices and taxes in selected countries, 2017



Notes: EU G4 includes France, Germany, Italy and United Kingdom. India's electricity price and tax is only available to 2015. Electricity taxes for the United States and India are a weighted average of the various rates at state-level (Bankbazaar, 2018). India's gasoline and diesel price are based on Delhi (Petroleum Planning & Analysis Cell, 2017). Tax rates for China are estimates based on OECD (2018) and Avalara (2019). Electricity prices in this graph are for households.

Sources: IEA elaboration based on *IEA World Energy Prices* (database) (2018e); *IEA Energy Prices and Taxes* (database) IEA (2018f), EIA (2019); Tax Foundation (2017); Bankbazaar (2018); OECD (2018); Government of India (2016).

Transport taxes often differ across vehicle types (e.g. buses, passenger cars, trucks or motorcycles), whether the vehicle is used for a commercial or personal nature, or according to parameters that correlate with the energy efficiency and/or the environmental performance of the vehicle class. Overall, they constitute a significant part of national, state and local government revenue. The combination of taxes on transport vehicle and fuel use, for example, was recently estimated to be as high as 3.5% of GDP (OECD, 2014).

Given that electric vehicles are two-to-five-times more efficient than a comparable ICE vehicle and lead to zero tailpipe emissions of local pollutants in high-exposure areas such as urban roads, EVs have benefited from subsidies and rebates, to varying degrees in many car markets (Figure 5.4) (IEA, 2019a). Depending on the specific case considered, the system of vehicle taxation (either at the registration phase or in the form of recurring annual fees) can be designed in a way that leads to net generation of revenue or be revenue neutral (cases of systems leading to net subsidies are uncommon).[58] With a significant transition towards zero-emissions vehicles (including EVs), the volume of vehicles offering good environmental performance will weigh progressively more in the total of all vehicles. All else being equal, this results in a net decline of taxes that are collected through these schemes.

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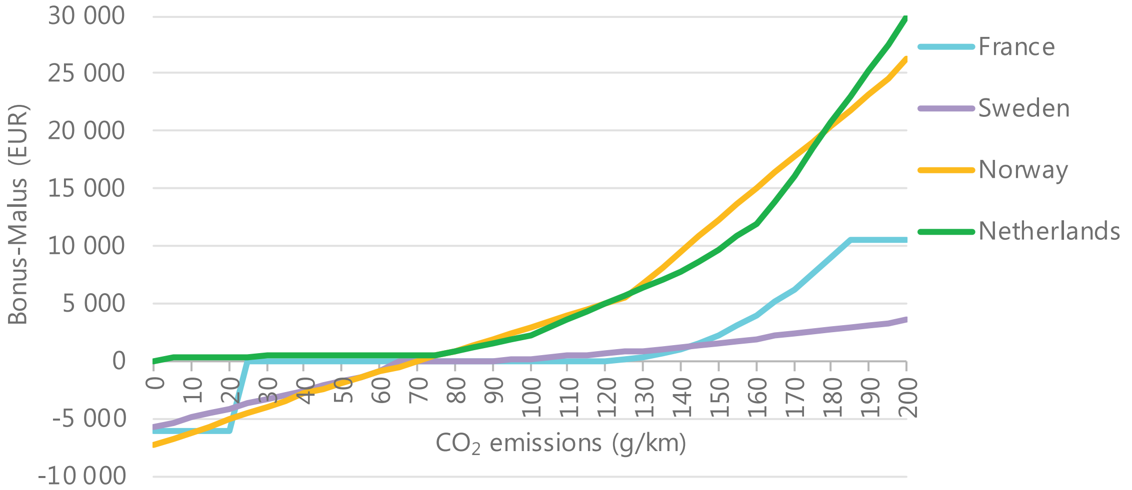
[57] The highest electricity taxes are in the European Union and Brazil, whereas low electricity taxes are found in the United States, India and ASEAN (IEA, 2018e).

[58] The combined use of a differentiated set of taxes, excluding subsidies, is by definition a revenue-generating approach. It has characterised jurisdictions that tend to apply high vehicle taxation rates overall, as in the case of the vehicle registration taxes in Denmark (IEA, 2018g). The use of differentiated vehicle taxes enable the models with poor environmental performances to subsidise the incentives for models with better environmental performances and is often referred to as a fee bate or bonus/malus scheme. An iconic example of this approach is the case of France (Government of France, 2018).

Figure 5.4. Passenger car taxation based on tailpipe CO_2 emissions in selected countries, 2018



Notes: g/km = grammes per kilometre. Sweden applies its malus (tax) for a three-year period of ownership. The figure shows the total malus the owner of a new gasoline vehicle would have to pay over the first three-years of ownership; owners of diesel vehicles would pay an extra fee. For the Netherlands, taxation rates for vehicles with emissions above 61 grammes of carbon dioxide per kilometre (g CO_2/km) are based on gasoline vehicles. An extra fee per g CO_2 (not shown in the figure) applies to diesel vehicles with emissions above 61 g CO_2/km.

Sources: IEA elaboration based on ACEA (2018).

A number of countries apply vehicle purchase taxes that differentiate on the basis of tailpipe GHG emissions and offer incentives for vehicles with the best performance supported by taxes on vehicles with poor performance.

The efficiency advantage of EVs, combined with the change in energy carrier that they enable (from oil products to electricity) means that, even at similar levels of taxation per unit of energy, BEVs and PHEVs are subject to lower charges per km in comparison with ICE vehicles (Figure 5.5). The effect is stronger if the level of fuel taxation per unit energy is not the same for oil products and electricity, a development that could become more common if fuels are taxed based on their carbon content and if power generation accelerates to low-carbon sources than the pool of liquid fuels used by transport vehicles.

The examples provided in Figure 5.4 show that, without any adjustment to the current taxation schemes, an expanding uptake of electric vehicles and other zero-emission technologies has the potential to lead to changes in tax revenue derived from vehicle and fuel taxes. Figure 5.4 illustrates effects coupled with taxes applied to vehicle and fuels, but additional impacts can also be associated with road use taxes, including countries that already have started to apply differentiated charges for EVs and other vehicles using zero-emissions technologies.[59]

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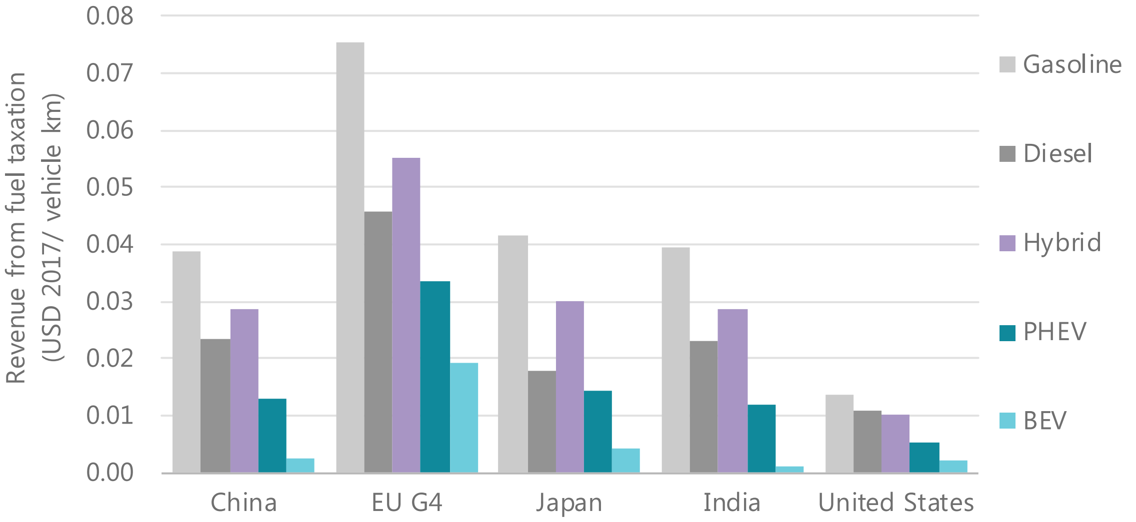
[59] In Norway, for example, zero-emissions vehicles have been exempted from parking fees, road tolls and they have been granted free access on ferries. Since 2018, local authorities are authorized to apply fees that are up to 50% of those imposed on ICE cars. The national taxation has not changed and EVs remain exempt from purchase tax, value-added tax, annual tax and road user tax (personal communication with Asbjørn Johnsen, Norwegian Public Roads Administration).

Figure 5.5. Revenue from taxation of new cars based on energy use per vehicle km and powertrain type, 2017



Notes: EU G4 includes France, Germany, Italy and United Kingdom. Average fuel consumption per powertrain is based on fuel economy values from the IEA Mobility Model and the Argonne National Laboratory GREET model, linked to the 2017 Worldwide Harmonised Light Vehicle Test Procedure (WLTP) values and market shares of vehicle size segments of the IEA-GFEI database on new LDV registrations with a real-driving correction of 20% (ANL, 2018; IHS Markit, 2018) (IEA, 2019b). PHEVs are assumed to be in all-electric mode for 60% of their vehicle kilometres and one-third using gasoline. Hybrids are assumed to use gasoline. Electricity taxes for India and United States are based on the weighted average of residential electricity consumption, sales tax and local taxes per state. Values for Japan, EU G4 and the United States (except US electricity tax) are based on the IEA World Energy Prices 2018 database (IEA, 2018e). Tax rates for China and India are estimates based on Bankbazaar (2018) and Avalara (2019).

Sources: IEA assessment based on IEA (2018e), EIA (2019), Tax Foundation (2017), Bankbazaar (2018), OECD (2018), Government of India (2016), Avalara (2019) and IHS Markit (2018) for the IEA-GFEI database.

There are large differences in tax revenue per vehicle kilometre between powertrains and among countries.

Solutions

Near-term options

Ensuring that the policies defining road use, vehicle and energy taxes in transportation are ready to adapt to the changes in the vehicle and fuel markets is the minimum near-term solution needed to handle the challenge posed by the technology transition towards electric mobility.

Key examples of features that would enable this adaptation capacity include:

- Adjustments of the emissions thresholds (or the emissions profile) that define the extent to which vehicle registration taxes are subject to differentiated fees (fee bates or bonus/malus), as well as those that define the charges applied in annual circulation taxes, in order to ensure that these schemes can maintain their overall characteristics (i.e. keep providing financial incentives for the adoption of vehicles offering good environmental performance) while adjusting the total amount of revenue they generate.[60]

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[60] These changes should be implemented in a way that ensures consistency of the policy signals for OEMs, given their long-term planning horizon needs for investment in low-carbon technologies.

- Adjustments of the taxes applied to oil-based fuels in order to ensure that the overall amount of revenue generated from fuel taxation does not change, even in the presence of a net decline in fuel use.
- Revisions of the exemptions and/or the differentiation of road use charges applied to vehicles with different environmental performances, such as tolls applied for the use of road infrastructure.

Similar considerations can be extended to regulatory instruments such as access restrictions that apply differentiated treatments for zero-emissions vehicles (for example, electric cars were granted free access to bus lanes in Norway), since they also need to be adapted over time.[61]

A solution adopted in California to address the loss of revenue from the use of oil products induced by zero-emission vehicles is the application of an additional registration fee (taking effect in 2020). This represents concrete action to address the challenges of less revenue from usual vehicle taxation schemes, but also a number of drawbacks. They include limited capacity to deal with revenue loss that would occur with a major transition to EVs, disconnection between the fixed nature of the fee and infrastructure use (which varies according to the vehicle mileage) and a negative impact on EV sales share (as this acts in the opposite direction of important policy instruments supporting the EV uptake, like differentiated vehicle taxes or fee bates) (Jenn, 2018a)

Long-term solutions

The long-term stabilisation of fiscal revenue from transport is important to ensure continued availability of funding for the development and maintenance of transport infrastructure, among other goals. But it cannot only be based on the adjustments listed as near-term options. This is due to the growing impact of such adjustments to the taxation structure and to distortions that they risk imposing on the fiscal framework applied to the transport sector. For example, a continued increase on taxes applied to oil products, without changes to taxes to electricity, would place a progressively unfair (and economically unsustainable) burden on vehicles that rely on oil products to recover costs capable to finance road transport infrastructure development and maintenance. It might also result in equity concerns. For example, this would be the case if oil product-based vehicles are cheaper to buy, and therefore more likely to be the option of choice for poorer households, and/or if car dependence is stronger in areas that have poorer access to public transport options and cheaper housing prices, as in the case of some of the suburbs surrounding major metropolitan areas.

A long-term solution to the challenges posed by the transition towards zero-emissions vehicles is therefore very likely to require the development of structural reforms in tax schemes (OECD, 2019c). Given the nature of taxes applied to the transport sector, these reforms will need to consider the combination of taxes applied to distances driven, vehicles and fuels. The combination of instruments that could lead to a solution suited to handle the transition depends on their capacity to achieve key performance targets, including long-run revenue stability, the management of external costs and ease of implementation (Table 5.5).

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[61] In the Norway bus lane example, it is worth mentioning that the municipality of Oslo restricted the bus lane access on two specific corridors during rush hours to only electric cars with two or more persons on-board. This was due to congestion during rush hour in these corridors, a phenomenon that increased with the growth of EV sales (IEA, 2018g).

Table 5.5. Taxes and charges relative to revenue stability, management of external costs and ease of implementation

	Vehicle tax	**Fuel** (carbon) **tax**	**Distance-based charges** (DBCs)
Long-run revenue stability	**Good**: To ensure revenue stability, fee bates or differentiated vehicle taxes also need to gradually cover alternative fuel vehicles.	**Limited:** With a transition to zero-emission vehicles and fuels/electricity, the revenue from fuel taxes is set to decline.[a]	**Good**: DBCs establish a stable revenue stream even when transport decarbonises because they relate to travel demand, not to the fuel or vehicle used to drive.[b]
Internalising GHG emission costs	**Limited**: Vehicle taxes can be set based on specific fuel consumption, but they cannot grasp differences of carbon intensities of fuels or vehicle mileage.	**Good**: Fuel taxes can account for external costs from CO_2 emissions because CO_2 emissions are proportional to fuel use.	**Limited**: DBCs can be designed to reflect energy use/km, but face challenges to grasp differences in carbon intensity of energy sources.
Internalising air pollution costs	**Limited**: Vehicle taxes can account for pollutant emission performances of vehicles, but they cannot reflect the location-specific nature of local pollution and its impacts.	**Limited**: Fuel taxes can be set based on fuel quality, but they cannot reflect the location-specific nature of local pollution and its impacts.	**Good:** DBCs can be designed to reflect pollutant emission performances of vehicles and can deal with the location-specific nature of their costs (exposure varies by location).
Recovering infrastructure costs	**Limited**: Vehicle taxes cannot grasp differences of vehicle mileage, or in terms of location and typology of the infrastructure they use.	**Limited**: Fuel taxes can be designed to account for energy use per km, but with implementation challenges. They cannot reflect well differences in location and type of infrastructure.	**Good**: DBCs are best suited to recover infrastructure costs, given their capacity to be location-specific. They are also best placed to deal with infrastructure use rate (congestion).
Ease of implementation	**Good**: Vehicle taxes have low administrative cost and are easy to collect.	**Good**: Fuel taxes have a low administrative burden and are easy to collect.[f]	**Limited**: DBCs face high administrative cost barriers, but there is room for cost reductions from technological progress. Demonstrated technologies can also address privacy concerns.[g]

[a] The one-off character of a registration or a purchase tax also renders revenue dependent on fleet turnover and the business cycle.

[b] Distance-based charges are a promising tool to manage a transition to more automated vehicles and shared services.

[c] Fuel quality influences pollutant emissions, but vehicle technologies are the main determinant of vehicle performance in this respect.

[e] Differences in vehicle efficiency make fuel taxes uneven if converted once they are expressed in "per km driven" terms. This could be corrected setting taxation levels in a way that accounts for differences in vehicle efficiency. In the case of electricity, this would be challenging since it would require different levels of taxation for various end-uses and separate metering.

[f] Fuel taxation is well suited to apply carbon taxes, also for EVs and fuel cell electric vehicles, especially if carbon taxes are embedded in electricity (or hydrogen) prices and are uniformly applied across all sectors. If fuel taxation aims to collect infrastructure costs, it would face implementation challenges for EVs because of a need for different levels of taxation across end-uses and separate metering.

[g] For example, in Oregon's experimental distance-based charging programme and the German truck tolling system, driving related data are destroyed as soon as drivers pay their road user charge.

Source: OECD (2019c) with IEA elaboration

Indications in Table 5.5 suggest that gradually increasing taxes on carbon-intensive fuels, combined with the use of distance-based charges to recover infrastructure costs and to reflect the costs of pollution and congestion (which requires the variation of distance-based charges depending on the extent of the pollution and congestion levels) can support the long-term transition to zero-emissions mobility while maintaining revenue from transport taxes.[62] Distance-based charges are also well suited to manage the impacts of disruptive technological change in road transport, including those related to electrification, automation and shared mobility services. To date, however, only a few places have considered or implemented distance-based charges (Box 5.6). Alternative approaches would need to consider a broader set of instruments, not only limited to the transport system.

Box 5.6. Distance-based charges in use today

Distance-based charges in use today consist primarily of tolls (typically applied to highways and bridges). In a limited number of cases, mostly urban areas, distance-based charges are used primarily to manage travel demand (by adapting the charges for different times of the day) and mitigating pollution (by increasing the cost of travelling for vehicles leading to higher rates of pollutant emission per passenger-km).

For intercity travel, the highway tolls are the main instrument to collect distance-based charges. The main alternative to distance-based pricing for highway driving has been the use of a fee-based system, unrelated to distance driven. An example is the “vignette” in Switzerland. In the European Union, distance-based charges for trucks apply within the framework of the Eurovignette Directive (1999/62/EC) and subsequent amendments (2006/38/EC and 2011/76/EU). This aims to recover costs associated with the construction, operation and maintenance of road network (user pays principle), complementing it with a light version of the polluter pays principle allowing toll rates to vary (to a limited extent) in order to account for environmental (air pollution and noise) or traffic management objectives (OECD, 2019c).

To date, distance-based charges are not widely used in cities because of implementation challenges, but there is growing interest in the concept. To date, four cities have implemented road charging schemes (London, Milan, Singapore and Stockholm). Of these, Singapore has a zonal differentiation (bringing them close to a distance-based charge approach), while London, Milan and Stockholm adopted a cordon-based approach, having no (or weaker) links with the amount of kilometres driven. New York decided in 2019 to introduce charges from 2021 to enter Manhattan’s most congested neighbourhoods (Hu, 2019).

There are no examples of nationwide applications of distance-based charges for light-duty

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[62] For example, Jenn (2018a) indicates that fuel taxes will become increasingly outdated as a mean to fund transportation infrastructure, and the OECD (2019c) points to the adoption of a gradual increase in fuel or carbon taxes to cover the external costs closely related with fossil fuel use in vehicles and the phasing-in of distance-based charges for cars to reflect external costs closely related to driving. OECD (2019c) also warns about the need to ensure that the revenue potential from distance-based charges is adequate for the challenges posed by the technology transition, mentioning for example that in the European Union, this would need a revision of the maximum values allowed in the legislative framework regulating distance-based charges to reflect the full driving-related external costs.

vehicles. Only the Netherlands has attempted a roll-out of a nationwide road pricing policy, which was in 2010 (MuConsult, 2017). The draft plan included the option to differentiate according to environmental characteristics, and time and location of use (Geurs, 2010). The plan did not gain parliamentary approval and the new government in 2010 did not include road pricing in their government agreement (Government of the Netherlands, 2010). Since 2017, the Dutch government has the intention to run pilots for alternative vehicle taxation for passenger cars, such as road pricing, but it does not plan to implement a nationwide policy (Government of the Netherlands, 2017; Government of the Netherlands, 2018). The government does plan to implement road pricing for freight trucks, which is already in place in several European countries.

The United States has several state-level pilot projects to test road pricing. The test cases are clustered in the "I-95 Corridor Coalition", with 13 states[63] participating, and the Road Use Charges (RUC) West Coalition, which involves 14 states[64] in the west. Delaware has been the main pilot state on the east coast with funding for two multi-year pilots, followed by a multi-state truck pilot in 2019 (I-95 Coalition, 2019a). Oregon is the most advanced, with policies in place that enable the implementation of road pricing, while Washington, California, Colorado and Minnesota have conducted pilots as well (OReGO, 2018; I-95 Coalition, 2019b).

Early consideration of the implications for tax revenue is important even if technological changes take time to percolate through the entire car fleet. An early start and a thorough preparation and discussion with stakeholders are important to institute reform at an appropriate extent and depth for the longer term challenges posed by transport decarbonisation (OECD, 2019c). Early preparation and gradual implementation helps reduce the risk of disruption and creates room for developing, designing and implementing the necessary accompanying measures and appropriate policy responses. In particular, due attention is required for the effects that tax reform could have for individuals and households of different incomes, and/or access to alternative transport modes other than individual vehicles.[65]

Shared and automated mobility

The emerging mobility revolutions of sharing and automation could significantly reshape road transport over the coming decades, with major implications for vehicle electrification. A transition to shared and/or autonomous vehicles and services with high utilisation rates could put EVs at a competitive advantage. Yet, several challenges remain for EVs to meet all the operational and technical requirements of such services.

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[63] Maine, New Hampshire, Massachusetts, Pennsylvania, Vermont, New York, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Caroline, Georgia and Florida.

[64] Oregon, California, Colorado, Hawaii, Washington, Utah, Arizona, Idaho, Montana, Nevada, New Mexico, North Dakota, Oklahoma and Texas.

[65] For example, accompanying policy measures may encourage the development of alternative travel modes (e.g. public transport) in the long-run or support those households that are affected disproportionally by the reform in the short-run, but cannot easily cope due to budget constraints.

Challenges

Despite the significant fuel and maintenance savings potential of EVs in shared fleets (car sharing, app-based ride-sharing and taxis), adoption of EVs in these fleets has been slow. For instance, EV shares on the major ride-sharing platforms remain below 1%, except Didi (1.3%) (Slowik et al., 2019). Several challenges must be overcome to spur electrification of shared mobility.

EVs are generally more expensive to purchase. While this could be overcome in well-managed fleets, it is a significant issue for vehicles owned by drivers, given that they are often capital constrained.

Another barrier to BEV adoption in these services is that few models available today meet all the specific operational requirements of taxis and ride-sharing services, which typically use vehicles in the medium and large market segments (where the availability of BEVs is currently limited) and include sufficient range (exceeding 250 km/day and possibly reaching 400 km, often including the use of auxiliary power loads such as air conditioning).

Taxis and ride-sharing fleets with range limitations and limited access to overnight/off-peak charging may face similar challenges, as searching for available chargers during busy periods could mean foregone revenues for drivers. Free-floating car sharing fleets also rely on public (and often fast) charging, requiring EVs with sufficient range, a well-designed charging network and/or user incentives to charge. Operational challenges for fleets can be further exacerbated by the combination of these issues.

The intensive use patterns of fleets also raises issues around battery durability. More frequent and more rapid charge cycles of fleet vehicles could degrade the battery more quickly (compared to private cars), adversely affecting range over the lifetime of the vehicle.

If (and when) fleets become highly automated, their even higher utilisation rates are likely to increase daily travel distances, requiring either larger and more expensive battery packs that are sufficient for an entire day of operations, or more frequent recharging (and downtime). Autonomous cars may also require significant power for on-board electronics. However, the efficiency of chips used in autonomous pilot vehicles is improving rapidly and has already dropped from 3-5 kW in the first generation to less than 1 kW (Dunietz, 2018; Hawkins, 2017; Gawron et al., 2018).

Since vehicle sharing and automation are innovations that will be adopted first and most widely in cities, and given concerns that ride-sharing services could lead to more vehicle travel and congestion, it is imperative that electric drive technologies are adopted rapidly in these new mobility services (Rodier and Michaels, 2019). Air pollution concerns in cities have prompted regulatory responses, with more and more cities restricting operations of vehicles that emit air pollutants. Realising rapid electrification will not only reduce local air pollution, but can promote EV adoption among private cars buyers and roll out of public charging infrastructure.

Solutions

Significant technology progress could help to address the challenges outlined. Urban driving offers optimal conditions for high fuel efficiency of EVs, thanks in part to the important contribution of regenerative braking to reduce fuel use per kilometre (IEA, 2019a). Higher rates of regenerative braking could also slow battery degradation rates (Keil and Jossen, 2015). Plug-in hybrid electric vehicles may also help bridge the range issue in the near term. Battery technology is improving rapidly, allowing newer EVs to achieve higher energy densities and longer ranges. Battery technology improvements may also alleviate durability issues. Recent case studies from Tesla show that this may already be less of a concern for certain battery designs (Lambert, 2019). Rapid cost declines in electric vehicles as well, realised through new manufacturing processes, may soon help EVs achieve parity, first on the basis of total ownership costs, and eventually even in purchase price, with conventional vehicles.

In the period where EVs reduce total ownership costs versus conventional ICE cars only after a few years of operation, high upfront costs may be less of a concern for fleets; mobility service providers that purchase and operate their own vehicles will both have greater access to capital than private car buyers, and high mileage will lead to faster pay back of initial capital costs. This is likely to strengthen the total cost of ownership advantage for EVs, providing them with a compelling business case at earlier stages and for a broader set of uses.

A combination of policy and company efforts could also accelerate the electrification of fleets. Uber's Clean Air Programme in London works in concert with the city's Ultra-Low Emissions Zone, providing financial incentives to drivers to switch to or drive more in EVs. To promote adoption of EVs among private owners who earn a living driving their vehicle as a taxi or for app-based ride-sharing companies (transport network companies [TNCs]), energy service companies (ESCOs) can play a role in offering financial solutions to clear initial cost barriers of EV adoption. Maven, a car sharing company, offers a service of short-term rentals of the Chevrolet Bolt BEV for USD 229 per week to drivers working for TNCs and other shared platforms. ESCOs could get into this game as well, follow similar EV leasing strategies with preferential terms for highly used mobility service cars. Utilities can design preferential contracts when installing home chargers or public chargers that can help spread costs of charging over time, leveraging the higher utilisation of mobility service cars.

Although the economics of electrifying ride-sharing vehicles are favourable, new policies and company efforts are key to accelerate the transition to all-electric vehicle fleets (Pavlenko et al., 2019). Ride-sharing fleet operators (e.g. Didi) are increasingly working with EV manufacturers to design purpose-built EVs in order to address issues around range, passenger capacity and cargo space.

Autonomous vehicle (AV) pilot projects are underway in over 80 cities around the world, and nearly all are using some form of electrified vehicle. In California, EVs now account for around 70% of automated vehicle trial miles, with PHEVs accounting for half of all miles. The reasons that AV pilot projects are overwhelmingly choosing EVs are numerous. For PHEVs there are benefits in cost, technology compatibility and reduced local pollutant emissions, which are likely to help AVs in their quest for wide public acceptance. The strong EV penetration and growing momentum to electric AVs suggests that progress in vehicle automation and electrification are likely to be self-reinforcing trends.

The intensive and distinct use patterns of shared and/or automated fleets implies higher (and different) needs for charging compared to private EVs. The availability and coverage of public and fast chargers could be a critical factor in how quickly these fleets become electric and how business models evolve around shared and/or automated mobility. In the near term, appropriate data sharing between policy makers, utilities and fleet operators could help anticipate needs for charging infrastructure as mobility service fleets electrify. Over the long-term, shifts towards shared autonomous electric vehicle fleets could improve the economics of charging infrastructure by increasing utilisation, promoting faster returns on investment and reducing reliance on subsidies and indirect revenue streams through grid services.

With growing adoption of shared (and potentially autonomous) mobility, the importance of policies designed to more directly incentivise the use of EVs over conventional vehicles will grow. Countries and cities have a wide range of policy options at their disposal. These include, *inter alia*, fuel taxes, zero-emissions zones, road pricing, high occupancy vehicle and transit lane access, incentives for electric mobility services. National, regional, and municipal governments around the world are implementing a range of policies to encourage general EV adoption and use (Hardman et al.,(2017). Country and city specific objectives, constraints and contexts will continue to shape the design of appropriate policy mixes for each jurisdiction. Researchers and policy makers are exploring alternative policy frameworks that could be effective in promoting electrification of shared and, eventually, autonomous fleets (Jenn, 2018b). California's SB-1014 "California Clean Miles Standard and Incentive Program: zero-emissions vehicles" approved in September 2018 aims to establish annual emissions reduction targets for TNCs (per passenger-mile). London's Ultra-Low Emissions Zone encourages all road users, including fleets, to switch to EVs. Supporting the roll-out of charging infrastructure will continue to be crucial to further EV adoption and use, including fast-charging infrastructure in densely populated urban areas and a robust charging network to support a transition to all-electric vehicle fleets. Cities where taxi and bus fleets are already making the transition to electric vehicles may be able to leverage fast-charging stations built for these fleets to spur a transition to electric shared mobility.

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Statistical annex

This annex presents the electric vehicle (EV) and electric vehicle supply equipment (EVSE) time series data for the 44 countries covered in this report[1]. These include the Electric Vehicles Initiative (EVI) 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, 2019) for European countries that are not members of the EVI and data extracted from commercial databases (EV Volumes, 2019; Marklines, 2019; ACEA, 2019; OICA, 2019; CAAM, 2019).

In the following tables, the category "others" includes Austria, Belgium, Bulgaria, Croatia, Cyprus,[2] Czech Republic, Denmark, Estonia, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxemburg, Malaysia, Malta, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and Turkey.

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[1] Numbers reported in this annex can differ from the data published last year in the Global EV Outlook 2018 due to revisions from databases or new analysis conducted.

[2] 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".

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.

Electric car stock

Table A.1. Electric car stock (battery electric cars [BEV] and plug-in hybrid cars [PHEV]) by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia							0.05	0.30	0.60	1.92	3.69	5.06	7.34	10.95
Brazil										0.06	0.15	0.32	0.68	1.11
Canada							0.52	2.54	5.66	10.73	17.69	29.27	45.95	90.10
Chile							0.01	0.01	0.02	0.03	0.07	0.10	0.23	0.41
China					0.48	1.91	6.98	16.88	32.22	105.39	312.77	648.77	1 227.77	2 306.3
Finland							0.06	0.24	0.47	0.93	1.59	3.29	6.34	12.05
France	0.01	0.01	0.01	0.01	0.12	0.30	3.03	9.29	18.91	31.54	54.49	84.00	118.77	165.48
Germany	0.02	0.02	0.02	0.09	0.10	0.25	1.89	5.26	12.19	24.93	48.12	72.73	109.56	177.07
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80	7.00	10.30
Japan					1.08	3.52	16.13	40.58	69.46	101.74	126.40	151.25	205.35	255.10
Korea						0.06	0.34	0.85	1.45	2.76	5.95	11.21	25.92	59.60
Mexico								0.09	0.10	0.15	0.25	1.03	2.23	4.01
Netherlands				0.01	0.15	0.27	1.14	6.26	28.67	43.76	87.53	112.01	119.33	148.49
New Zealand						0.01	0.03	0.06	0.09	0.41	0.91	2.41	5.88	11.42
Norway			0.01	0.26	0.40	0.79	2.63	7.15	15.67	35.44	69.17	114.05	176.31	249.00
Portugal						0.72	0.91	0.96	1.14	1.34	2.46	4.29	8.69	17.03
South Africa									0.03	0.05	0.29	0.67	0.86	1.01
Sweden							0.18	1.11	2.66	7.32	15.91	29.33	49.67	78.63
Thailand		0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.10	0.37	0.38	0.40	0.60
United Kingdom	0.22	0.55	1.00	1.22	1.40	1.68	2.89	5.59	9.34	24.08	48.51	86.42	133.67	184.03
United States	1.12	1.12	1.12	2.58	2.58	3.77	21.50	74.74	171.44	290.22	404.09	563.71	762.06	1 123.37
Others	0.53	0.53	0.53	0.61	0.64	0.80	3.33	8.15	14.10	25.99	49.71	79.59	133.26	216.41
Total	**1.89**	**2.23**	**2.69**	**5.15**	**7.48**	**14.97**	**62.95**	**182.82**	**387.19**	**712.25**	**1 254.45**	**2 004.66**	**3 147.28**	**5 122.46**

Table A.2. Battery electric car (BEV) stock by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia							0.05	0.22	0.41	0.78	1.54	2.21	3.42	5.22
Brazil										0.06	0.12	0.25	0.32	0.40
Canada							0.22	0.84	2.48	5.31	9.69	14.91	23.62	46.28
Chile							0.01	0.01	0.02	0.02	0.03	0.05	0.17	0.28
China					0.48	1.57	6.32	15.96	30.57	79.48	226.19	483.19	951.19	1 767.06
Finland							0.06	0.11	0.17	0.36	0.61	0.84	1.35	2.12
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
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
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80	7.00	10.30
Japan					1.08	3.52	16.13	29.60	44.35	60.46	70.93	86.39	104.49	131.02
Korea						0.06	0.34	0.85	1.45	2.76	5.67	10.77	24.07	53.71
Mexico								0.09	0.10	0.15	0.24	0.50	0.73	0.93
Netherlands				0.01	0.15	0.27	1.12	1.91	4.16	6.83	9.37	13.11	21.12	46.18
New Zealand						0.01	0.03	0.05	0.08	0.19	0.49	1.65	4.58	8.94
Norway			0.01	0.26	0.40	0.79	2.63	6.81	15.01	33.10	58.88	83.10	116.13	162.27
Portugal						0.72	0.91	0.96	1.10	1.29	1.97	2.78	4.67	9.10
South Africa									0.03	0.05	0.17	0.27	0.33	0.40
Sweden							0.18	0.45	0.88	2.12	5.08	8.03	12.39	19.54
Thailand		0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.28
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
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
Others	0.53	0.53	0.53	0.61	0.64	0.78	3.23	7.09	12.04	20.59	35.43	49.05	71.51	106.48
Total	**1.89**	**2.23**	**2.69**	**5.15**	**7.48**	**14.59**	**53.53**	**112.92**	**225.50**	**415.74**	**736.90**	**1 198.37**	**1 945.78**	**3290.80**

Table A.3. Plug-in hybrid electric car (PHEV) stock by country, 2005-18 (thousands of vehicles)

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Australia								0.08	0.18	1.13	2.15	2.85	3.92	5.72
Brazil											0.03	0.08	0.36	0.71
Canada							0.30	1.70	3.18	5.42	8.00	14.36	22.33	43.82
Chile										0.01	0.04	0.05	0.06	0.13
China						0.34	0.66	0.92	1.65	25.92	86.58	165.58	276.58	539.24
Finland								0.13	0.30	0.57	0.97	2.44	4.99	9.93
France							0.10	0.70	1.53	3.60	9.28	17.03	25.82	41.47
Germany							0.24	1.40	3.02	7.41	18.52	31.81	50.47	81.92
India														
Japan								10.98	25.11	41.28	55.47	64.86	100.86	124.08
Korea								0.00	0.00	0.00	0.27	0.44	1.84	5.89
Mexico								0.00	0.00	0.00	0.01	0.53	1.50	3.08
Netherlands							0.02	4.35	24.51	36.94	78.16	98.90	98.22	102.31
New Zealand								0.01	0.01	0.22	0.42	0.76	1.30	2.48
Norway								0.34	0.66	2.34	10.28	30.95	60.18	86.73
Portugal									0.04	0.05	0.49	1.52	4.02	7.92
South Africa											0.13	0.40	0.53	0.61
Sweden								0.66	1.78	5.21	10.83	21.29	37.28	59.09
Thailand										0.06	0.32	0.32	0.32	0.32
United Kingdom						0.02	0.03	1.02	2.09	10.02	27.55	54.96	88.66	123.28
United States							7.98	46.57	95.58	150.94	193.77	266.65	360.51	483.00
Others						0.02	0.10	1.06	2.06	5.40	14.29	30.54	61.75	109.93
Total						**0.38**	**9.42**	**69.90**	**161.69**	**296.51**	**517.54**	**806.29**	**1 201.5**	**1 831.65**

New electric car sales

Table A.4. New electric car sales (BEV and PHEV) by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia							0.05	0.25	0.29	1.32	1.77	1.37	2.28	3.61
Brazil								0.09	0.17	0.06	0.09	0.17	0.36	0.43
Canada							0.52	2.02	3.12	5.07	6.96	11.58	16.68	44.15
Chile							0.01	0.01	0.01	0.02	0.04	0.03	0.13	0.18
China					0.48	1.43	5.07	9.90	15.34	73.17	207.38	336.00	579.00	1 078.53
Finland							0.03	0.18	0.22	0.44	0.69	1.43	3.06	5.71
France	0.01	0.01	0.01		0.01	0.19	2.73	6.26	9.62	12.64	22.95	29.51	37.60	46.70
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
India			0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00	1.20	3.30
Japan					1.08	2.44	12.62	24.44	28.88	32.29	24.65	24.85	54.10	49.75
Korea						0.06	0.27	0.51	0.60	1.31	3.19	5.26	14.71	33.68
Mexico							0.00	0.09	0.01	0.05	0.10	0.78	1.20	1.79
Netherlands				0.01	0.03	0.12	0.88	5.12	22.42	15.09	43.77	24.48	11.07	29.16
New Zealand				0.00	0.00	0.01	0.02	0.03	0.04	0.32	0.49	1.50	3.47	5.54
Norway			0.01	0.24	0.15	0.40	1.84	4.51	8.52	19.77	33.73	44.89	62.26	72.69
Portugal						0.72	0.19	0.05	0.18	0.20	1.12	1.84	4.39	8.34
South Africa									0.03	0.02	0.24	0.38	0.20	0.15
Sweden						0.00	0.18	0.93	1.55	4.67	8.59	13.42	20.35	28.96
Thailand						0.00	0.01	0.01	0.01	0.07	0.27	0.00	0.03	0.20
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
United States	1.12			1.47		1.19	17.73	53.24	96.70	118.78	113.87	159.62	198.35	361.32
Others	0.53			0.08	0.03	0.16	2.53	4.79	6.14	12.06	23.10	30.44	62.20	83.15
Total	**1.89**	**0.34**	**0.84**	**2.24**	**2.32**	**7.59**	**48.95**	**118.68**	**204.92**	**325.80**	**545.96**	**752.06**	**1 174.45**	**1 975.18**

Table A.5. New battery electric car (BEV) sales by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia							0.05	0.17	0.19	0.37	0.76	0.67	1.21	1.80
Brazil								0.07	0.13	0.06	0.06	0.13	0.07	0.09
Canada							0.22	0.62	1.64	2.83	4.38	5.22	8.71	22.66
Chile							0.01	0.01	0.01	0.00	0.01	0.02	0.12	0.11
China					0.48	1.09	4.75	9.64	14.61	48.91	146.72	257.00	468.00	815.87
Finland							0.03	0.05	0.05	0.18	0.24	0.22	0.50	0.78
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
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
India			0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00	1.20	3.30
Japan					1.08	2.44	12.61	13.47	14.76	16.11	10.47	15.46	18.10	26.53
Korea						0.06	0.27	0.51	0.60	1.31	2.92	5.10	13.30	29.63
Mexico							0.00	0.09	0.01	0.05	0.09	0.25	0.23	0.20
Netherlands				0.01	0.03	0.12	0.86	0.79	2.25	2.66	2.54	3.74	8.63	25.07
New Zealand				0.00	0.00	0.01	0.01	0.02	0.03	0.11	0.30	1.16	2.94	4.36
Norway			0.01	0.24	0.15	0.39	1.84	4.18	8.20	18.09	25.78	24.22	33.03	46.14
Portugal						0.72	0.19	0.05	0.14	0.19	0.67	0.81	1.89	4.43
South Africa									0.03	0.01	0.12	0.10	0.07	0.07
Sweden						0.00	0.18	0.27	0.43	1.24	2.96	2.95	4.36	7.15
Thailand						0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.03	0.20
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
United States	1.12			1.47		1.19	9.75	14.65	47.69	63.42	71.04	86.73	104.49	238.82
Others	0.53			0.08	0.03	0.14	2.45	3.84	5.13	8.72	14.21	14.20	22.86	34.97
Total	**1.89**	**0.34**	**0.84**	**2.25**	**2.32**	**7.21**	**39.9**	**58.21**	**113.1**	**191.**	**323.18**	**463.57**	**754.33**	**1 345.03**

Table A.6. New plug-in hybrid electric car (PHEV) sales by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia								0.08	0.10	0.95	1.01	0.70	1.08	1.80
Brazil								0.02	0.03		0.03	0.05	0.29	0.35
Canada							0.30	1.40	1.48	2.24	2.58	6.36	7.97	21.49
Chile										0.01	0.02	0.01	0.02	0.07
China						0.34	0.32	0.26	0.73	24.27	60.66	79.00	111.00	262.66
Finland								0.13	0.17	0.26	0.44	1.21	2.55	4.93
France							0.10	0.60	0.83	2.07	5.68	7.75	11.61	15.65
Germany							0.24	1.16	1.62	4.39	11.11	13.29	29.50	31.44
India														
Japan							0.02	10.97	14.12	16.18	14.19	9.39	36.00	23.22
Korea											0.27	0.16	1.41	4.05
Mexico											0.01	0.52	0.97	1.58
Netherlands					0.00		0.02	4.33	20.16	12.43	41.23	20.74	2.45	4.09
New Zealand							0.00	0.01	0.01	0.21	0.20	0.34	0.54	1.19
Norway						0.00	0.00	0.33	0.32	1.68	7.95	20.67	29.23	26.55
Portugal									0.04	0.01	0.44	1.03	2.50	3.91
South Africa										0.00	0.12	0.28	0.13	0.08
Sweden								0.66	1.12	3.43	5.63	10.46	15.99	21.81
Thailand										0.06	0.26			
United Kingdom						0.02	0.01	0.99	1.07	7.93	19.24	27.40	33.70	34.62
United States							7.98	38.59	49.01	55.36	42.83	72.89	93.86	122.49
Others						0.02	0.08	0.96	1.01	3.34	8.89	16.25	39.34	48.18
Total						**0.38**	**9.06**	**60.48**	**91.82**	**134.80**	**222.78**	**288.49**	**420.12**	**630.16**

Market share of electric cars

Table A.7. Market share of electric cars (BEV and PHEV) by country, 2005-18 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia								0.01%	0.01%	0.11%	0.19%	0.15%	0.25%	0.41%
Brazil													0.02%	0.02%
Canada							0.02%	0.10%	0.22%	0.35%	0.45%	0.73%	0.99%	2.32%
Chile										0.01%	0.02%	0.02%	0.06%	0.07%
China								0.06%	0.08%	0.36%	0.98%	1.39%	2.30%	4.48%
Finland								0.12%	0.16%	0.41%	0.63%	1.20%	2.58%	4.74%
France							0.12%	0.33%	0.53%	0.70%	1.18%	1.44%	1.76%	2.15%
Germany							0.01%	0.11%	0.23%	0.42%	0.72%	0.73%	1.59%	1.96%
India				0.01%	0.02%	0.02%	0.06%	0.01%	0.02%	0.04%	0.02%	0.07%	0.04%	0.10%
Japan						0.06%	0.33%	0.58%	0.65%	0.69%	0.59%	0.50%	1.23%	1.13%
Korea									0.05%	0.12%	0.21%	0.34%	0.98%	2.21%
Mexico								0.01%			0.01%	0.06%	0.09%	0.14%
Netherlands							0.15%	1.02%	5.38%	3.89%	9.75%	6.39%	2.67%	6.57%
New Zealand										0.09%	0.20%	0.58%	1.32%	2.12%
Norway				0.22%	0.15%	0.31%	1.32%	3.24%	5.89%	13.34%	21.08%	26.64%	37.07%	46.42%
Portugal						0.32%	0.12%	0.05%	0.17%	0.14%	0.56%	0.80%	1.89%	3.92%
South Africa									0.01%		0.06%	0.10%	0.05%	0.04%
Sweden							0.05%	0.31%	0.53%	1.44%	2.37%	3.41%	6.28%	7.92%
Thailand										0.01%	0.03%			
United Kingdom							0.06%	0.13%	0.17%	0.59%	1.11%	1.39%	1.83%	2.10%
United States							0.17%	0.43%	0.71%	0.77%	0.70%	0.98%	1.26%	2.45%
Others								0.09%	0.12%	0.29%	0.54%	0.72%	1.48%	1.21%

Table A.8. Market share of battery electric cars (BEV) by country, 2005-18 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia											0.08%	0.07%	0.13%	0.21%
Brazil														
Canada									0.12%	0.19%	0.28%	0.33%	0.52%	1.19%
Chile											0.01%	0.01%	0.05%	0.04%
China								0.06%	0.08%	0.24%	0.69%	1.06%	1.86%	3.39%
Finland										0.17%	0.22%	0.19%	0.42%	0.64%
France							0.12%	0.30%	0.49%	0.58%	0.89%	1.06%	1.21%	1.43%
Germany								0.07%	0.18%	0.27%	0.37%	0.34%	0.73%	1.05%
India				0.01%	0.02%	0.02%	0.06%	0.01%	0.02%	0.04%	0.02%	0.07%	0.04%	0.10%
Japan						0.06%	0.33%	0.32%	0.33%	0.34%	0.25%	0.31%	0.41%	0.60%
Korea									0.05%	0.12%	0.19%	0.33%	0.89%	1.95%
Mexico								0.01%			0.01%	0.02%	0.02%	0.02%
Netherlands							0.15%	0.16%	0.54%	0.69%	0.57%	0.98%	2.08%	5.65%
New Zealand											0.12%	0.45%	1.12%	1.67%
Norway				0.22%	0.15%	0.31%	1.32%	3.00%	5.67%	12.21%	16.11%	14.37%	19.66%	29.47%
Portugal						0.32%	0.12%	0.05%	0.13%	0.14%	0.34%	0.35%	0.82%	2.08%
South Africa									0.01%		0.03%	0.03%	0.02%	0.02%
Sweden							0.05%	0.09%	0.15%	0.38%	0.82%	0.75%	1.34%	1.96%
Thailand														
United Kingdom							0.06%	0.08%	0.12%	0.27%	0.38%	0.39%	0.53%	0.66%
United States							0.09%	0.12%	0.35%	0.41%	0.44%	0.53%	0.66%	1.62%
Others								0.09%	0.12%	0.23%	0.39%	0.47%	0.91%	0.51%

Table A.9. Market share of plug-in hybrid electric cars (PHEV) by country, 2005-18 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia								0.01%	0.01%	0.11%	0.11%	0.08%	0.12%	0.21%
Brazil													0.02%	0.02%
Canada							0.02%	0.10%	0.10%	0.15%	0.17%	0.40%	0.47%	1.13%
Chile										0.01%	0.01%	0.00%	0.01%	0.03%
China										0.12%	0.29%	0.33%	0.44%	1.09%
Finland								0.12%	0.16%	0.24%	0.41%	1.01%	2.15%	4.09%
France								0.03%	0.05%	0.11%	0.29%	0.38%	0.54%	0.72%
Germany							0.01%	0.04%	0.05%	0.14%	0.34%	0.40%	0.86%	0.92%
India														
Japan								0.26%	0.32%	0.34%	0.34%	0.19%	0.82%	0.53%
Korea											0.02%	0.01%	0.09%	0.27%
Mexico												0.04%	0.07%	0.13%
Netherlands								0.86%	4.84%	3.21%	9.18%	5.42%	0.59%	0.92%
New Zealand										0.09%	0.08%	0.13%	0.20%	0.45%
Norway								0.24%	0.22%	1.13%	4.97%	12.26%	17.41%	16.95%
Portugal									0.03%	0.01%	0.22%	0.45%	1.08%	1.84%
South Africa											0.03%	0.08%	0.03%	0.02%
Sweden								0.22%	0.38%	1.06%	1.55%	2.66%	4.93%	5.97%
Thailand										0.01%	0.03%			
United Kingdom								0.05%	0.05%	0.32%	0.73%	1.01%	1.31%	1.44%
United States							0.08%	0.31%	0.36%	0.36%	0.26%	0.45%	0.60%	0.83%
Others										0.06%	0.15%	0.25%	0.57%	0.70%

Electric light commercial vehicles (LCV)

Table A.10. Electric LCV stock (BEV and PHEV) by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia														
Brazil														
Canada											0.01	0.01	0.01	0.01
Chile							0.01	0.01	0.02	0.03	0.07	0.10	0.23	0.34
China						0.25	0.93	1.99	3.12	4.58	17.58	37.45	83.73	138.04
Finland														0.05
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
Germany	0.02	0.02	0.02	0.05	0.05	0.22	0.50	1.45	2.04	2.76	3.77	6.22	11.40	16.69
India														
Japan							0.85	3.34	5.40	6.45	7.27	7.60	7.92	8.20
Korea											0.02	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	3.22
New Zealand														
Norway								0.01	0.01	0.56	1.27	1.97	2.92	4.81
Portugal													0.08	0.33
South Africa														
Sweden							0.01	0.28	0.50	0.78	1.11	1.15	1.23	3.71
Thailand														
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
United States						0.01	0.19	1.01	2.08	3.56	5.21	5.21	5.21	5.21
Others	0.26	0.26	0.26	0.61	0.61	0.83	0.98	2.08	2.73	3.65	5.37	7.46	9.47	14.51
Total	**0.63**	**0.79**	**0.99**	**2.05**	**2.27**	**3.99**	**8.16**	**19.29**	**30.61**	**42.98**	**69.20**	**101.58**	**164.12**	**244.11**

Table A.11. New electric LCV sales (BEV and PHEV) by country, 2005-18 (thousands of vehicles)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia														
Brazil														
Canada											0.01			
Chile							0.01	0.01	0.01	0.02	0.04	0.03	0.13	0.11
China					0.54	0.25	0.68	1.07	1.12	1.47	12.98	19.87	46.28	54.30
Finland													1.00	0.05
France	0.26					0.80	1.68	3.65	5.11	4.49	4.93	5.56	6.31	8.10
Germany	0.02			0.03		0.17	0.28	0.95	0.60	0.72	1.02	2.45	4.47	5.29
India														
Japan							0.85	2.49	2.07	1.05	0.83	0.32	0.33	0.28
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
New Zealand														
Norway							0.00	0.00		0.56	0.71	0.70	0.94	1.89
Portugal							0.01	0.02	0.03	0.02	0.06	0.04	0.19	0.25
South Africa														
Sweden							0.01	0.28	0.21	0.28	0.33	0.05	0.20	2.47
Thailand														
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	0.95	1.18
United States						0.01	0.18	0.82	1.08	1.48	1.65			
Others	0.26			0.35		0.22	0.17	1.31	0.75	1.30	2.26	3.02	3.24	5.04
Total	**0.63**	**0.16**	**0.20**	**0.59**	**0.72**	**1.72**	**4.20**	**11.35**	**11.46**	**12.77**	**26.06**	**33.35**	**64.54**	**79.99**

Table A.12. Market share of electric LCVs (BEV and PHEV) by country, 2005-18 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia														
Brazil														
Canada														
Chile							0.01%	0.01%	0.01%	0.02%	0.05%	0.04%	0.15%	0.11%
China					0.04%	0.02%	0.04%	0.06%	0.06%	0.08%	0.85%	1.17%	2.70%	2.87%
Finland													6.35%	0.30%
France	0.06%			0.10%		0.19%	0.39%	0.95%	1.38%	1.20%	1.28%	1.34%	1.42%	2.41%
Germany	0.01%			0.01%		0.09%	0.12%	0.43%	0.28%	0.31%	0.42%	0.94%	1.64%	2.04%
India														
Japan							0.15%	0.38%	0.31%	0.15%	0.13%	0.05%	0.05%	0.04%
Korea											0.01%	0.01%		
Mexico														
Netherlands						0.08%	0.12%	0.59%	0.35%	1.14%	0.35%	0.24%	0.64%	1.38%
New Zealand														
Norway								0.01%		1.87%	2.14%	1.99%	2.73%	5.30%
Portugal							0.01%	0.10%	0.15%	0.09%	0.19%	0.13%	0.50%	0.67%
South Africa														
Sweden							0.02%	0.70%	0.57%	0.67%	0.73%	0.09%	0.35%	4.37%
Thailand														
United Kingdom	0.03%	0.05%	0.06%	0.07%	0.09%	0.11%	0.10%	0.18%	0.12%	0.25%	0.28%	0.30%	0.26%	0.33%
United States							0.03%	0.12%	0.19%	0.18%	0.17%			
Others														

Electric vehicle supply equipment stock

Table A.13. Publicly accessible chargers (slow and fast) by country, 2005-18 (chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia													476	727
Brazil														459
Canada								724	1 179	2 321	3 424	4 035	5 841	7 940
Chile							2	18	20	31	40	40	62	100
China										30 000	58 758	141 254	213 903	275 000
Finland									267	383	836	847	847	931
France								809	1 802	1 827	10 445	19 618	21 184	24 132
Germany								1 518	2 447	2 846	5 058	23 901	24 014	25 724
India												25	247	352
Japan						312	801	1 381	1 794	11 517	22 091	24 321	28 762	29 971
Korea							62	177	292	388	790	1 566	5 612	9 303
Mexico													1 502	2 706
Netherlands						400	400	2 803	5 791	11 981	18 008	32 524	33 282	36 671
New Zealand													104	293
Norway						2 800	3 123	3 746	4 651	5 385	5 513	7 541	9 209	12 371
Portugal							1 078	1 127	1 175	1 195	1 260	1 295	1 605	1 786
South Africa													124	239
Sweden								505	1 020	1 165	1 520	2 162	4 071	7 000
Thailand													96	96
United Kingdom							1 503	2 840	5 691	7 742	9 240	13 260	15 241	17 424
United States			374	381	419	542	4 392	13 160	16 867	22 633	31 674	38 168	43 037	54 500
Others							1 306	4 145	5 980	8 207	14 199	20 812	24 029	30 884
Total			**374**	**381**	**419**	**4 054**	**12 667**	**32 953**	**48 976**	**107 621**	**182 856**	**331 369**	**433 248**	**538 609**

Table A.14. Publicly accessible slow chargers by country, 2005-18 (chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia													436	666
Brazil														454
Canada								722	1 172	2 266	3 361	3 900	5 168	7 100
Chile								10	12	21	25	25	41	74
China										21 000	46 657	86 365	130 508	163 667
Finland									250	357	706	706	706	706
France								800	1 700	1 700	9 865	18 620	20 153	22 736
Germany								1 500	2 400	2 606	4 587	22 213	22 213	23 112
India													222	327
Japan										8 640	16 120	17 260	21 507	22 287
Korea							29	59	115	151	449	1 075	3 081	5 394
Mexico													1 486	2 677
Netherlands						400	400	2 782	5 770	11 860	17 786	32 120	32 875	35 852
New Zealand														89
Norway						2 800	3 105	3 688	4 511	5 185	5 185	7 040	8 292	11 145
Portugal							1 072	1 120	1 158	1 178	1 238	1 254	1 452	1 602
South Africa													87	158
Sweden								500	1 000	1 065	1 251	1 737	3 456	6 050
Thailand													88	88
United Kingdom							1 503	2 804	5 435	7 182	8 174	11 497	13 062	14 732
United States			333	339	373	482	3 903	11 695	14 990	20 115	28 150	35 089	39 601	50 258
Others							1 299	3 940	5 419	7 533	12 518	18 617	21 164	25 934
Total			**333**	**339**	**373**	**3 682**	**11 311**	**29 620**	**43 932**	**90 859**	**156 072**	**257 518**	**325 598**	**395 107**

Table A.15. Publicly accessible fast chargers by country, 2005-18 (chargers)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia													40	61
Brazil														5
Canada								2	7	55	63	135	673	840
Chile							2	8	8	10	15	15	21	26
China										9 000	12 101	54 889	83 395	111 333
Finland									17	26	130	141	141	225
France								9	102	127	580	998	1 031	1 396
Germany								18	47	240	471	1 688	1 801	2 612
India												25	25	25
Japan						312	801	1 381	1 794	2 877	5 971	7 061	7 255	7 684
Korea							33	118	177	237	341	491	2 531	3 910
Mexico													16	29
Netherlands								21	21	121	222	404	407	819
New Zealand													104	204
Norway							18	58	140	200	328	501	917	1 226
Portugal							6	7	17	17	22	41	153	184
South Africa													37	81
Sweden								5	20	100	269	425	615	950
Thailand													8	8
United Kingdom								36	256	560	1 066	1 763	2 179	2 692
United States			42	42	47	60	489	1 464	1 877	2 518	3 524	3 079	3 436	4 242
Others							7	205	561	674	1 681	2 195	2 865	4 951
Total			**42**	**42**	**47**	**372**	**1 356**	**3 332**	**5 044**	**16 762**	**26 784**	**73 851**	**107 650**	**143 502**

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

3TsG	Tin, tantalum, tungsten and gold
AC	alternating current
ACEA	European Automobile Manufacturers Association
ASEAN	Association of Southeast Asian Nations
AV	autonomous vehicle
BEV	battery electric vehicle
CAD	Canadian dollar
CAFE	corporate average fuel-economy standards
CAN	controller area network
CCS	combined charging system
CHAdeMO	Charge de Move
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-eq	carbon-dioxide equivalent
CPO	charge point operator
DC	direct current
DoT	Department of Transport
DPER	Department of Public Expenditure and Reform
DSO	distribution system operator
DSR	demand-side response
EAFO	European Alternative Fuels Observatory
EC	European Commission
EEA	European Environment Agency
EEA	European Economic Area (EU members + Iceland, Liechtenstein and Norway)
EESL	Energy Efficiency Services Limited (India)
EPA	Environmental Protection Agency (United States)
EPBD	Energy Performance Buildings Directive
ETP	Energy Technology Perspectives
EU	European Union
EUR	Euro
EV	electric vehicle, i.e. BEV, PHEV or FCEV
EVI	Electric Vehicles Initiative
EVS	electric vehicle system
EVSE	electric vehicle supply equipment
FCEV	fuel-cell electric vehicle
FY	fiscal year
GBA	Global Battery Alliance
GBP	United Kingdom pound

GDP	Gross domestic product
GEVO	Global Electric Vehicle Outlook
GHG	greenhouse gas
GVW	gross vehicle weight
HEV	hybrid electric vehicle
HDV	heavy-duty vehicle
HFT	heavy freight trucks
ICE	internal combustion engine
IEA	International Energy Agency
JPY	Japanese yen
KRW	Korean won
LFP	lithium iron phosphate
LCA	life-cycle analysis
LCV	light commercial vehicle
LDV	light-duty vehicle[1]
Lge	litres of gasoline equivalent
LPG	liquefied petroleum gas
LSEV	low-speed electric vehicle
MEAEF	Ministry of Economic Affairs and Employment of Finland
MFT	medium freight trucks
MoE	Ministry of Energy
NCA	nickel cobalt aluminium
NEDC	New European Driving Cycle
NEV	New energy vehicle
NEVO	Nordic Electric Vehicle Outlook
NGO	non-governmental organisation
NMC	nickel manganese cobalt
NPS	New Policies Scenario
NZD	New Zealand dollar
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OICA	International Organization of Motor Vehicle Manufacturers
PHEV	plug-in hybrid vehicle
PLC	power line communication
PLDV	passenger light-duty vehicle
R&D	research and development
RMB	Chinese yuan
RMI	Responsible Mineral Initiatives
SAEV	shared autonomous electric vehicle
SDS	Sustainable Development Scenario
SUV	sport-utility vehicle
TCO	total cost of ownership
TCP	Technology Collaboration Programme
TNC	transportation network company
TTW	Tank-to-wheel
UK	United Kingdom
USD	United States Dollar

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[1] Including passenger cars and light commercial vehicles.

V	Volt
V2G	Vehicle-to-grid
V2X	Vehicle-to-[element], e.g. vehicle-to-vehicle or vehicle-to- infrastructure
VAT	Value-added tax
VPP	Virtual power plant
VRE	Variable renewable energy
WLTP	World-wide Harmonized Light Vehicle Test Procedure
WTT	Well-to-tank
WTW	Well-to-wheel
ZEV	Zero-emissions vehicle

Units of measure

g CO_2	grammes of carbon dioxide
g CO_2/km	grammes of carbon dioxide per kilometre
Gt	gigatonne
GW	gigawatt
GWh	gigawatt-hour
kW	kilowatt
kWh	kilowatt-hour
Lge	litres of gasoline equivalent
Mt CO_2	million tonnes of CO_2
MW	megawatt
Pa	Pascal
t CO_2	tonnes of CO_2
Wh/kg	watt-hour per kilogramme

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INTERNATIONAL ENERGY AGENCY

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