

Global EV Outlook 2018

Towards cross-modal electrification

INTERNATIONAL ENERGY AGENCY

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Executive summary

New electric vehicle sales

Sales of new electric cars¹ worldwide surpassed 1 million units in 2017 – a record volume. This represents a growth in new electric car sales of 54% compared with 2016. Electric cars accounted for 39% of new car sales in Norway in 2017 – the world’s most advanced market of electric cars in terms of sales share.² Iceland and Sweden, the next two most successful markets, achieved 11.7% and 6.3% electric car sales share, respectively, in 2017.³

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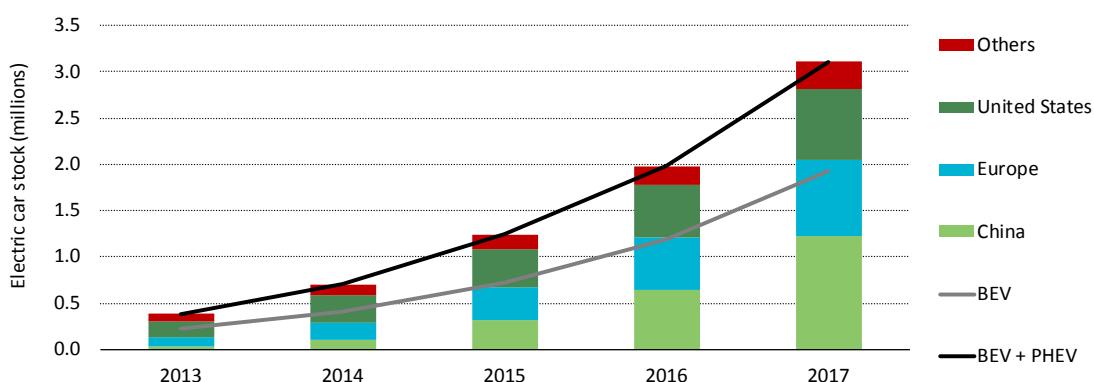
More than half of global sales of electric cars were in the People’s Republic of China (hereafter, “China”), where electric cars had a market share of 2.2% in 2017. Electric cars sold in the Chinese market more than doubled the amount delivered in the United States, the second-largest electric car market globally.

Electrification of other transport modes is also developing quickly, especially for two-wheelers and buses. In 2017, sales of electric buses were about 100 000 and sales of two-wheelers are estimated at 30 million; for both modes, the vast majority was in China.

Vehicle stock

The global stock of electric cars surpassed 3 million vehicles in 2017 after crossing the 1 million threshold in 2015 and the 2 million mark in 2016. It expanded by 56% compared with 2016 (Figure ES 1). In 2017, China had the largest electric car stock: 40% of the global total.

Figure ES 1 • Evolution of the global electric car stock, 2013-17



Notes: The electric car stock shown is primarily estimated on the basis of cumulative sales since 2005. Where available, stock numbers from official national statistics have been used (provided that the data can be shown to be consistent with sales evolutions).

Sources: IEA analysis based on country submissions, complemented by ACEA (2018); EAFO (2018a).

Key point: Global electric car stock is expanding rapidly, crossing the 3 million vehicle threshold in 2017.

¹ Electric vehicles include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel-cell electric vehicles (FCEVs). In this report, their modal scope covers PLDVs, Light Commercial Vehicles (LCVs), buses, trucks and two- and three-wheeler. This report also focuses on BEVs and PHEVs, which are much more widely sold and used than FCEVs. Electric cars refer to electric vehicles falling in the category of passenger light-duty vehicles (PLDVs).

² In this report, market share is defined as the share of new electric car registrations as a percentage of total new passenger light-duty cars registrations.

³ The leadership shown by Nordic countries is analysed in significant detail in the recent *Nordic EV Outlook 2018* (IEA, 2018a).

In 2017, the stock of electric buses increased to 370 000 units and electric two-wheelers reached 250 million. The electrification of these modes has been driven mostly by developments in China, which accounts for more than 99% of both electric bus and two-wheeler stocks, though registrations in Europe and India are also on the upswing.

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Chargers

Electric vehicle (EV) uptake is closely mirrored by the growth of charging infrastructure.⁴ In 2017, private chargers at residences and workplaces, estimated to number almost 3 million worldwide, were the most widely used charging installations for electric cars owned by households and fleets. Charging outlets on private property for fleets (primarily buses) number some 366 000 units, almost all in China.

Publicly accessible chargers complement the role of private ones and should be viewed as an important component of the EV supply infrastructure. Most of the publicly accessible chargers are slow charging outlets, which numbered almost 320 000 worldwide in 2017. They are complemented by more than 110 000 fast chargers. Fast chargers are especially important in urban environments due to land availability constraints, such as in densely populated Asian cities. In addition, fast chargers are essential to increase the appeal of EVs by enabling long distance travel. This is a critical facet that the major markets such as China, the European Union and the United States clearly have embraced in ramping up their ambition in defining targets for the number of installations and network density.

Policy support

Vehicles

So far, EV deployment has mostly been driven by policy. The main markets by volume (China) and sales share (Norway) have the strongest policy push. This is true for light-duty vehicles (LDVs) as well as for buses and two-wheelers. By far the largest volumes of deployed electric buses and two-wheelers are in China, the country with the longest running policies targeting cross-modal electrification.

Looking ahead, the strongest current policy signals emanate from electric car mandates in China and California, as well as the European Union's recent proposal on carbon dioxide (CO₂) emissions standards for 2030. Electrification targets announced by the government of India and by a number of other countries and major cities worldwide also point at growing EV uptake.

Chargers

Policies are also supporting the development of both private and publicly accessible charging outlets. As more energy companies, automakers, utilities and grid service providers form alliances to develop EV support infrastructure, public funding could be gradually withdrawn from the build-out of public charging, moving towards self-sustaining and business-driven solutions. Ensuring higher occupancy for publicly accessible chargers is crucial to enable this transition. Given the need to maintain the publicly accessible charging infrastructure across an entire road network, it is possible that targeted support for some electric vehicle supply equipment (EVSE) installations will be needed for cases where full cost recovery conflicts with the need to ensure the provision of adequate charging options.

⁴ Electric vehicle supply equipment refers to chargers and charging infrastructure for electric vehicles.

Battery developments and cost reductions

The development of batteries for consumer electronics provided invaluable experience for the production of lithium-ion (Li-ion) cells. It facilitated increased production and justified considerable investment in research and development, leading to significant cost reductions and improved performance. The impressive progress made in recent years to improve battery performance and reduce costs enabled the use of Li-ion batteries in the automotive sector, and this is now opening up opportunities for further improvements.

Key cost and performance drivers identified for the further improvement of Li-ion batteries include battery chemistry, energy storage capacity, manufacturing scale and charging speeds. These solutions suggest that Li-ion batteries are likely to remain the technology of choice for EVs in the next decade. Several post Li-ion technologies are also showing potential for improved performance and further cost reductions, but their current technology readiness level is still low.

Batteries are currently the main reason of the higher upfront costs of EVs in comparison with incumbent technologies. Our analysis of the total cost of ownership of EVs and internal combustion engine vehicles (ICEVs) shows that battery cost reductions hold significant promise for improving the appeal of EVs for individuals making a vehicle purchase decision. In particular, this analysis shows that the cost competitiveness of BEVs is strongest in fleets with intensive use patterns, such as buses, taxis, ride-hailing services and shared cars.

Announced investment in large-scale battery manufacturing facilities confirms that there is increasing confidence in the future of electric mobility and that augmenting production capacity is likely to catalyse further battery cost reductions.

Outlook

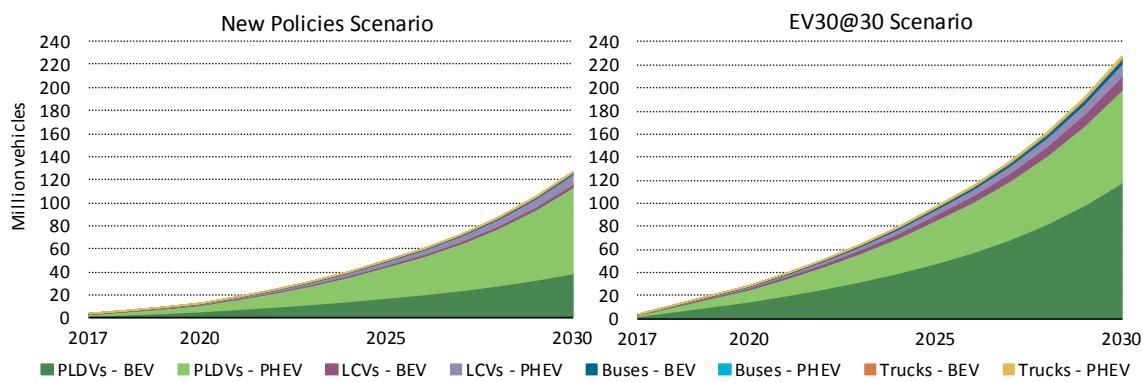
Vehicle uptake

Supportive policies and cost reductions are likely to lead to significant growth in the market uptake of EVs in the outlook period to 2030. In the New Policies Scenario, which takes into account existing and announced policies, the number of electric light-duty vehicles on the road reaches 125 million by 2030. Should the policy ambitions continue to rise to meet climate goals and other sustainability targets, as in the EV30@30 Scenario, then the number of electric LDVs on the road could be as high as 220 million in 2030 (Figure ES 2) – 130 million battery electric and 90 million plug-in hybrids, respectively.

Rapid developments in scaling up battery production and reducing costs enabled by increasing electric car sales, primarily driven by policies targeting LDVs, have positive spill over effects across other modes of transport:

- Even though electric two-wheelers are not currently a prime policy focus in most regions, they are projected to experience a significant growth - 39% of the world two-wheelers will be electric (in terms of stock share) by 2030 in the New Policies Scenario. This high share primarily reflects China's lead and continuing commitment to the electrification of two-wheelers, together with India's stated ambition to electrify its two-wheelers (the two countries are the world's largest two-wheeler markets). Europe, where fuel taxes induce quicker cost recovery over the vehicle life, is also at the forefront of this transition. If further regulatory pressure is applied to better harness full economic and environmental benefits, and a 50% global stock share can be achieved in 2030 in the EV30@30 Scenario.
- Urban buses also experience a significant transition to electric drivetrains, despite some challenges such as the high capital cost of buses and the complexity of installing charging

Figure ES 2 • Global EV stock in the New Policies and EV30@30 scenarios, 2017-30



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2018b).

Key point: The EV30@30 Scenario sees 228 million EVs (excluding two- and three-wheelers), mostly LDVs, by 2030; around 100 million more than in the New Policies Scenario.

Chargers

As EV penetration grows to 2030, so does the number of charging outlets installed. Private chargers are expected to outnumber electric LDVs by 10%. This accounts for a reduction in the opportunity for electric car owners to install a charger at home (with the diversification of electric car buyer profiles as the market expands), but increasing availability of charging infrastructure at workplaces. This also accounts for lower ratios of charging outlets per electric LDV in densely populated areas such as China and Japan.

This scale of publicly accessible charging infrastructure is consistent with the recommendations of the EU Alternative Fuels Infrastructure (AFI) Directive, which suggests a ratio of one publicly accessible charger for ten electric cars. The ratio of publicly accessible chargers per electric car required, however, may end up being much lower than one charger for ten electric cars, as evidenced by the ratio currently observed in Norway – the most advanced electric car market in 2017 in terms of market share. In Norway, there is only one publicly accessible charger for 19 electric cars. The actual deployment of publicly accessible charging infrastructure in the coming years, in a large part, will depend on countries' and regions' strategies and policies regarding the availability of charging infrastructure in public spaces.

The charging infrastructure for buses is projected to be exclusively based on fast chargers (minimum 50 kW), which will allow for the recharging of two buses per night.

Materials demand

The shift to EVs will increase demand for some materials. In particular, a rapid ramp-up in the demand of cobalt and lithium may pose some risks. The supply of cobalt is especially critical due to the concentration of mining and refining facilities in a handful of countries. Ongoing developments

in battery chemistry aim to reduce their cobalt content; battery chemistry with less cobalt can achieve higher energy and power densities, but also tend to have lower thermal stability. Even accounting for this, the cobalt demand for EVs is expected to be ten times higher than current levels by 2030 in the New Policies Scenario in a central assessment on battery chemistries, and over 25 times larger in the EV30@30 scenario. Uncertainties about the future growth of cobalt demand, together with low volumes of historic global cobalt demand (in comparison to other materials), led to price surges in recent years.

Enabling a smooth transition to electric mobility requires ensuring a stable supply of cobalt at moderate prices. The contribution of regulators in this respect should focus on reducing uncertainties on EV uptake, as this would facilitate investment in extraction capacity and the emergence of contractual arrangements spanning longer periods of time.

Policy insights

Policy needs for a timely and sustainable transition to electric mobility require a wide array of measures and supporting actions. They must be adapted to specific market contexts. Plus, they must be adaptable as markets evolve to mass adoption of electric vehicles.

In the early stages of EV deployment and diffusion, public procurement schemes (for instance, buses and municipal vehicles) have the double benefit of demonstrating the technology to the public and providing the opportunity for public authorities to lead by example. Importantly, they also allow the industry to produce and deliver bulk orders and initiate economies of scale. Taxes that reflect the CO₂ content are important to ensure that the policy environment is conducive to increased EV uptake. Fiscal incentives at vehicle purchase, as well as complementary measures that enhance the value proposition of driving electric on a daily basis (e.g. preferential parking rates, road toll rebates and low emission zones) are pivotal to attract consumers and businesses to electric vehicles.

More comprehensive policies are critical to lay the foundation for a transition to electrification and to assuage stakeholders' uncertainties. Increasingly stringent, technology-neutral regulations on tailpipe CO₂ emissions and mandates requiring that automakers sell a minimum share of zero- or low-emission vehicles are well suited for this purpose.

Policy-makers will also need to set appropriate signals for charging infrastructure and grid service businesses to enable viable business models to emerge and to facilitate a smooth integration of EVs in power grid operations. Approaches should be designed to reap maximum benefits from the available synergies of transport electrification with increasing supplies of variable renewables. In particular, changes in the regulations governing grid operations, such as allowing non-utility stakeholders to enter the charging services market (which is currently not permitted in a number of countries), can easily lift key barriers to innovation and investment. National or local regulations targeting new or renovated buildings are also a prime resource to expand the EV-readiness of the building stock and to facilitate consumer EV adoption.

Both our scenarios suggest that in the 2020s, foregone revenues from fuel taxation will call for alternative tax approaches. Taxation based on vehicle activity (e.g. distance-based pricing) is well suited to recover funds needed for investments and maintenance of transport infrastructure, to give a price to the emission of local pollutants – based on their impact on health and the environment, and to reduce traffic congestion.

The uptake and widespread diffusion of EVs does not come without long-term social, sustainability and natural resource implications. Clearly defined and respected norms and requirements for traceability are needed across the battery supply chain. Regulators can play an important role in

setting minimum standards related to labour and environmental conditions, and in developing effective instruments to ensure that they are properly enforced. Regulatory frameworks shall not only be targeting the EV battery materials supply chain, but also the end-of-life and material recycling processes, with the aim to facilitate cost reductions for battery recycling and to maximise the residual value of batteries at the end of their useful life.

1. Introduction

Electric vehicles (EVs) for road transport boost energy efficiency, require no direct fuel combustion and rely on electricity – the most diversified energy carrier, thereby contributing to a wide range of transport policy goals. These include enhanced energy security, better air quality, less noise and, in concert with a low-carbon power generation mix, reduced greenhouse gas emissions. Plus, as one of the most innovative clusters in the automotive sector, EVs have substantial potential to enhance economic and industrial competitiveness and to attract investment where major markets can be developed.

Dynamic market uptake of electric vehicles has occurred in recent years. On-going support and commitments for increased deployment of EVs from policy makers and the automotive industry suggest that this trend is not going to abate in the coming decade. In fact, increased sales volumes together with growing competition in the development of new technologies are likely to contribute to continuous reductions in the cost of manufacturing batteries – the most important cost component for EVs. Cost reductions in EV-related technologies further strengthen their competitiveness compared with internal combustion engine vehicles. This reinforces the case for road EVs taking an expanding market share, and perhaps a leading role in the evolution of transportation across all modes.

This report aims to analyse in detail the factors that have influenced recent developments in electric mobility, the dynamics behind the rapid evolution, the impacts on future prospects 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. It is dedicated to accelerating the deployment of electric vehicles worldwide.

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. The EVI serves as a platform for knowledge-sharing on policies and programmes that support EV deployment.

Governments currently active in the EVI include Canada, the People's Republic of China ("China"), Finland, France, Germany, India, Japan, Mexico, Netherlands, Norway, Sweden, United Kingdom and United States. This group includes the largest and most rapidly growing EV markets worldwide and accounted for the vast majority of global EV sales in 2017. Canada and China are the co-leads of the initiative. The International Energy Agency serves as the EVI co-ordinator.¹

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; GreenTech Malaysia; International Council for

¹ In addition to the 13 EVI countries listed in this paragraph, Chile and New Zealand recently announced their intention to join the EVI as of May 2018.

Clean Transportation (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; Mission 2020; Natural Resources Defence Council (NRDC); National Renewable Energy Laboratory (NREL) of the United States; Nordic Energy Research; Partnership on Sustainable, Low Carbon Transport (SloCaT); REN21; Rocky Mountain Institute (RMI); Swedish Energy Agency; The Climate Group; the United Nations Environment (UN Environment); the United Nations Human Settlements Programme (UN Habitat); the United Nations Industrial Development Organization (UNIDO); World Resources Institute (WRI) and Urban Foresight.

To date, the EVI has developed analytical outputs that include several editions of the *Global EV Outlook* (2013, 2015, 2016 and 2017) (IEA, 2017a; IEA, 2016; IEA, 2013; IEA, 2015), the *Nordic EV Outlook 2018* (IEA, 2018a) and two editions of the *EV City Casebook* (Urban Foresight, 2014; IEA, 2012), with a focus on initiatives taking place at a local level. The EVI has also successfully engaged private sector stakeholders in roundtables in Paris in 2010, in Stuttgart in 2012, and at COP21 in Paris in 2015 and COP22 in Marrakesh in 2016 to discuss the roles of industry and government in EV development as well as the opportunities and challenges ahead for EVs.

The EV30@30 campaign

The EV30@30 campaign, launched at the Eighth Clean Energy Ministerial in 2017, redefined the EVI ambition by setting the collective aspirational goal for all EVI members of a 30% market share for electric vehicles in the total of all vehicles (except two-wheelers) by 2030.

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

- Supporting the deployment of EV chargers and tracking progress.
- Galvanising public and private sector commitments for EV uptake in company and supplier fleets.
- Scaling up policy research, including policy efficacy analysis, information and experience sharing and capacity building.
- Supporting governments in need of policy and technical assistance through training and capacity building.
- Establishing the Global EV Pilot City Programme, a global co-operative programme that aims to facilitate the exchange of experiences and the replication of best practices for the promotion of EVs in cities.

Content and scope

This report analyses the development of the EV market until the end of 2017, covering EV registrations (vehicle sales), EV stock estimates (mainly based on cumulative sales) and the availability and characteristics of the supply equipment that they require. It reviews recent policy implementation across the main markets relevant for EV and electric vehicle supply equipment (EVSE) deployment. These analyses are to be found in Chapters 2 and 3.

The report includes an assessment of electricity demand resulting from EVs, oil savings due to the replacement of internal combustion engine (ICE) vehicles, a quantitative assessment of greenhouse

gas (GHG) emissions mitigation and qualitative considerations on the reduction of air pollutant emissions (Chapter 4). Going beyond the focus on passenger cars in previous versions of the *Global EV Outlook*, the scope of this edition looks beyond light-duty vehicles (LDVs)² to electric buses, light commercial vehicles (LCVs), trucks and two-wheelers.

The analyses benefit from an overview of the status and prospects for battery technologies that builds on the insights gained in a technical workshop on batteries for electric mobility convened by the IEA and the Electric Vehicles Initiative in March 2018.³ This assessment is followed by a section outlining how cost reductions from the development of battery technologies and EV market growth translate to reductions in the total cost of ownership (TCO) of EVs (Chapter 5).

The outlook section of the report (Chapter 6) builds on the insights discussed in the policy assessment, the technology analysis and the TCO evaluation to outline two scenarios of EV deployment in the period to 2030:

- The first scenario is an update of the EV analysis in the *World Energy Outlook* New Policies Scenario, factoring in transport and EV-related policies already announced and reviewed in the first section of the report, as well as their implications for technology developments and related spill over effects, looking at all road transport modes.
- The second scenario reflects a policy case characterised by a wider adoption of EVs, in line with the global EV30@30 campaign if it were to be applied at a global scale.

The scenarios are analysed in terms of EV stocks, related battery production capacity and material demand, EVSE deployment, electricity demand, oil savings and GHG emission reductions.

Finally, Chapter 7 is dedicated to the discussion of policy needs stemming from the observations made in the previous Chapters.

The countries covered include EVI members, those included in the European Alternative Fuels Observatory, as well as a number of other countries that have a growing interest in participating in the activities of the EVI: Australia, Brazil, Chile⁴, Korea, Malaysia, New Zealand⁵, Portugal, South Africa and Thailand.

² LDVs include passenger cars and light commercial vehicles.

³ The workshop facilitated discussion of key topics related to battery development for automotive applications. Topics included: battery chemistry; technologies to scale up production; the likely evolution of materials demand; opportunities for second-life applications of automotive batteries and the recycling of materials.

⁴ See footnote 1.

⁵ See footnote 1.

2. Vehicles

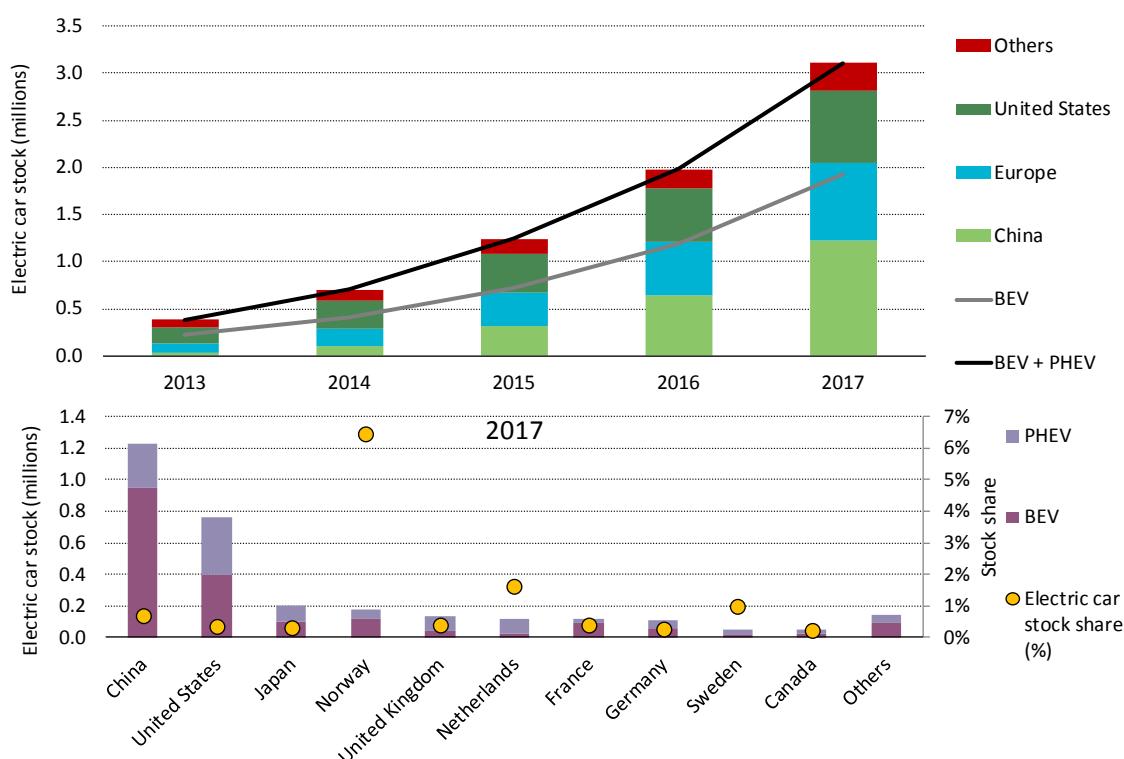
Cars and light commercial vehicles

Stock

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The global stock of electric passenger cars reached 3.1 million in 2017 (Figure 2.1) an increase of 57% from the previous year.¹ This is similar to the growth rate of 60% 2015 and 2016. Battery electric vehicles (BEVs) account for two-thirds of the world's electric car fleet (see Box 2.1 for update on Fuel-cell electric vehicle stock).

Figure 2.1 • Passenger electric car stock in major regions and the top-ten EVI countries



Note: BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle. Stock shares are calculated based on country submissions and estimates of the rolling vehicle stocks developed for the IEA Mobility Model. The vehicle stocks are estimated based on new vehicle registration data, lifetime range of 13–18 years, and vehicle scrappage using a survival curve that declines linearly in the last five years of the active vehicle life. Lifetimes at the low end of the range are used for countries with higher income levels (and vice versa).

Source: IEA analysis based on country submissions, complemented ACEA (2018), EAFO (2018a).

Key point: There were more than 3 million electric passenger cars on the road worldwide in 2017, 40% of which were in People's Republic of China ("China").

Around 40% of the global electric car fleet is in China, where the number of electric cars on the road surpassed 1 million in 2017, while the European Union and the United States each accounted for about a quarter of the global total. By far, Norway has the world's highest share at 6.4% of

¹ In this report, an electric car refers to either a battery electric vehicle (BEV) or a plug-in hybrid electric vehicle (PHEV) in the passenger light-duty vehicle (PLDV) segment. It does not include hybrid electric vehicles (HEVs) without a plug.

electric cars in its vehicle stock. While the number of electric cars is notably on the rise, only three of the EVI member countries have a stock share of 1% or higher: Norway (6.4%), Netherlands (1.6%) and Sweden (1.0%).

Box 2.1 • Fuel-cell electric vehicle stock status

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Fuel-cell electric vehicles (FCEVs) are another type of electric vehicle. Their key difference from BEVs and PHEVs is that FCEVs use hydrogen as a fuel instead of electricity.² In 2017, the global FCEV car stock surpassed 7 200 units- significantly less than BEVs and PHEVs (Advanced Fuel Cells TCP, 2018):

The United States, with more than 3 500 FCEV cars (in particular in California), accounted for almost half of the global FCEV fleet.

Japan has the second-largest FCEV stock, with 2 300 units and the highest ratio of FCEV car stock per electric car stock (1.1%).

By the end of 2017, almost 1 200 FCEVs circulated on European roads, primarily in Germany and France.

In addition to the 3.1 million passenger electric cars, there were nearly 250 000 electric light commercial vehicles (LCVs) on the road in 2017. The largest electric LCV fleet is in China (170 000 vehicles)³, followed by France (33 000 vehicles) and Germany (11 000 vehicles). Electric LCVs are often part of a company or government fleet (Box 2.2). The majority of electric LCVs registered to date are BEVs (99%).

Box 2.2 • Electrification of light commercial vehicles: The case of Deutsche Post – DHL and StreetScooter

Deutsche Post – DHL Group (DPDHL), a major logistics company, is at the forefront of private companies in terms of electrification of LCVs. The company aims to reduce emissions of its logistics operations to net zero by 2050 and currently operates the largest electric vehicle fleet in Germany (16 000 electric vans, bicycles and tricycles). It has also undertaken in-house development and manufacturing of its own electric vans, tricycles and bicycles as part of this vision. Since 2011, the DPDHL subsidiary StreetScooter has produced and is operating 5 500 electric vans in two models (WORK and WORK L) and 1 300 electric bicycles and tricycles (Liedtke, 2018). This venture is so successful that the company is now selling its electric vehicles to third-parties (mainly municipalities and other businesses) (StreetScooter, 2018).

Sales and market shares

In 2017, global sales of electric cars crossed the threshold of 1 million units (1.1 million). In 2016 the rate of sales growth slowed compared with 2015, but sales picked up in 2017, registering a year-on-year increase of 54% (compared with 38% in 2016).

² This report focuses on BEVs and PHEVs and excludes FCEVs unless otherwise stated.

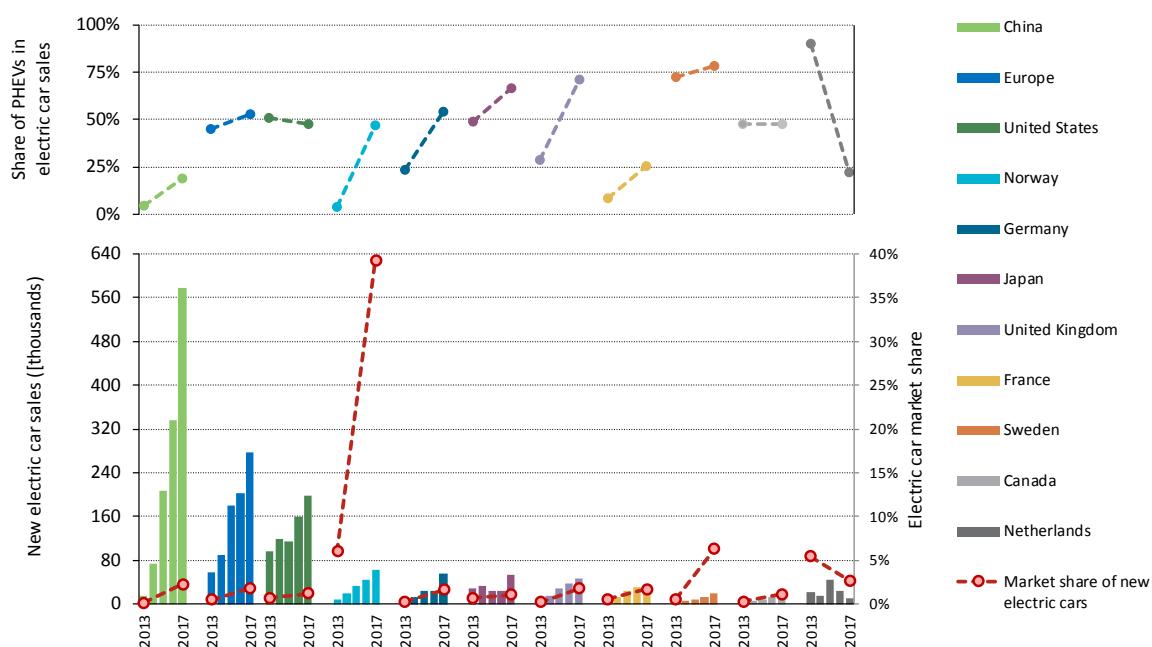
³ LCVs in China included in this number are characterised as “special vehicles”, and include non-passenger transport vehicles such as street-cleaning vehicles, garbage trucks and other light-duty delivery trucks.

China has the world's largest electric car market and nearly 580 000 electric cars were sold there in 2017, up 72% from the year before (Figure 2.2). China accounts for half of the global electric car market.⁴

Norway is the absolute leader in terms of market share, with 39% of new car sales being electric, a value that is six-times higher than Sweden, which has the third-highest market share globally (6%), after Iceland (12%, not included in Figure 2.2) (IEA, 2018a). The strongest sales growth in 2017 was in Germany and Japan, where sales more than doubled from 2016 sales levels.

Two-thirds of electric car sales in 2017 were BEVs, though the share of PHEVs in electric car sales has increased in most EVI countries in recent years (Figure 2.2).⁵ Markets in China, France and the Netherlands showed the strongest orientation towards BEVs in 2017, while PHEV shares were highest in Japan, Sweden and the United Kingdom.

Figure 2.2 • Electric car sales and market share in the top-ten EVI countries and Europe, 2013-17



Note: The countries in Figure 2.2 represent the ten leading EVI countries. This ranking closely resembles the ten leading countries worldwide in terms of sales - the only exception is Korea (not an EVI member), which is in the top-ten countries with 14 780 electric car sales in 2017.

Source: IEA analysis based on country submissions, complemented by ACEA (2018) and EAFO (2018a).

Key point: China has the highest sales volume of electric cars globally, followed by the United States. Norway is the world leader in market share terms.

Even though the Netherlands has the world's second-highest stock share of electric cars, it is the only EVI member country where the annual sales volume and market share declined from 2013 to 2017. This reflects a change in the Netherland's taxation system related to the private use of company cars, which ended a tax incentive for PHEVs in early 2017 while retaining a tax advantage

⁴ China accounts for about one-third of the worldwide car market when including internal combustion engine vehicles.

⁵ In *Nordic EV Outlook 2018* a similar trend was observed in the Nordic electric car market, and it was found that this trend may be linked to incentive structures favouring PHEVs and the introduction of a wider variety of PHEV models especially in recent years (IEA, 2018a).

for BEVs.⁶ Electric car sales in the Netherlands were largely PHEVs before 2016, but PHEV sales nearly came to a halt in 2017 while BEV sales continue to increase.

Market drivers

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The uptake of electric vehicles is still largely driven by the policy environment. The ten leading countries in electric vehicle adoption all have a range of policies in place to promote the uptake of electric cars. Effective policy measures have proved instrumental in making electric vehicles more appealing to customers (including private individuals and businesses), reducing risks for investors and encouraging manufacturers to scale up production (IEA, 2017a; IEA, 2018a). Key examples of instruments employed by local and national governments to support EV deployment include public procurement programmes (Box 2.3), financial incentives to facilitate the acquisition of EVs and cut their usage cost (e.g. by offering free parking), and a variety of regulatory measures at different administrative levels, such as fuel-economy standards and restrictions on the circulation of vehicles based on tailpipe emissions performance.

In Norway, survey results show that financial incentives such as value-added tax (VAT) and vehicle registration tax exemptions, free access to toll roads and circulation tax rebates were ranked, in that order, by electric car owners as the most influential factors for their purchase decision (IEA, 2018a). In the Netherlands, changes of the financial advantages provided for a PHEV resulted in a significant decline in the market share of PHEVs. In Denmark, changes to the vehicle registration tax for BEVs in 2016 led to a reversal of the cost competitiveness of a number of electric car models, leading to a significant drop in electric car sales in 2016 (IEA, 2018a). These cases indicate that financial incentives, and particularly those that reduce the upfront purchase price, are the main policy mechanisms driving today's market uptake of electric cars.

Box 2.3 • Use of public procurement programmes to stimulate the initial roll-out of EVs

Public procurement can play a significant role in increasing the visibility of electric vehicles in the public space, fostering the scale-up of vehicle production and building the charging infrastructure, lowering costs and stimulating the emergence of related expertise and businesses. Recognising the benefits of public procurement as an initiator of the electric mobility transition and its potential to contribute to air quality and climate goals, eight major countries signed and launched the Government Fleet Declaration at the Marrakech COP22 in 2016 (CEM-EVI, 2016).⁷

Key commitments outlined in this declaration in France include minimum thresholds of 50% low-emission vehicles for fleet renewals at the national level and 20% for local authorities, both established in 2015, as well as a target of full electrification of new buses by 2025. Canada recently announced that 75% of its new light-duty administrative fleet vehicles will be HEVs, PHEVs or BEVs from 2019, and that government fleet procurements will move to 80% zero-emission vehicles by 2030. In the United States, the federal government put forward in 2015 a purchase share target for electric passenger vehicles of 20% by 2020 and 50% by 2025. In India, Energy Efficiency Services Limited (a joint venture set up under the Ministry of Power) intends to build on bulk procurement and demand aggregation to procure and deploy electric vehicles to transition the national fleet of government vehicles (about 500 000 cars) to EVs.

⁶ This policy change is in line with the Netherland's strategy to phase out the sales of PHEVs and promote sales of BEVs in order to facilitate a move to zero-emission transport that is needed to reach the national GHG reduction ambitions and its climate pledges in the Paris Agreement (Munnix, 2018). The larger market shares of PHEVs in earlier years were instrumental to kick-start the transition to electric cars in the Netherlands and have driven the development of its EVSE network.

⁷ Canada, China, France, Japan, Norway, Sweden, United Kingdom and United States.

PHEV and BEV shares are determined by technical characteristics, cost aspects, and, to a large extent, can be influenced by the policy environment. Recent IEA analysis shows that the availability of BEV models is greater in the small and mid-size car segments, while PHEV models are found primarily among mid- to large-size cars.⁸ The same analysis indicates that the EV technology option with the lowest upfront purchase price (which can be influenced by public policies) tends to be the one gaining the highest share of sales (IEA, 2018a).

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The need to ensure that financial incentives remain manageable from a state budget perspective, combined with prospects for cost reductions in key electric car components (namely batteries), suggests that the main policy lever will need to be structured as self-sustaining financial mechanisms (such as differentiated taxation embedding a bonus/malus or “feebate” scheme, as in the case of several European countries) or gradually shift to standards, regulations and mandates. Performance-based standards and regulations enable governments to give a strong direction to the vehicle market and can be technology neutral. Mandates and incentives complement these instruments, incentivising specific zero-emission technologies. All of these policy tools allow public authorities to set targets in line with their policy goals to diversify the energy mix used in transport, and to reduce carbon dioxide (CO₂) emissions and air pollution.

This shift away from financial support towards standards, regulations and mandates can already be observed when looking at some of the key policy updates announced in the last year, such as in China and the European Union (outlined in the next section).

Key policy updates

Major developments in China, the European Union, India and the United States

In 2017, China, the European Union and India, which together account for roughly 60% of the global LDV market, proposed or implemented significant policy changes that are likely to accelerate the phase-in of electric cars and shape their deployment on a global scale. On the other hand, recent announcements on the roll-back of federal regulations on the fuel economy of cars in the United States are expected to have a negative impact on the uptake of electric cars.

China

In September 2017, China’s government issued a new energy vehicle (NEV) credit mandate that takes effect in 2018 (MIIT, 2017). The mandate sets a minimum requirement for the car industry regarding the production of new energy vehicles (PHEVs, BEVs and FCEVs), with some flexibility offered through a credit trading mechanism. Annual mandatory minimum requirements on the number of NEV credits that need to be earned are set for car manufacturers. Credits can be earned either through producing or importing new energy cars or through the purchase of NEV credits from other manufacturers who have excess credits.⁹

NEV credits can only be earned if the vehicle meets minimum range requirements, and depends on the vehicle’s range and energy efficiency level (or rated power of fuel-cell systems in the case of FCEVs). The number of credits allocated is also capped at a maximum for each vehicle type (Table 2.1).

⁸ The concentration of BEVs in the small car segments reflects their general use for short distance and commuter trips, and the additional cost for large battery capacity needed for larger electric cars which may be used more for longer distance trips. The reason why PHEVs models are not found in the small car segment is likely due to the increased complexity and associated cost in developing dual powertrains for small cars, when their relatively low fuel economy and typical range allow for reasonable battery sizes and thus a single electric powertrain (IEA, 2017a).

⁹ The rule only applies to manufacturers with an annual production or import volume of at least 30 000 cars.

The target of the NEV credit mandate is 10% of the passenger car market in 2019 and 12% in 2020. These shares are not to be confused with actual sales shares, since electric cars can get a rating of more than one credit point.¹⁰ The total number of electric cars that are required to be produced and imported under the mandate is therefore affected by the mix of electric powertrains and related performance of the NEVs (this affects the average number of credits allocated to the NEVs produced and imported). For example, if the average credits allocated per NEV produced or imported in 2020 were to have a value of two, the mandate would require a combined production and import of approximately 1.7 million electric cars, or a 6% electric car market share; if the average number of credits allocated per vehicle is four, the total electric car production would be lower, at 0.9 million electric cars and a 3% electric car market share.¹¹

Table 2.1 • Minimum range requirements and credits per electric vehicle under China's NEV credit system

Vehicle type	BEV	PHEV	FCEV
Minimum electric range (km)	100	50	300
Range of NEV credits per vehicle	1-6	1-2	2-5

Note: The number of credits per vehicle for a BEV is calculated as: $(0.012 \times \text{electric range} + 0.8) \times \text{efficiency adjustment factor}$. For a PHEV, the calculation is: $2 \times \text{efficiency adjustment factor}$. For a FCEV: $0.16 \times \text{FCEV system rated power} \times \text{efficiency adjustment factor}$. The adjustment factor is 1 if the vehicle's energy consumption in kilowatt-hour per 100 kilometres (kWh/100 km) relative to its kerb mass in kilograms (kg) is within the reference value range. If it is higher or lower compared with the reference value range, the efficiency adjustment factor is either 0.5 or 1.2 respectively (1.2 only in the case of BEVs). The reference value range is 12-20 kWh/100 km for a BEV with a kerb mass of 800 kg. The maximum number of credits to be earned is capped for each vehicle type to the maximum presented in this table.

Source: ICCT (2018).

Key point: NEV credits are higher for zero-emission options and for vehicles with higher distance ranges.

Additionally, the national Electric Vehicle Subsidy Program grants subsidies for the purchase of electric cars. The level of subsidy allocated depends on three characteristics: the vehicle range in kilometres (km); energy efficiency in kilowatt-hour per 100 km (kWh/100 km); and battery pack energy density in Watt-hour per kilogramme (Wh/kg). In February 2018, the program was amended, lowering the subsidy level for PHEVs and low-range BEVs (< 300 km), and increasing the levels for long-range BEVs (>300 km). This means that those EV models that are subject to the largest cost increment with respect to ICE technologies receive larger subsidies (MIIT, 2018). In addition, the final subsidy received depends on the energy density and efficiency of the car's battery pack, with more credits for battery technologies with higher energy densities and vehicles with higher efficiency.¹² These changes are intended to push original equipment manufacturers (OEMs) to invest in manufacturing electric cars with ranges that are closer to those of ICE cars (the

¹⁰ Hence, if several electric vehicles with NEV credit ratings larger than one enter the market, the actual percentage of electric vehicles coming into the fleet can be lower than the percentages indicated by the NEV credit mandates.

¹¹ This estimate is based on a case where 26 million passenger cars would be sold in China in 2020.

¹² Only cars with a battery pack energy density of 120 Wh/kg or higher can receive a full BEV subsidy while cars with higher energy densities receive incrementally higher subsidies (capped at 20% increase maximum for energy densities of 160 Wh/kg and higher). Battery packs below 120 Wh/kg receive incrementally lower subsidies and if the battery is less than 105 Wh/kg, the car receives no subsidy. Similarly, a deviation in performance of energy efficiency (measured in kWh/100 km) compared with the reference level results an incrementally higher or lower subsidy.

most popular BEV cars in 2017 were low-range models) and the focus on battery performance drives car makers towards battery chemistries with higher energy densities. The changes in the Chinese Electric Vehicle Subsidy Program enter into effect in June 2018, following a transition period in which electric cars are eligible for 70% of the previous subsidy scheme.

In September 2017, China also reportedly considered a national ban on the production and sales of ICE cars running on gasoline and diesel. The announcement did not specify details on the timeline of such a ban (Reuters, 2017a; Zhenhua, 2017).

European Union

In November 2017, the European Commission proposed an update of the CO₂ emissions standards for new passenger cars and LCVs for the period to 2030 as part of its Clean Mobility package (EC, 2018a).¹³ The proposed target is a 15% reduction in the CO₂ emissions per kilometre (km) for new vehicles in 2025 and a 30% reduction in 2030 (EC, 2018b). In order to provide for the transition from the current to the future framework, the proposal also includes the already established fleet wide target of 95 grammes of CO₂ per kilometre (gCO₂/km) for cars and 147 gCO₂/km for LCVs for 2020/2021.¹⁴ Both targets are based on the New European Driving Cycle (NEDC) but, as from 2021, will be measured according to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP), introduced in September 2017 to overcome some of the shortcomings of the NEDC.¹⁵ The proposed regulation includes a scheme to allocate specific emission targets to each manufacturer and a penalty of EUR 95 per gCO₂/km that exceeds the target for each newly registered vehicle, if manufacturers exceed their specific emission targets (EC, 2018b).

Given that the current emissions level for a hybrid vehicle (HEV) with performance characteristics similar to the average European car is close to 80 gCO₂/km (NEDC), the implication of this regulatory proposal is that low- and zero-emission vehicles will be necessary in the 2030 framework to meet the overall target.¹⁶ The proposed regulation outlines a vision that includes production shares of low- and zero-emission vehicles that reach 15% in 2025 and 30% or more in 2030.¹⁷ This is also reflected in the inclusion of an incentive scheme to stimulate the uptake of low- and zero-emission vehicles. Manufacturers achieving a share of low- and zero-emission vehicles, which is higher than the proposed benchmark level, will be rewarded in the form of a less strict overall CO₂ target (by up to 5%). This could allow manufacturers to have a relatively higher production and sales of vehicles with higher emissions per km, such as SUVs, which are often marketed at higher prices. Even if the proposed regulation comes with binding limits (and penalties) on the need to achieve overall reductions in gCO₂/km, its incentive component differs significantly from a mandate, given that not meeting the targeted shares of low- or zero-emission does not involve a penalty.

In its low-carbon economy roadmap, the European Commission indicates that it aims to reduce its GHG emissions by 80% in 2050 compared with 1990 levels. To achieve this, the roadmap suggests

¹³ Emission limits are set according to vehicle kerb weight.

¹⁴ If the CO₂ emissions per km were to be expressed in NEDC terms, it would imply that cars and vans need to reach 81 and 125 gCO₂/km respectively in 2025, and 67 and 103 gCO₂/km respectively in 2030.

¹⁵ Despite its name, the NEDC is a driving cycle that was last updated in 1997. It has been used to measure emission levels of car engines and fuel economy in passenger cars and some LCVs. It is now being replaced by the WLTC and test procedure, aiming to deliver fuel-economy values that better reflect estimates obtained in real-world driving conditions.

¹⁶ Low-emission vehicles are defined as those that have tailpipe emissions of less than 50 gCO₂ per km and are typically represented by PHEVs. Zero-emission vehicles have zero tailpipe emissions and typically include BEVs and FCEVs.

¹⁷ These thresholds would be exact shares if they were to be met only with zero-emission vehicles. They would need to be higher if they were also to include a fraction of low-emission cars or LCVs, given that low-emission and zero-emission vehicles are credited with different weighting factors to reach the thresholds.

that emissions from transport should be reduced by more than 60% below 1990 levels by 2050 (EC, 2018c). Respecting these long-term commitments would require increasing shares of low and zero-emission vehicles (ZEVs)¹⁸, and hence an incrementally stricter CO₂ emission standard after 2030.

India

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Public authorities and other Indian stakeholders made a number of EV-related policy announcements over the past year. They demonstrate strong commitment, concrete action and significant ambition to transition the country's vehicle market to EVs.

- In April 2017, the government of India outlined a vision aiming to have an all-electric vehicle fleet by 2030 (Government of India, 2017a). This followed the establishment in 2012 of the National Electric Mobility Mission Plan (NEMMP) 2020, which aimed to promote hybrid and electric vehicles (Government of India, 2012). It also followed the development of the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME). FAME is an incentive scheme that reduces the upfront purchase price of hybrid and electric vehicles launched in 2015 under the NEMMP 2020 (Gazette of India, 2015) to stimulate early adoption and market creation of hybrid and electric vehicles (Government of India, 2015).¹⁹
- In May 2017, the National Institution for Transforming India (NITI Aayog) outlined a vision for the transformation of mobility in the country, proposing a set of actionable and specific solutions to accelerate India's leadership in advanced mobility (NITI Aayog and Rocky Mountain Institute, 2017).
- In September 2017, Tata Motors won the first public procurement EV tender in India by Energy Efficiency Services Limited (EESL) (Government of India, 2017b).²⁰
- In December 2017, the Indian automotive industry released a white paper proposing a pathway towards all new vehicle sales being all electric by 2047 and 100% of intra-city public transport as all electric by 2030 (SIAM, 2017).
- In February 2018, the Ministry of Heavy Industries and Public Enterprises stated that it had not set any target for electric cars for 2030 and referred to the FAME scheme as the instrument in place to enable wider adoption of EVs (Government of India, 2018a).
- Shortly after this, the Ministry of Power launched a National E-Mobility Programme to be implemented by EESL (Government of India, 2018b). EESL is expected to keep focusing on public procurement to facilitate demand creation for EVs in India. It launched an EV procurement tender right in March 2018 (EESL, 2018). Launching the National E-Mobility Programme, the Ministry of Power also announced that it is focusing on creating the charging infrastructure and a policy framework so that by 2030 more than 30% of vehicles in India are electric.

¹⁸ ZEVs and refer here to vehicles without tailpipe emissions. These include BEVs and FCEVs. Low-emission vehicles refer to vehicles that are zero-emission enabled but may lead to tailpipe emission under specific operational modes or conditions that are significantly lower than ICE vehicles or hybrid vehicles with similar performances. This category includes in particular PHEVs.

¹⁹ However, only one-fifth of the budget for fiscal year (FY) 2016 and FY 2017 has been allocated. India sold only 22 000 BEVs in 2016, well short of the sales growth needed to meet the 6-7 million hybrid and electric vehicle sales target for 2020 in the NEMMP 2020 (NITI Aayog and Rocky Mountain Institute, 2017).

²⁰ In December 2017, the government introduced a subsidy scheme to roll out electric public transport services (buses, taxis, and three-wheelers) in 11 major cities (Government of India, 2017c). The incentives cover up to 60% of the purchase cost of electric buses, capped at INR 10 million (Indian rupee) (USD 150 000 [United States dollars]) for buses produced locally (Government of India, 2017d).

Despite the dynamic action shown by the initiatives mentioned, the lack of consistency among visions and measures communicated at different times and by different actors suggests that India needs to ensure greater co-ordination in defining its electric vehicle policy as it moves forward.

United States

In April 2018, the United States Environmental Protection Agency (EPA) announced a change in the GHG emissions standards for new light-duty vehicles sold in the United States between 2022 and 2025 (US Government Public Office, 2018). This decision results from a new determination following a mid-term evaluation of the standards, which was a regulatory requirement of the 2012 rule establishing the GHG emission standards for the 2017-25 period. In the mid-term review, the EPA examined a range of factors, such as the penetration of fuel efficient technologies, fuel price developments, vehicle electrification and consumer acceptance of efficient technologies. The EPA determined that the standards set during the previous administration were too stringent in light of the record of these factors and must be revised as appropriate (US Government Public Office, 2018). The details of the standards resulting from this decision are yet to be defined.

Based on the 2012 rule making, the EPA had estimated that about 5% of the domestic new light-duty vehicle sales in 2025 would need to be plug-in electric to comply with the standards (EPA, 2016; ICCT, 2017a). This new decision will likely reduce the uptake of electric cars at a national level.

The state of California, which was granted a waiver by the EPA to implement its GHG emission standards in 2009 (Federal register, 2009), has vowed to stick with the stricter rules even if federal standards are rolled back (Davenport and Tabuchi, 2018). This represents a risk for stakeholders, as it could end up creating one set of rules for cars sold in California and the states that follow its lead²¹ and weaker rules for the rest of the states, effectively creating two markets.

California's zero-emissions vehicle (ZEV) programme²² is by itself a policy that would keep granting support for the roll-out of electric vehicles in the United States. The programme assigns each OEM "ZEV credits", similar to the Chinese NEV credit mandate, so that OEMs are required to meet a set percentage of ZEV sales either through direct ZEV sales or through the purchase of tradable credits. In 2016 California's governor issued an executive order to call for 1.5 million ZEVs on the road by 2025 (State of California, 2016a). In January 2018, this ambition was increased with a new executive order calling for a target of 5 million ZEVs in California by 2030, complemented by a proposed new initiative to continue the state's clean vehicle rebates system and spur more infrastructure investments (State of California, 2018).

Two- and three-wheelers

Currently there are nearly 900 million two-wheelers in circulation in ASEAN (Association of Southeast Asia Nations), China and India, a number that is of similar magnitude to the total

²¹ Ten states have adopted California's ZEV mandate: California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont. More aligned to California's Clean Cars Standards in the 2011-16 period (Maryland.gov, 2014).

²² Note that in the ZEV programme of California, ZEV refers to vehicles that produce zero exhaust emissions under any possible operational modes or conditions. Nevertheless, the standard also allows for Transitional Zero Emission Vehicles – including PHEVs meeting strict evaporative and tailpipe emission standards and having extended warranties on their emission-control components – to generate ZEV credits (CARB, 2018).

volume of passenger light-duty vehicle (PLDVs) circulating globally. Two-wheelers account for 80% of private passenger vehicles in these three regions, taken together.

Historically, two-wheelers have been powered by ICEs and fuelled by gasoline. However, recent years have seen a very significant surge in the number of electric two-wheelers. China accounts for nearly all of the electric two-wheelers (see Box 2.4), far ahead of others: in 2017, the number of electric two-wheelers on the road in the China was around 250 million units (China News, 2017; IEA, 2018b), sustained by annual sales that are around 30 million.²³ This stock is almost 100-times larger than the number of electric LDVs in the world today. China also has an estimated 50 million electric three-wheelers (China News, 2017).

Box 2.4 • Why are electric two-wheelers widespread in China and not in other parts of Asia?

The electrification of two-wheelers in China has been spurred by two main central government policies. First, in 1999, the government designated certain electric two-wheelers as bicycles which enabled them to travel in bicycle lanes and exempted them from the need for registration and from requiring a driver's licence.²⁴ Second, many cities severely restricted the ownership and use of gasoline motorcycles in their urban cores (Cherry, 2010).

Chinese electric two-wheelers are characterised by low costs, below those of an ICE scooter, primarily because of relatively simple manufacturing processes and limited battery requirements. The latter are possible because of the limitations on maximum speed (typically below 20 km/hour) and power rating, as well as the opportunity to target the battery size to the distance required for daily commutes (typically less than 40 km).

In other regions in Asia, a number of factors have hindered the commercial success of electric two- and three-wheelers so far. These include:

- A lack of regulations that limit the use of ICE in two- and three-wheelers.
- A lack of a dedicated infrastructure, for example the designated lanes that are commonplace in China.
- The power requirements since the top speed and carrying capacity of two-wheelers are higher on average in other Asian regions than in China.²⁵
- The average daily distance travelled by two-wheelers is higher in other Asian countries, requiring larger batteries.

Low-speed electric vehicles

Low-speed electric vehicles (LSEVs)²⁶ have emerged in China as a competitor to both electric two- and three-wheelers and electric cars. The lower speeds allow them to be subject to less

²³ This is estimated considering two-wheeler sales over time and scrappage ages in the range of eight to ten years.

²⁴ The access to bike lanes in China provided an advantage for electric bike (e-bike) users thanks to reduced congestion. This contributed to their success, but has led to safety concerns as electric two-wheelers made motorised travel available to a growing share of the population. The increased use of bike lanes by electric two-wheelers led some cities to ban e-bikes in recent years. Future regulatory regimes for e-bikes will need to be considered to help further development of electric two-wheelers, including licenses, training, insurance and security features.

²⁵ In India, the majority of two-wheelers sold (84%) have an engine capacity between 100 and 125 cm³ (SIAM, 2017). These vehicles typically have a maximum speed above 50 km/h and maximum power of 6-7 kilowatts. On the other hand, the vast majority (98%) of electric two-wheelers currently on the road in India (around 210 000) can reach a top speed of 25 km/h with a power rating not exceeding 250 Watts (SIAM, 2017).

strict rules and regulations (IEA, 2017a). Because a limited number of LSEVs are officially registered, it is difficult to know exactly how many LSEVs are on the road in China, but estimates indicate about 4 million units.

The LSEV sector has been in the grey zone of regulation for a few years, but recently more regions in China have tightened the restrictions by limiting driving to certain lower speed roads or prohibiting LSEVs. This included occasional road-side checks in the Shandong province, where the LSEV uptake first started and which accounts for about 60% of China's LSEV sales (First Electric Vehicle Network, 2018a). Similar regulations and enforcement regimes have ramped up in neighbouring Henan province (Sohu, 2018a), that witnessed a growing diffusion of this type of vehicles (Gao et al., 2017). This, combined with the discussion on the development of a new national standard for LSEVs (Xinhua, 2017), likely dampened 2017 LSEV production statistics, which remained, in Shandong province, at the same level as reported for 2016 (First Electric Vehicle Network, 2018a; First Electric Vehicle Network, 2018b).

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Medium- and heavy-duty road electric vehicles

Spill overs from the rapid deployment of light-duty electric vehicles are poised to open new opportunities for electrification of the medium- and heavy-duty road modes. Public bus fleets and other municipal services with regular routes and schedules (such as refuse and street-cleaning vehicles) are attractive early targets. So far, the use of electric trucks has proceeded most notably among large fleets of commercial and service vans that operate in urban environments. Today's use of medium- and heavy freight electric trucks with duty cycles such as regional and long-haul operations are at pilot or demonstration scales; they have been conventionally viewed as unlikely candidates for electrification. The following sections highlight and contrast recent developments for city buses and trucks.

Rapid market penetration: The case of city buses

Data submitted from EVI member countries and collected from published sources show that China accounts for the vast majority of global sales of battery electric buses and minibuses. Despite a slight decline in electric bus sales in 2017, estimated at slightly above 100 000 units (85% of which are BEVs) (Sun, 2018), high sales volumes of electric buses outlined in last year's edition of the *Global EV Outlook* (IEA, 2017a) are confirmed in this year's data update.

By the end of 2017, the fleet of BEV and PHEV buses in China reached nearly 370 000 units (Sun, 2018). This estimate exceeds half a million vehicles if buses are combined with other commercial electric vehicles (CAAM, 2018). Cumulative sales available for other countries suggest that 2 100 additional electric buses are currently in circulation in Europe, Japan and the United States (EAFO, 2018a; EB Start, 2018). In 2017, 250 FCEV buses were operating worldwide (Advanced Fuel Cells TCP, 2018).

Drivers of electric bus uptake in China

Electric bus sales in China have been promoted primarily by subsidies that started in 2009 with application to BEV, PHEV and FCEV buses,²⁷ and were progressively reduced over time. National

²⁶ LSEVs are small vehicles with four wheels and a maximum speed of around 40-70 km/h with relatively short electric driving ranges.

²⁷ Prior to 2013, subsidies also applied to HEVs.

support schemes have been targeted to a selection of "pilot cities". Central government outlays to subsidise the purchase of commercial electric vehicles in 2015 totalled upwards of RMB 46 billion, about USD 8.4 billion (Wang et al., 2017). Subsidies were provided by the central government directly to manufacturers and complemented by regional and municipal subsidies, which in many instances matched central government subsidies (Wang et al., 2017).²⁸ China's government has provided additional subsidies to pilot cities to develop charging infrastructure since 2013. In 2017, the subsidy policy was updated to prevent fraud; the overall subsidy volumes were reduced and they were converted into operational subsidies to target the support scheme to transit operators of electric buses. These changes were implemented in tandem with cuts in subsidies available for transit operators relying on conventional fuels (diesel) (Sun, 2018).²⁹

In cities such as Shenzhen, Beijing and Tianjin, subsidies bring the purchase price of battery electric buses within the range of conventional diesel buses, thus substantially reducing what is generally seen as the main barrier to electric bus adoption. By the end of 2017, the city of Shenzhen completely transformed its urban bus fleet of 16 359 buses to all-electric models and it is now targeting its taxi fleet (Dixon, 2018).³⁰ Many Chinese cities, including those mentioned above, have adopted additional targets for the electrification of public and logistic fleets, mail coaches, and sanitation trucks (Zhang and Bai, 2017).

In addition to Shenzhen's all-electric bus fleet, local subsidies and sales targets in Beijing and Tianjin, as well as provincial targets in Hebei and regional targets in the Jing-Jin-Ji region, have promoted electric bus sales since about 2013. The precise terms of incentive policies are often tweaked according to changes in local goals. To take the example of Beijing, subsidy levels for battery electric buses were initially pegged to bus lengths, but in 2016 these were revamped to be calculated on the basis of unit-load energy consumption in Watt-hours per kilometre-kilogram (Wh/km kg).

Cities in China benefit from the fact that, in many cases, they are quite new, enabling city planners to integrate charging infrastructure and routing for electric public bus fleets at the design stage.

Electric bus uptake in cities

Outside of China, cities have not yet realised the volumes of electric bus sales seen in cities such as Shenzhen, Beijing and Tianjin. Nonetheless, some North American and European cities, as well as global coalitions such as the member cities of the C40 network, have also begun to deploy electric transit buses and/or have pledged to purchase only electric drive vehicles for public fleet replacements and upgrades in the near term.

Nordic cities, such as Oslo, Trondheim and Gothenburg, are operating electric buses; Gothenburg's launch of three Volvo electric buses in June 2015 was a forerunner in the region (Kane, 2016). Oslo aims to transition to a fleet running entirely on renewables in the 2025-30 timeframe (Ruter, 2018). Extending the 2015 announcement of the C40 Clean Bus Declaration Act (C40, 2015), 12 mayors

²⁸ These subsidies targeted air quality improvements and local industry development.

²⁹ The national government has implemented measures to more directly regulate and monitor OEMs to prevent future fraud (Ministry of Finance, 2016).

³⁰ Shenzhen awarded its nominally competitive tender for battery electric transit buses to the local manufacturer BYD, and until recently imposed a fee of RMB 50 million (USD 8 million) on all other EV makers that sell their output in the city (Wang et al., 2017). This is an example of regional protectionism, common in certain industrial regions of China, resulting in benefits for targeted commercial EV manufacturers. While this protectionism serves the interests of promoting regional and local industries, the national policy approved in February 2018 to reform EV subsidies includes a prohibition for local authorities to discriminate against non-local vehicle manufacturers (MIIT, 2018), prioritising the need to co-ordinate policies to align with national industrial policy goals (e.g. by targeting subsidies to vehicles with specific battery chemistry or performance attributes such as range).

representing cities on five continents, pledged in 2017 that from 2025, only electric buses would be added to their municipal fleets (C40, 2017).³¹ The mayors further committed to establishing a “major area” within each of their cities as a low-emissions zone. Progress is to be monitored and status reports are to be publicly shared every two years. Other projects, such as the Soot-free Bus Project of the Climate and Clean Air Coalition (CCAC), target the adoption of soot-free, zero-emission (and primarily electric) buses in twenty major world cities (CCAC, 2018).

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At the European Union level, a growing number of cities are building pilot projects, most of which were started in the past five years. The ZeEUS project (Zero Emission Urban Bus System) coordinates among a network of 40 partners (including public transit authorities and operators, vehicle manufacturers, energy providers, academic and research centres, engineering firms and associations). The ZeEUS project has set up ten demonstration sites across ten European cities to monitor and improve upon technical, economic and operational performance of electric city buses (ZeEUS, 2018). The JIVE and JIVE 2 demonstration projects, launched in January 2017, aim to deploy fleets of hydrogen fuel-cell urban buses initially across nine European cities or regions and then across 14 additional cities (JIVE, 2017).

A handful of European cities have already expanded operations beyond the demonstration to commercial scales, regularly operating a large fleet of electric buses. Ambitions also extend to the national level: the Netherlands aim to transition to all emissions-free bus sales by 2025 and an all-electric fleet by 2030 (Living Lab, 2018; IPO, 2017). Sweden has maintained a support policy for electric buses since 2016 (HEV TCP, 2018).

Electric bus technologies

There are two principal parameters that determine the design of an electric bus: the body materials and the recharging strategy.

Typical conventional bus bodies are built using a steel frame which ensures good structural properties at low cost. Some electric bus manufacturers are developing alternative structural designs based on aluminium or carbon fibre. These lighter materials ensure a lower kerb weight, which reduces the energy consumption of the vehicle. For example, Linkker and Ebusco electric buses both have an aluminium frame, their kerb weight is between 10.5 and 12 tonnes and their propulsion energy consumption is around 90 kilowatt-hours per 100 kilometres (kWh/100 km) (VTT, 2015). By comparison, other electric bus models based on steel frames have kerb weights around 14 t and propulsion energy consumption around 110-130 kWh/100 km.

Electric buses can be designed to operate for a full day of operations on a single battery charge and to recharge at night at a depot, when electricity prices are typically lower. This strategy is referred to as overnight charging (Lajunen, 2018). This design requires batteries in excess of 250 kWh in order to satisfy the operational (range) requirements while charging can be done with relatively slow chargers in the depot. The alternative charging strategy, known as opportunity charging, relies on fast chargers at the terminals or along a bus route. The fast chargers are often accessed through a pantograph,³² which may either extend up from the bus or down from catenary lies, and charge times can vary between five and ten minutes, depending on the scheduling needs. The benefits of this strategy are that the electric bus requires a much smaller battery (around 80 kWh) which results in a lower purchase price, lower fuel consumption thanks to less weight and more space for

³¹ Signatories included the mayors of Auckland, Barcelona, Cape Town, Copenhagen, London, Los Angeles, Mexico City, Milan, Paris, Quito, Seattle and Vancouver (C40, 2017).

³² Other technologies for fast charging exist, including inductive designs and buses equipped with supercapacitors in addition to or instead of batteries.

passengers. The fast chargers require a high-power capacity (200-400 kilowatts [kW]) and have higher equipment, installation and maintenance costs compared to depot chargers (for more detail on charging infrastructure costs and considerations, see Chapter 3). Moreover, battery designs that accommodate very large charging loads use more expensive lithium-titanate anodes. These chemistries are used by Solaris and Proterra buses, which support opportunity charging.

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A specific challenge of electric buses compared to other powertrains is the impact of HVAC loads on energy consumption, particularly in cold climates. Auxiliary loads can range between 6-14 kW, which translates to energy consumption of 20-40 kWh/100 km (Lajunen and Tammi, 2016). In extremely cold climates, electric buses are at times equipped with a diesel-powered heater (ELIPTIC, 2017).

Electric bus manufacturers

The majority of electric buses sold to date have been made by Chinese manufacturers for the domestic market. Although a number of OEMs provide electric buses, two major Chinese bus manufacturers (BYD and Yutong) have also been active in the international electric bus market. Both companies produce urban electric buses in a variety of sizes, and each also makes one intercity electric bus model. The bestselling standard BYD 12 meter urban bus has a battery capacity of around 330 kWh which enables it to travel more than 250 km (BYD, 2018) and different configurations are available.

In Europe there are a variety of manufacturers making electric buses. These include both incumbent bus OEMs (such as Volvo, Solaris and VDL) that have begun to offer electric models as well as many new entrants focusing on electric buses. The diversity of bus makers translates to a wide variety of models available in the European market (ZeEUS, 2016). Some European OEMs (such as Ebusco and Linkker) use aluminium body components to reduce vehicle weight, extending their range or reducing battery requirements (ZeEUS, 2016; Linkker, 2018).

In the United States, the major player is Proterra, an OEM founded by a former Tesla employee that specialises exclusively in electric buses. Proterra manufactures bus body components using carbon fibre and can deliver buses with up to 440 kWh of battery capacity, which equates to 480 km of range (Proterra, 2018).

Trucks – on the road from demonstration to commercial scale

The use of electric trucks is currently limited to small demonstration fleets and targeted programmes developed by companies under corporate social responsibility activities. The early roll-out of electric trucks has been essentially developed in projects that were set up and led by logistics companies, requiring ad-hoc adaptations and reworking of conventional ICE trucks: until 2017, the majority of electric trucks in circulation were retrofits (Ayre, 2018). One iconic example is the testing exercise in beverage distribution being carried out by Heineken in the Netherlands (FRevue, 2018).

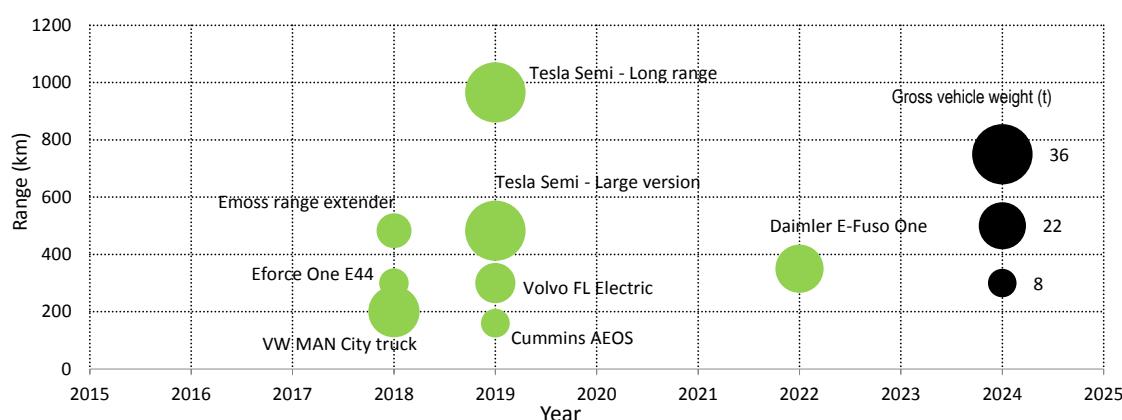
Most plug-in and battery electric models that have been introduced so far are medium freight trucks (with a gross vehicle weight [GVW] between 3.5 and 15 tonnes) that operate in urban and/or suburban contexts (e.g. municipal services and delivery fleets, both public and private). A smaller but growing number of electric heavy freight truck (HFTs, with a GVW of more than 15 tonnes) models have been developed for pilot projects. Figure 2.3 shows the range, load and (expected) introduction of all-battery electric, hybrid battery electric with fuel-cell range extenders, and fuel-cell HFT models that have been or are being developed for the commercial market, albeit mostly in limited volumes.

Starting in 2017, a number of major OEMs announced electric truck models, such as Tesla with the Semi model (Tesla, 2018a), and Daimler announcing series production from 2021 (Daimler, 2018a). This is complemented by a growing number of concept and prototype mid- and heavy-duty electric, hybrid electric and hybrid fuel-cell range extended models being designed that are currently being built and tested (ICCT, 2017b), and indicate that there is a growing interest and commitment in developing mass production of electric trucks.

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Demonstration and trial projects of plug-in and pure battery electric truck operations, as well as of dynamic charging or electric road systems concepts, also continue to gain momentum. The performance and economics of these vehicles and demonstrations show steady improvement. Most of the projects are running in California, Sweden, Germany and the Netherlands, supported by local or national governments, industry partners (including utilities, OEMs and fleet operators), and research and advocacy groups.

Figure 2.3 • Heavy-duty electric truck models announced for commercialization (GVW > 15 tonnes)



Note: The figure gives an overview of selected electric trucks which have recently been introduced to the market or will be available in the near term. This list is not exhaustive and focuses on freight vehicles with a long range, which excludes terminal and service vehicles for street-cleaning and garbage collection. The list includes a single electric truck with a hydrogen fuel-cell range extender (the EMOSS Range extender). The figure shows the maximum range and the largest available model, respectively. GVW is estimated where no information available.

Sources: Allison Transmission (2018); Ayre (2018); Baumann (2018); Daimler (2018a); Daimler (2018b); E Force One (2018); EMOSS (2018); MAN Truck Germany (2018); Rathmann (2018); Tesla (2018a); Volvo Group (2018).

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

EV deployment targets

A growing number of governments are setting objectives for EV deployment, providing increasingly clear signals to manufacturers and other industrial stakeholders, building confidence on the future policy framework and enabling the mobilisation of investment. Table 2.2 summarises deployment targets and objectives currently in place for the 2020-30 timeframe.

Additionally, ten countries, collectively representing over 60% of the global electric car stock, endorsed the EV30@30 Campaign in 2017, pledging to actively pursue the collective objective of 30% EV sales by 2030 (the target applies to all modes considered together, with the exception of two- and three-wheelers) (CEM-EVI, 2017).

Table 2.2 • Announced country targets and objectives for EV deployment, 2020-30

Country or region	EV 30@30 ¹	2020-30 EV target or objective	Source
Canada	✓	-	
China	✓	<ul style="list-style-type: none"> • 5 million EVs by 2020, including 4.6 million PLDVs, 0.2 million buses and 0.2 million trucks. • New energy vehicle (NEV)² mandate: 12% NEV credit sales of passenger cars by 2020.³ • NEV sales share: 7-10% by 2020, 15-20% by 2025 and 40-50% by 2030. 	EVI (2016a); MIIT (2017); Marklines (2017); State Council (2012)
European Union		<ul style="list-style-type: none"> • Post 2020 proposed CO₂ targets for cars and vans include benchmarks: 15% EV sales by 2025 and 30% by 2030 (exceeding these benchmarks allows for less stringent specific emissions targets to be met by OEMs). 	EC (2018b)
Finland	✓	<ul style="list-style-type: none"> • 250 000 EVs by 2030. 	MEAEFF (2017)
France	✓	<ul style="list-style-type: none"> • Objectives under revision. 	EVI (2018)
India	✓	<ul style="list-style-type: none"> • 30% electric car sales by 2030. • 100% BEV sales for urban buses by 2030. 	Government of India (2018c); SIAM (2017)
Ireland		<ul style="list-style-type: none"> • 500 000 EVs and 100% EV sales by 2030. 	DPER (2018)
Japan	✓	<ul style="list-style-type: none"> • 20-30% electric car sales by 2030. 	METI (2014)
Mexico	✓	-	
Netherlands	✓	<ul style="list-style-type: none"> • 10% electric car market share by 2020. • 100% EV sales in PLDVs by 2030. • 100% electric public bus sales by 2025 and 100% electric public bus stock by 2030. 	EVI (2016b); IPO (2016); Rijksoverheid (2017)
New Zealand		<ul style="list-style-type: none"> • 64 000 EVs by 2021. 	Ministry of Transport (2018)
Norway	✓	<ul style="list-style-type: none"> • 100% EV sales in PLDVs, LCVs and urban buses by 2025. • 75% EV sales in long-distance buses and 50% in trucks by 2030. 	National Transport Plan (2016)
Korea		<ul style="list-style-type: none"> • 200 000 EVs in PLDVs by 2020. 	MOTIE (2015)
Slovenia		<ul style="list-style-type: none"> • 100% electric car sales by 2030. 	Novak (2017)
Sweden	✓	-	
United Kingdom		<ul style="list-style-type: none"> • 396 000 to 431 000 electric cars by 2020. 	EC (2017a)

Country or region	EV 30@30 ¹	2020-30 EV target or objective	Source
United States (selected states)		<ul style="list-style-type: none"> • 3 300 000 EVs in eight states combined by 2025.⁴ • ZEV⁵ mandate in ten states⁶: 22% ZEV credit sales in passenger cars and light-duty trucks by 2025.⁷ • California: 1.5 million ZEVs and 15% of effective sales by 2025, and 5 million ZEVs by 2030. 	CARB (2016); State of California (2018; 2016a); ZEV PITF (2014)
Other European Union ⁸		<ul style="list-style-type: none"> • 450 000 to 760 000 electric cars by 2020. • 5.42 million to 6.27 million electric cars by 2030 	EC (2017b)

Notes to the table:

¹ The countries that joined the EV30@30 Campaign set a collective aspirational goal to reach a 30% sales share for EVs by 2030, which encompasses PLDVs, LCVs, buses and trucks (CEM-EVI, 2017).

² "New energy vehicles" include BEVs, PHEVs and FCEVs.

³ The 12% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible for multipliers between 2 and 4.

⁴ California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, Vermont.

⁵ ZEV = zero emission vehicle. In the case of California's programme, ZEV refers to vehicles that produce zero exhaust emissions under any possible operational modes or conditions. Nevertheless, the standard also allows for Transitional Zero Emission Vehicles— including PHEVs respecting tight evaporative and tailpipe emission controls – to generate ZEV credits.

⁶ Eight above-cited States plus Maine and New Jersey, who joined in 2016.

⁷ The 22% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible to receive credits between 0.5 and 3.

⁸ This entry summarises the EU country targets stemming from submission for the AFI Directive 2017 for countries that submitted a target and are not covered elsewhere in this table. These include: Austria, Belgium, Bulgaria, Czech Republic, Hungary, Italy, Latvia, Lithuania, Luxembourg, Poland, Portugal, Slovak Republic and Spain. These European Union countries are not EVI countries and have not released a modified target since their AFI Directive submission. Note that Germany submitted a 1 million electric car target by 2020 in the AFI Directive, however the chancellor announced that this target could not be met (Reuters, 2017b), and therefore this target was excluded from this table.

Key point: Through the first half of 2018, major EV markets and other countries have set EV deployment targets as well as objectives for the industry for the 2020-30 timeframe.

ICE vehicle bans and access restrictions

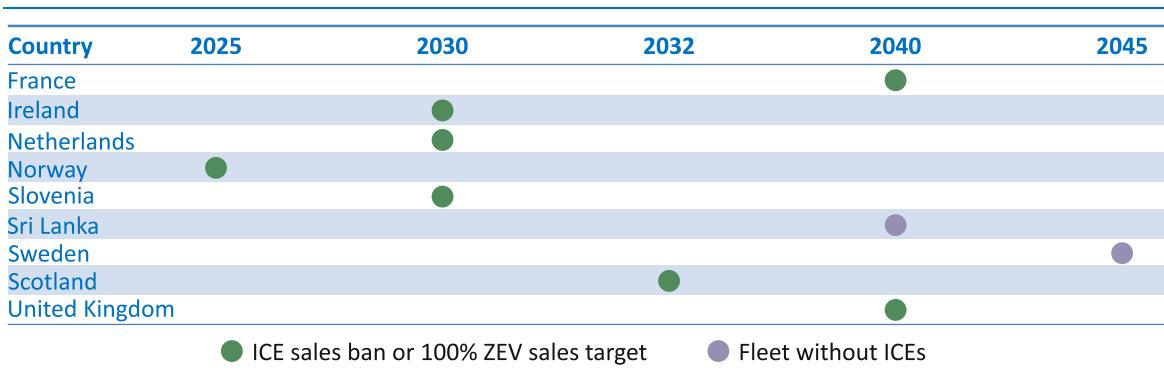
National and supra-national EV deployment targets have been complemented by announcements by several national governments pledging their intention to end sales or registrations of new internal combustion engine (ICE) vehicles by a given year. In addition, a number of local administrations have pledged to implement restrictions prohibiting access to certain areas for ICEs (in some cases only for diesel ICEs).³³ Table 2.3 and Table 2.4 provide an overview of these restrictions.

When looking at ICE bans, it is relevant to highlight that Germany's Federal Administrative Court granted cities the right to set an access restriction ban on based specific emission levels (NO₂) recently (Bundesverwaltungsgericht, 2018).³⁴ The German government dismissed the idea of a nationwide diesel ban (Reuters, 2018a), but Germany is reportedly considering the use of a nationwide labelling scheme based on the emission performance of vehicles, similar to the one adopted in France in July 2017 (CRIT'Air, 2017; Chambers, 2018). This allows cities to target vehicles taking into account their environmental performance.

³³ Access restrictions are specific to the case and apply to different portions of an area under the jurisdiction of the local administration (e.g. city centres particular zones and/or entire metropolitan areas).

³⁴ Following this, a number of German cities are facing legal challenges from consumer associations and environmental organisations demanding policy action (Deutsche Umwelthilfe, 2018).

Table 2.3 • Announced sales bans for ICE vehicles

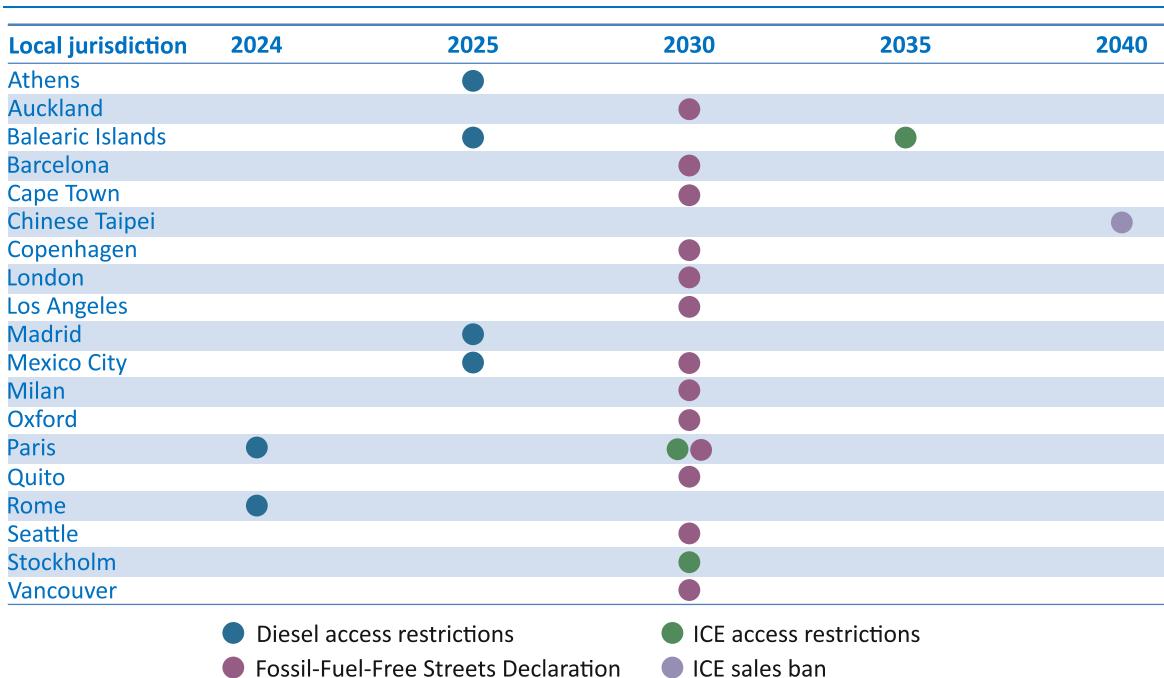


Notes: All these national ICE bans refer to announcements pledging to terminate sales or registration of new diesel and gasoline cars (excluding PHEVs). In the case of Sri Lanka, it is specified that the government is aiming to replace all vehicles with electric or hybrid models by 2040 (Phys.org, 2017). In addition to the bans listed in the table, China is reportedly considering a national ban on the production and sales of ICE cars (Reuters, 2017a; Zhenhua, 2017).

Sources: As indicated in table and complemented by information gathered by SLoCaT (2018); Ministère de la transition écologique et solidaire (2017) for France; Rijksoverheid (2017) for Netherlands; National Transport Plan (2016) for Norway; Novak (2017) for Slovenia; Phys.org (2017) for Sri Lanka; Government of Sweden (2017) for Sweden; ChargePlace Scotland (2017) for Scotland; Government of the United Kingdom (2017a) for United Kingdom; DPER (2018) for Ireland.

Key point: Several national governments pledged their intention to end sales or registrations of new internal combustion engine vehicles.

Table 2.4 • Announced access restriction mandates in local jurisdictions



Notes: Most cities apply ICE and diesel access restrictions only in certain zones (e.g. city centre) and for select modes (e.g. cars). The case of Copenhagen is unique in that the announced diesel ban will apply only to new diesel vehicles. The C40 Fossil-Fuel-Free Streets Declaration, committing its signatories to zero-emission buses from 2025 and zero-emissions in major areas of the cities by 2030 (C40, 2017), provided a significant boost in 2017 to the commitments made in 2016 by Paris and Mexico City, the first cities to announce restrictions for diesel ICEs as soon as 2025.

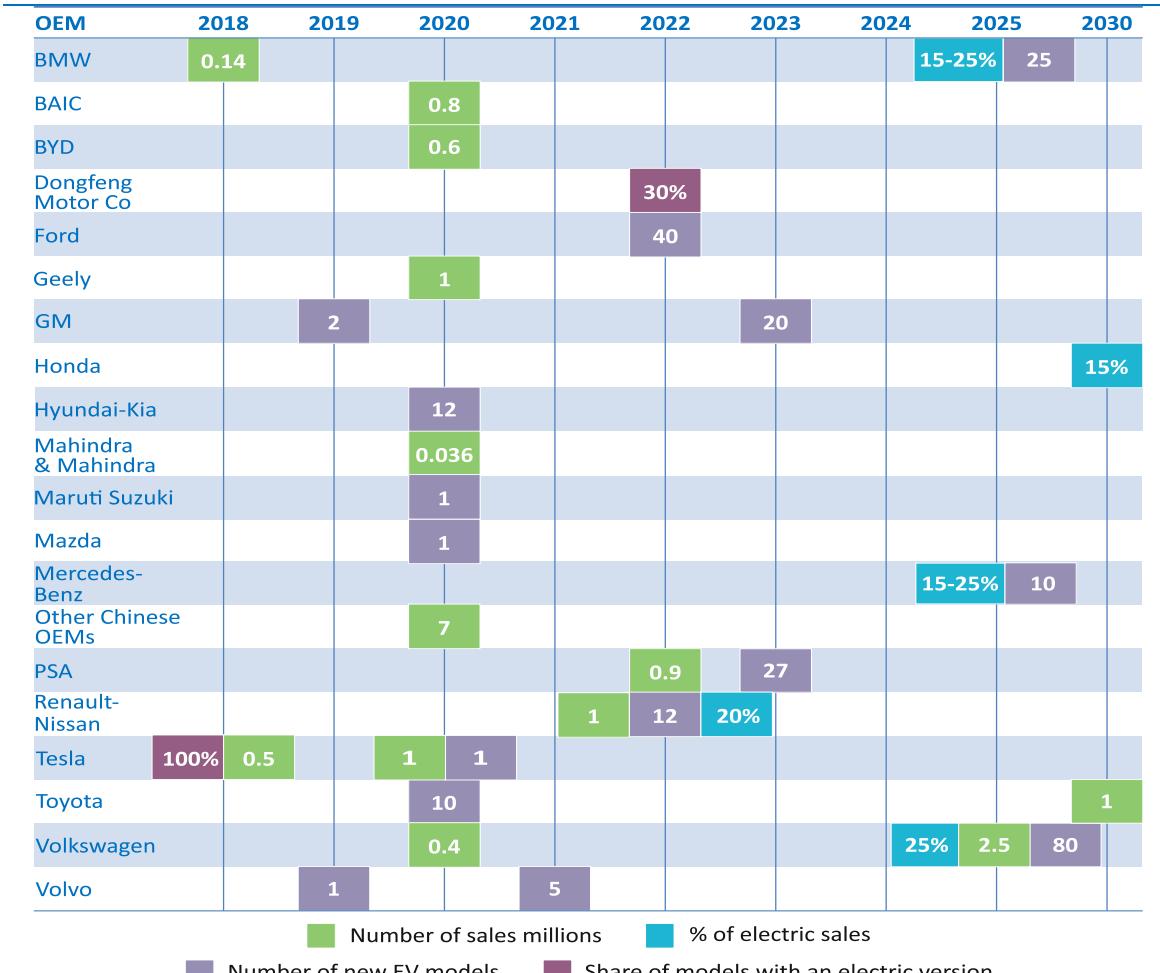
Sources: Harvey (2016) for Athens and Madrid; Electrive (2018) for Balearic Islands; Executive Yuan (2017) for Chinese Taipei; Mairie de Paris (2017) for Paris; Sicilia (2018) for Rome; Sunnerstedt (2018) for Stockholm; C40 (2017) for the rest of local jurisdiction.

Key point: A number of local administrations have pledged to implement restrictions prohibiting access to certain areas for ICEs.

Increasing relevance of electrification in OEM strategies

The dynamic public policy developments outlined above have been accompanied by a mobilisation of major stakeholders in the automotive industry. The number of announcements related to electric mobility issued by original equipment manufacturers (OEMs) over the past year was remarkable and came in the wake of several previous indications (IEA, 2017a).

Table 2.5 • OEM announcements related to electric cars



Notes: This table presents an overview 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 also include HEVs and give no specific indication regarding the PHEVs/BEV share are not included in this table. Instead, they are highlighted in these notes. Audi, part of the Volkswagen Group, announced that three new electric car models will be released in 2020 (Audi, 2017). Toyota announced an objective of 4.5 million sales of HEVs and PHEVs in 2030 (Toyota, 2017). Jaguar Land Rover announced that an electrified version of all new models will be available as from 2020 (BEV, PHEV or HEV) (Jaguar Land Rover, 2017). Renault Nissan announced an aim of 20% of its sales to be zero-emission vehicles in 2022 and 30% of sales to be either PHEVs or HEVs (Groupe Renault, 2017a). Volvo aims for 1 million combined sales of HEVs, PHEVs and BEVs by 2025. Honda is striving for two-thirds of sales to be FCEVs, HEVs or electric cars by 2030 (Honda, 2017). The number of sales presented in the table for China's OEMs such as BJEV-BAIC, BYD, Geely and others represents the production capacity targets rather than sales targets. Other Chinese OEMs include: Daimler-BAIC, JAC Motors, SAIC Motor, Great Wall Motor, Chery New Energy, Chang'an Automobile, GAC Group, Jiangling Motors, Lifan Auto, MIN AN Auto, Wanxiang Group, YUDO Auto, Chongqing Sokon Industrial Group, ZTE, National Electric Vehicle, LeSEE, NextEV, Chehejia, SINGULATO Motors, Ai Chi Yi We, WM Motor, Future Mobility Corporation, LEAPMOTOR, Sinomach, Youxia, Hanteng Autos, Yongyuan, Xiaopeng Zhaoping, Yujie and Zhengdao Shantou.

Sources: Electric Cars Report (2018) for BMW; BMW Group (2017) for BMW; Mitchell (2017) for BMW; Tabeta (2018) for Dongfeng Motor Co; General Motors (2017) for GM; Carey and White (2018) for Ford; Healey (2016) for Honda; Jin (2017) for Hyundai-Kia; The Economic Times (2018) for Mahindra & Mahindra; Charged Electric Vehicles Magazine (2017) for Mazda; Liu (2018) for Other Chinese OEMs; Daimler (2018c) for Mercedes-Benz; Reuters (2016) for Mercedes-Benz; Welch (2018); Nussbaum (2017); Cobb (2015); Voelcker (2017); Marklines (2018) for Tesla; Sheehan (2017) for Tesla; Reuters (2017c) for Volkswagen; Volkswagen (2016) for Volkswagen; Volkswagen (2017); Autocar (2018); Tesla (2018b); Maruti Suzuki (2018); Korosec (2017) for Volvo; Volvo Car Group, (2017) for Volvo; China Economic Net (2018) for Volkswagen; Xinhua (2018) for Geely; The Beijing News (2017) for BAIC; NBD (2018) for Geely; Groupe Renault (2017a) for Renault-Nissan; Toyota (2017) for Toyota; (China Economic Net, 2018) Groupe Renault (2017a 2017b) for Renault-Nissan; Reuters (2017d) and InsideEVs (2017) for PSA; Tabeta (2018) for Dongfeng Motor Co.

Key point: Several OEMs have announced increased EV production and development of new EV models.

Table 2.6 • Announcements by OEMs related to curbing or halting production of diesel ICE cars

OEM	Action
Fiat Chrysler	Phase out diesel across its model line-up as of 2022.
Honda	Discontinue production and sales of a flagship diesel-powered vehicle in Europe.
Porsche	No diesel units for major models of the brand; focus on optimised ICEs, PHEVs and BEVs.
Subaru	Withdraw diesel car production and sales by FY 2020.
Toyota	Stop selling diesel cars in Europe by the end of 2018.
Volvo	Stop developing diesel engines.

Sources: Campbell (2018) for Fiat Chrysler; Nikkei (2017a) for Honda; Porsche (2018) for Porsche; Nikkei (2017b) for Subaru; Toyota Europe (2018) for Toyota; Reuters (2017e) for Volvo.

Key point: A number of OEMs have announced that they will halt the production or development of diesel powertrains.

By now nearly all major OEMs have expressed an ambition or plan related to the development of electric cars (Table 2.5). The number and high ambition of these announcements indicate a strong industry commitment to invest in electric mobility and to scale up efforts to advance EV technology in the coming years. An analysis of the implications of this for future electric car uptake is provided in Chapter 6 (Figure 6.2).

Following the reduced popularity of diesel cars after the “diesel-gate” scandal, especially in Europe, a number of automakers also communicated their intentions to scale back or halt production of diesel models. Given the strategy of many automakers in Europe to provide diesel cars and LCVs as a means of achieving the regulated corporate average CO₂ emission targets (diesel has lower specific CO₂ emissions compared with gasoline), electrified powertrains are likely to become more relevant as alternatives for achieving regulatory compliance. Table 2.6 gives an overview of statements made on this subject.

3. Electric vehicle supply equipment (EVSE)

Charging standards

Current status

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This section looks at EV supply equipment and includes various options such as private and publicly accessible chargers and a range of possible power ratings that are suited to LDVs and buses. It gives significant focus to fast charging EVSE, as a consequence of policy developments over the last year, and despite the fact that they are viewed as a complement to private charging infrastructure rather than a replacement – especially for long distance journeys.

The three main EVSE characteristics that differentiate chargers from one another include:

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

Table 3.1 builds on the analysis developed for the *Global EV Outlook 2017* (IEA, 2017a) to provide an updated overview of the most prevalent charging standards (with details on level, current, power rating and types, i.e. sockets and connectors) for various global regions.¹ See Box 3.1 for a brief update on the state of FCEV infrastructure.

In addition to the information reported in Table 3.1, there are differences in communication methods of the different charging protocols. Protocols rely on different physical connections and there is little scope to make these approaches compatible. In the case of Level 2 and 3 AC chargers, there is a single protocol per type, and the same protocol is also used for Tesla connectors. In the case of DC fast chargers, Combined Charging System (CCS) connectors are coupled with power line communication (PLC) protocols (typically used in smart grid communications), while CHAdeMO, Tesla and GB/T use controller area network communication (originally developed for components inside cars) (CHAdeMO, 2018a).

Box 3.1 • State of FCEV refuelling infrastructure

In fuel-cell electric vehicles, hydrogen is stored in the vehicle in dedicated tanks at pressures of 35–70 megapascal (MPa). The connectors for 35 and 70 MPa hydrogen refuelling already are standardised (ISO, 2012).

Installation of hydrogen refuelling infrastructure has been limited to date. In 2017, 330 hydrogen refuelling stations were in operation worldwide, the majority are in Japan. On a global average basis, there are about four hydrogen refuelling stations per one hundred FCEV cars, with lower coverage in the countries characterised by higher FCEV car penetration (Japan and the United States). However, encouraging signs in the deployment of refuelling infrastructure and vehicles have emerged in various markets, including California, the People's Republic of China ("China"), Germany, Japan and Korea.

¹ In addition to the regions included in Table 3.1, CHAdeMO chargers can be found in Australia, South Africa, South America and several ASEAN countries (CHAdeMO, 2018a). Combined charging system combo 2 is being installed in Argentina, Australia, Brazil, Chile, Indonesia, New Zealand, Oman, Philippines, Saudi Arabia, South Africa, Thailand and the United Arab Emirates (Mahindra, 2018; CharIN, 2017c).

Table 3.1 • Overview of the EVSE characteristics in the main regions

	Conventional plugs	Slow chargers		Fast chargers	
Level	Level 1	Level 2		Level 3	
Current	AC	AC		AC, triphase	DC
Power	≤ 3.7 kW	> 3.7 kW and ≤ 22 kW	≤ 22 kW	> 22 kW and ≤ 43.5 kW	Currently < 200 kW
Type	China	Type I	GB/T 20234 AC		GB/T 20234 DC
	Japan	Type B	SAE J1772 Type 1	Tesla	Accepts all IEC 62196-3 standards
	Europe	Type C/F/G	IEC 62196-2 Type 2		CCS Combo 2 (IEC 62196-3)
	North America	Type B; SAE J1772 Type 1	SAE J1772 Type 1	(Under development) SAE J3068	CCS Combo 1 (SAE J1772 & IEC 62196-3)
	Australia	Type 1	IEC 62196-2 Type 2		Accepts all IEC 62196-3 standards
	Korea	Type A/C	IEC 62196-2 Type 2		CCS Combo 1 (IEC 62196-3)
	India	Type C/D/M	(Draft) IEC 60309 industrial socket (two wheelers) and IEC 62196-2 Type 2 (other vehicles)		(Draft) GB/T 20234 DC (< 20 kW) and CCS Combo 2 (IEC 62196-3) (≥ 20 kW)
					(Draft) CHAdeMO allowed

Notes: kW = kilowatt; AC = alternating current; DC = direct current; CCS = combined charging system; CHAdeMO = charge de move. Type 2 IEC 62196-2 and 62196-3 (CCS Combo 2) connectors are mandated by the European Union 2014/94 Directive. Conventional plugs refer to devices installed in private 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. The grey shaded area in the table indicates standards that are either under development or as yet undecided.

Sources: IEA elaboration based on AFDC (2017); Bohn (2011); CHAdeMO (2012); CharIN (2017a); CharIN (2017b); EC (2014); EV Institute (2017); HK EMSD (2015); State Grid Corporation of China (2013); Mallick (2017); Government of India (2018d); Gordon-Bloomfield (2013); CHAdeMO Association (2018b).

Key point: A variety of electrical sockets and connectors are in use in the main regions for electric vehicles.

Recent developments

Key developments in 2017 include:

- Korea adopted the CCS Combo 1 as the main standard for EVs (CharIN, 2018a).
- India released a draft notification providing indications on the deployment of electric vehicle charging infrastructure, identifying socket outlets or vehicle connectors to be used on EV chargers, as shown in Table 3.1 (Government of India, 2018d).

Charging at 200 kW and beyond

The main global development for charging standards in 2017 was that several fast charging standardisation bodies released new descriptions or official protocols to charge at up to 200 kW (China Electricity Council and Nari Group Corporation, 2016; CHAdeMO, 2018a; CharIN, 2018b; CharIN, 2018c). A limited amount of high-power chargers have been deployed, though there are no vehicles on the road that can charge at this level yet. CHAdeMO has officially published the protocol up to 200 kW and a draft protocol for up to 400 kW will be published in 2018 (CHAdeMO, 2018a). CCS has shared expected features of CCS 2.0 in their CCS System description document in 2017, but has not officially published CCS 2.0 as a protocol yet (CharIN, Personal communication, 2018c). The Chinese GB/T 20234.1 charging standard already has a maximum power of 200 kW within its scope since 2015 (SAC, 2015). Although charging at less than 200 kW, Tesla has been instrumental in the development of superchargers which enable their models to charge up to 120 kW, faster than any other technology currently available (O'Kane, 2017).

Use of standards across different modes

The charging standards and communication protocols discussed have been primarily developed for cars and light commercial vehicles. Nonetheless they are also being used in other modes.

- Electric two-wheelers mostly use level 1 charging, while three-wheelers may also be suitable for level 2.
- There are two main charging solutions available for buses: overnight charging in a bus depot (where various types of charging connectors and levels are used) or high-power opportunity charging at specific bus stops (see Chapter 2 for more details on electric buses).
- Due to the large-size battery requirements, buses relying on conventional charging in a bus depot need a level of fast charging (above 22 kW) capability to enable adequate overnight charging. In most cases, DC fast charging is used starting at 50 kW. Newer bus models allow for 150 kW conductive charging as well.
- Given the number of electric buses on the road in China compared to other countries and the strong preference for depot charging observed in China, most of the medium and heavy-duty electric vehicles currently on the road make use of the GB/T standard for DC fast charging.
- Both CHAdeMO and CCS also support the use of pantographs for buses and trucks (CharIN, 2018c; Shibata, 2017). Another standard that is developed for pantograph charging is the OppCharge standard, which describes charging levels of 150-450 kW (600 kW under development) and complies with the IEC 61851-23 (DC connection) and ISO 15118 standards (OppCharge, 2018).

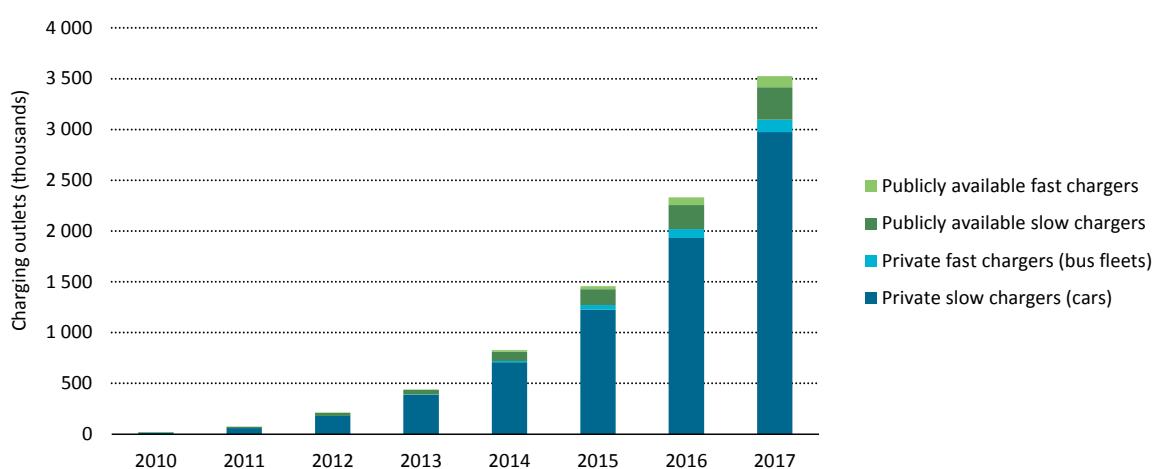
- As more transport modes are being electrified, it is likely that existing standards will need to be further elaborated to accommodate them. This is especially relevant for trucks, given the large power rating assessed for recent announcements related to the development of heavy-duty long-distance applications, as in the case of Tesla and its Semi truck (Campbell and Thomas, 2017).

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EVSE development and availability

Figure 3.1 provides an overview of the number of chargers deployed to date. It illustrates the ongoing upward trend of charging infrastructure observed from 2010 to 2017 for all charger types.

Figure 3.1 • Global EV charging outlets, 2010-17



Notes:

- Private chargers are estimated assuming that each electric car is coupled with 1.1 private chargers (level 1 or level 2), either at home or the workplace, in all countries except China and Japan. The estimates for China and Japan are based on 0.8 chargers per EV, based on the information reported by a survey (looking at a sample of roughly one third of the Chinese 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 80% in China (Sohu, 2018b; EVCIPA, 2018) available on the electric car stock and private EVSE installations.
- Electric two-wheelers are assumed to charge primarily at level 1 outlets and have not been included in this assessment.
- Private fast chargers are calculated here assuming that there is one outlet available per every three buses deployed in China. This is based on the ratio reported for Shenzhen (Lu, Lulu and Zhou, 2018) and generalised to the national level.²
- Chargers can come with different connectors (e.g. DC 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.³ This assessment accounts for the number of outlets on the basis of the number of cars that can charge simultaneously at maximum power.

Sources: IEA analysis based on EVI country submissions, complemented by Zheng (2018) and EAFO (2018b).

Key point: Private chargers outnumber publicly accessible ones.

² In China, the bus fleet is mostly based on depot charging. In Shenzhen, there are approximately 8 000 EVSE outlets for more than 16 000 buses, which equates to an approximate ratio of one charger per three buses (Lu, Lulu and Zhou, 2018). In Europe, the ratio of chargers per bus is closer to one depot charger per bus.

³ It is not possible to charge two vehicles simultaneously on the same charger (even equipped with two different DC connectors) at maximum power rating. However, this is possible in the case of chargers equipped with one AC connector and one DC connector (with some exceptions due to power capacity constraints). Exception are chargers using the CHAdeMO 1.2 standard, which specify simultaneous charging of multiple vehicles and dynamic change of current, allowing for simultaneous DC charging split across two (or more) vehicles (CHAdeMO, 2018c).

Private chargers

Light vehicles: Cars and two-wheelers⁴

The availability of statistics on private chargers is limited, given methodological challenges to track level 1 outlets (since they are not exclusively used for electric cars) and the lack of information collected on level 2 chargers installed on private property. The uncertainty on data accuracy is significant, calling for an improved capacity to track this type of information.

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The data shown in Figure 3.1 are based on the assumption that, in all countries except China, each electric car is coupled with one private charger (level 1 or level 2), either at home or at the workplace. This simple choice intends to highlight the difference in magnitude between private and publicly accessible chargers in the case of electric cars. It is grounded on the following considerations:

- In Europe, and namely in the Nordic region, surveys indicate a clear preference for home and workplace chargers: more than 90% of EV owners in Norway and Sweden charge their car daily or weekly at home and 20-40% of owners do so at work (IEA, 2018a).⁵
- In the United States, estimates are in the range of around 0.9 home chargers per electric car, complemented by 0.325 additional chargers at the workplace (Melaina, 2016; Jadun, 2017).
- The ratio used here (1.1 EVSE for every EV) for all countries except China and Japan is therefore consistent with the assumption that workplace chargers complement charging outlets at private residences.

Data for China indicate that there were 232 000 private chargers in 2017 (Zheng, 2018). Nevertheless, information reported by a survey (looking at a sample of roughly one third of the Chinese electric car owners) by the China Electric Vehicle Charger Infrastructure Promotion Alliance, suggests that the fraction of chargers sold to private electric car owners was close to 80% in China (Sohu, 2018b). China's national 2020 target of 4.3 million private EVSE outlets for 4.6 million electric cars also translates into 0.93 chargers per EV (NDRC, 2015). Given the range of data available and the high level of uncertainty, the data shown for China in Figure 3.1 assumes a ratio of 0.8 chargers per EV applied to the 1.2 million electric cars on the road.

- Similar constraints apply to densely populated cities in Japan. For example, more than 60% of Tokyo's population lives in multi-family residences. This has pushed the municipality to target EVSE support policies to develop charging outlets in residential multi-family buildings (The Nation, 2018). Given the limited information available, but also taking into account of the high rate of fast chargers per EV, private chargers in Japan have been estimated here using the same ratios assumed for China.
- Electric two- wheelers are assumed to charge primarily on level 1 outlets, while electric three-wheelers may use either level 1 or level 2 chargers. Two- and three-wheelers have not been included in the data shown in Figure 3.1.

⁴ LCVs are not included in this section as currently there are insufficient data over an adequate geographic area to draw meaningful conclusions.

⁵ The numbers differ per year (decreasing trend since 2014) and per Nordic country.

Medium- and heavy-duty vehicles

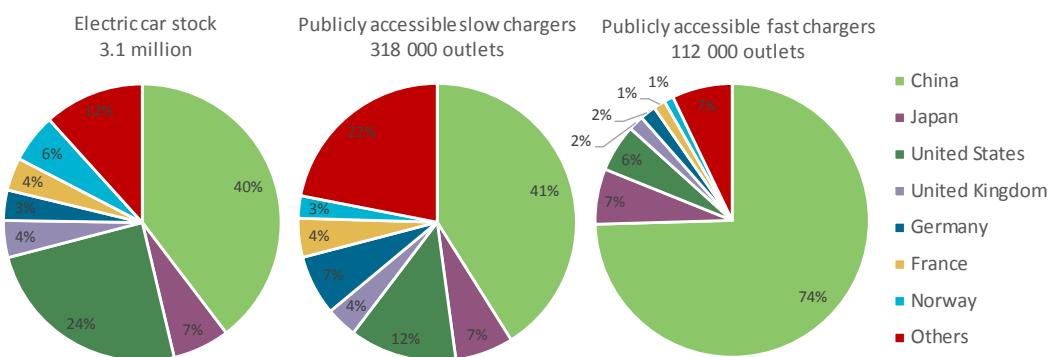
Estimating the amount of dedicated charging outlets for fleets of medium- and heavy-duty vehicles is also challenging, given the limited information available. China so far has been the most active in deploying EVs for vehicle segments beyond passenger cars. Shenzhen, in particular, is one of the key cities in China in the drive towards electric mobility for modes other than LDVs and two-wheelers.

Given China's strong leadership in the deployment of vehicles and chargers for urban buses, the value shown in Figure 3.1 for private fast chargers basically reflects the situation for bus fleets in China, coupling the bus stock with one charger per three electric buses. This assumption is based on the values available for the city of Shenzhen (Lu, Lulu and Zhou, 2018).

Publicly accessible chargers

Comparing country-level data of publicly accessible EVSE outlets in 2017 with the electric car stock reflects significant variations across different markets (Figure 3.2).

Figure 3.2 • Electric car stock and publicly accessible charging outlets by type and country, 2017



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2018b).

Key point: China has approximately three-quarters of the world's publicly accessible fast chargers and a major part of the slow chargers.

Electric vehicle markets in many countries are still at an early stage of development. As a result, finding an explanation for differences in EVSE/EV ratios across countries is not straightforward.

Figure 3.2 and the ratio of publicly available EVSE outlets per electric car shown in Figure 3.3 helps to identify a few key aspects:

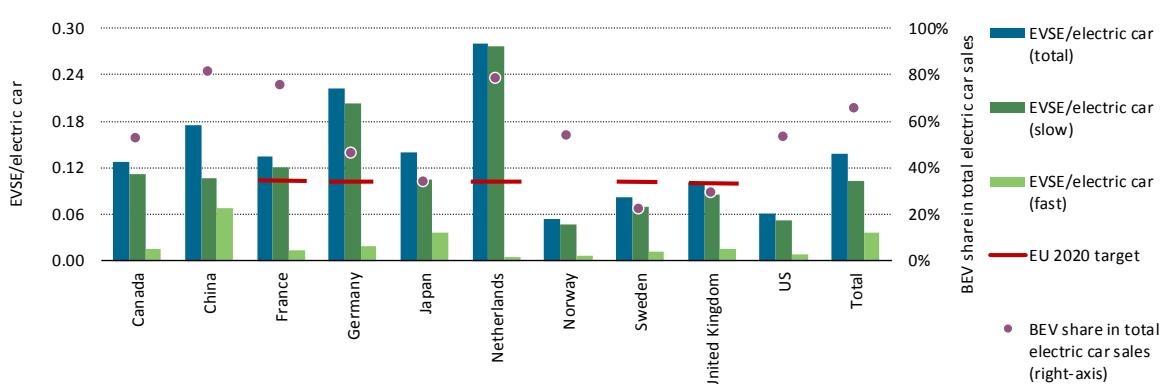
- China and Japan tend to have a higher reliance on fast chargers than other countries. This is consistent with constraints that apply to access to private chargers in densely populated cities and the low numbers of EVSE per EV observed for private chargers in the case of China.⁶

⁶ Several large charging stations have been built in China to serve the needs of various vehicle modes. For example, the Qian Hai charging station (built by XCharge and operated by Prime Union in Shenzhen) can charge 60 vehicles simultaneously with a maximum capacity of 3 200 kW (on average 53 kW per vehicle) (Xcharge, 2018a; Xcharge, 2018b). The charging station is populated by taxis (50%), LCVs (30%), passenger cars (10%) and buses (10%), highlighting the diversified use of the chargers.

- China's high EVSE/EV ratio for publicly accessible fast chargers can also be explained by the high utilisation rate of non-private vehicles, such as government fleets and taxis, likely to be more dependent on fast charging to fulfil their daily trips (Ou, 2017). Another element corroborating this is the relatively low range of BEVs in China, compared with BEVs marketed in other countries.
- Norway, the market with the highest electric car sales share globally in 2017, achieved its leadership role despite a rather low share of publicly accessible charging infrastructure compared with the electric car stock. This is consistent with survey results indicating a strong consumer preference in Norway for home charging (IEA, 2018a).

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Figure 3.3 • Ratio of publicly accessible charging outlets per electric car for selected countries, 2017



Notes: Data are based on the same assumptions as Figure 3.1 and Figure 3.2. The 2020 EVSE/EV target is the goal of the EU AFI Directive which stipulates that member states should ensure that publicly accessible charging points are built with adequate area coverage, suggesting a minimum of one recharging point per ten electric cars.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2018b).

Policy support: Key updates

National and supra-national measures

Charging infrastructure is dependent on local circumstances, national and supra-national policy frameworks – including the definition of clear deployment targets, regulations and the mobilisation of funding for direct investment and the provision of financial support. Effective frameworks help to catalyse the deployment of EVSE by creating conditions to alleviate key challenges to developing charging infrastructure and by ensuring the availability of adequate funding to foster its deployment.

EVSE deployment targets

EVSE deployment targets help set the horizon to match infrastructure developments with EV uptake objectives. Not all countries with EV uptake targets have set EVSE deployment targets, and many targets only highlight publicly accessible chargers and not private chargers. A few examples include:

- China plans to deploy 12 000 stations to swap batteries, 4.3 million private EVSE outlets and 500 000 publicly accessible chargers by 2020 (Xiaowen, 2018; Ou, 2017; China Daily, 2017). China differentiates its target geographically among Western China (promotion area), Middle China (demonstration area) and Eastern China (accelerating area) to address asymmetrical

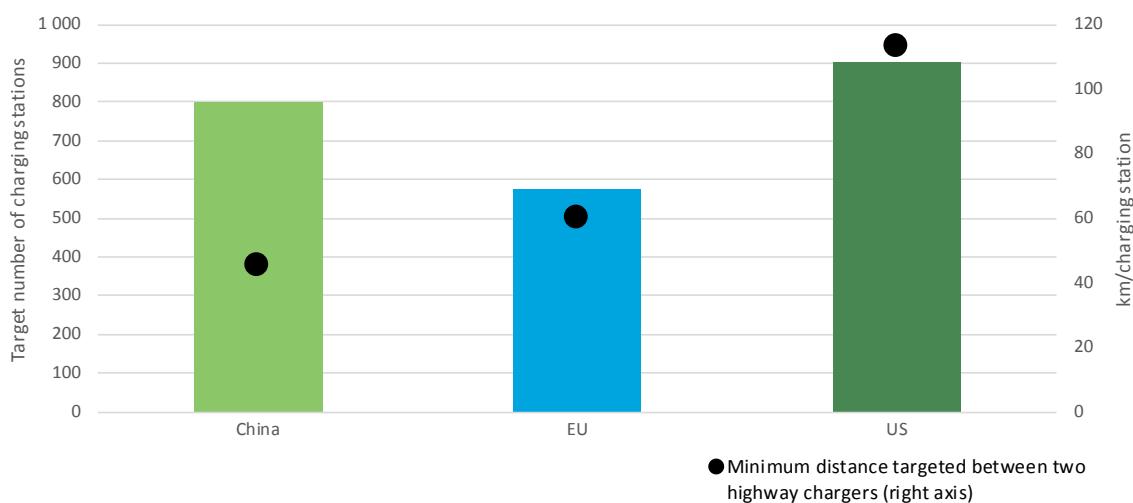
development within its electric car market. Some cities have an EV/EVSE ratio of 0.13 (one per eight) and other cities have a less strict ratio target of 0.07 (1 per 15) (ICCT, 2017c).

- The European Commission has requested its member governments to set deployment targets for 2020, 2025 and 2030 in order to match the level of infrastructure required by the AFI Directive (EC, 2014). In 2017, only 80% of EU countries submitted targets indicating that only 35% of the publicly accessible charging points required by 2020 have been deployed (Platform for Electromobility, 2018; EC, 2017d). However, due to delays in electric car deployment and several countries overshooting the EVSE deployment target, the ratio of one publicly accessible EVSE outlet per ten cars is likely to be achieved in 2020 (Platform for Electromobility, 2018).
- California has revised its infrastructure deployment target for 2025, along with its 2030 target of 5 million EVs: executive order B-48-18 updates the 2016 ZEV action plan and proposes to invest USD 900 million to deploy 250 000 EVSE outlets by 2025, of which around 10 000 outlets should be DC fast chargers (Electrify America, 2018a; State of California, 2018).

Highway chargers

Given the relevance of the availability of charging installations along major road networks to enable long distance driving of BEVs, major markets such as China, the European Union and the United States clearly have ramped up their ambition to install fast charging facilities along highways (Figure 3.4).

Figure 3.4 • Number of highway charging stations and distribution targets in selected regions



Notes: The values for China refer to a governmental target (2020). The European Union values refer to the targets set in the AFI Directive (2020). The United States values refer to the targets set by the Electrify America project (2030).

Sources: Ou (2017); China Daily (2017); European Commission (2017c); Electrify America (2018a).

Key point: The target deployment of EV charging infrastructure along major highways is at an interval of 45-115 km.

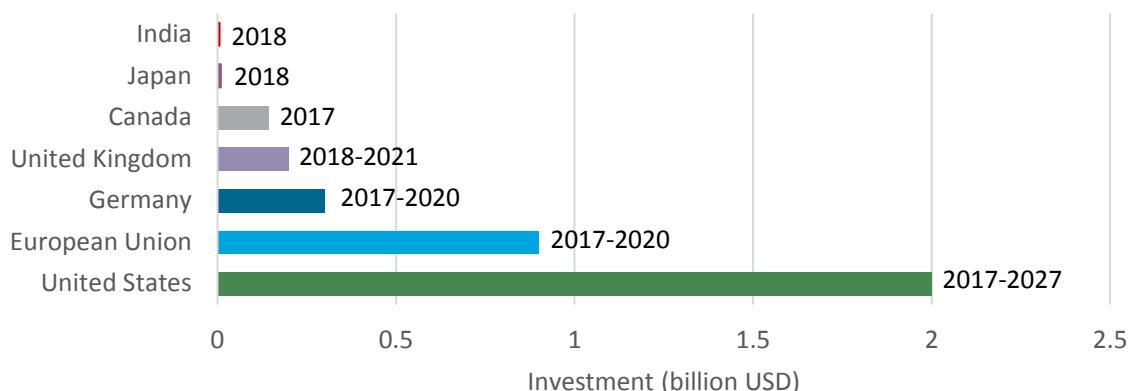
Fiscal policies

Fiscal policies for EVSE support can take the form of financial incentives, tax relief and direct investment. The extent to which countries provide direct investment in publicly accessible EVSE

outlets has declined in the past few years, while the number of countries with fiscal/financial incentives for EVSE deployment has increased substantially. Overall, government spending on charging infrastructure has significantly ramped up in recent years. A selection of examples in Figure 3.5 provides an overview of the current mobilisation of funding.

Figure 3.5 • Recent investment announcements for EV infrastructure development in selected countries

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Notes: This figure represents an overview based on available data and may not be complete. In the European Union, this support is intended for the Trans European Transport Network (TEN-T) as well as urban areas (EC, 2014). In Japan, it is the financial support offered by the national government in collaboration with the City of Tokyo for charging infrastructure (The Nation, 2018). In the United States, it is the amount that Electrify America is set to invest in charging infrastructure between 2017 and 2027 (Electrify America, 2018b). In 2016 Germany announced a national policy package that supports publicly accessible charging infrastructure with EUR 300 million (USD 338 million) to deploy 15 000 charging stations by 2020 (BMVI, 2017).

Sources: EC (2017c); Electrify America (2018a); Government of Canada (2017); Government of the United Kingdom (2017b); IEA (2018a); The Economic Times (2017); The Nation (2018).

Key point: The United States has earmarked the most investments for EV infrastructure development.

Despite the increase in funding available for EVSE development, not all policies have worked as planned. In the United Kingdom, a GBP 4.5 million (USD 5.8 million) fund for on-street residential charging has been left unused by most local authorities eligible for the fund (Brown, 2018). Many councils struggle to set up suitable projects to make use of the fund. This illustrates that along with allocating a budget for charging infrastructure installation, there needs to be consideration into assistance for applicant funding.

Regulatory policies

Building codes and permits

As private charging is dominant in most countries, it is important to enable electric car owners to install private charge points where they park. So far, most electric car owners in Europe and the United States have their own garage or driveway (IEA, 2018a). However, in order to reach a larger market share, electric car owners that live in apartment blocks, condominiums and city centre dwellings, require charging infrastructure as well. Many building regulations proscribe parking facilities, though only a limited number allow for or mandate EV charging outlets. The key barriers in building regulations are the procedure to make changes to car parking spaces in existing buildings (installation of charging outlets), to ensure that new building developments have the

capability to easily install charging infrastructure when needed and the issue of the party liable for payment (see IEA (2018a)). One of the key regulatory policies ensuring a greater diffusion of electric cars in private households is the development of building codes embedding requirements for "EV-ready" parking.⁷

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The political agreement on the update of the European Directive on the energy performance of buildings is the most significant development finalised in 2017 in this respect. This agreement states that new and renovated non-residential buildings (>10 parking spaces) must install at least one charging point and additionally one-out-of-five spaces must have a conduit installed. In new and renovated residential buildings (>10 parking spaces) every parking space must be equipped with a conduit. In addition, member states are asked to set up a requirement for a minimum number of recharging points to be installed in all buildings with more than 25 parking spaces, including provisions on minimum requirements for the installation of EVSE in new and refurbished buildings and in public parking lots (Council of the European Union, 2017). In Norway for parking lots and areas in new buildings, a minimum of 6% must be allocated to electric cars (IEA, 2018a). Other recent updates focus on a city level and are described in Figure 3.6.

Regulatory frameworks on electricity distribution

EV charging stations are integrated in the electricity system and, as such, are subject to power sector regulation.⁸ The regulatory structure has strong implications for the ownership structure and organisational arrangements of emerging charging infrastructure.

- In China, the electricity system is organised as state owned, vertically integrated monopolies which drive the expansion of charging infrastructure expansions (ICCT, 2017d). Private companies have entered the charging business especially in urban areas, in which the National Development and Reform Commission (NDRC) issues operating licences and the local administration regulates prices.
- In Germany and the United Kingdom, distribution companies are not allowed to operate charging infrastructure (ICCT, 2017d).
- In India, legislation considered charging infrastructure as electricity distribution, which is a licenced activity. This licence requirement has hindered market access of small-scale players (Sasi, 2018). In early 2018, an interim arrangement was setup to enable charging stations to operate without a licence, potentially improving the conditions in EV charging stations (First Post, 2018).
- In the United States, retail companies are not allowed to operate EVSE (ICCT, 2017d), but many states are in the process of making changes to this restriction. In California, a proactive approach aims to exclude EV charging stations from the definition of a public utility to allow utilities to develop and execute EVSE-related projects (Bloomberg, 2018a). California is

⁷ By including the necessary elements such as conduits for EVSE cables and grid connection to newly built parking spaces.

⁸ Current power sector regulation in many countries reflects market liberalisation efforts. In some cases, markets have been deregulated to allow retail competition: former state monopolies have been unbundled into separate companies along the different parts of the value chain, e.g. generation, transmission, distribution and retail. With this model, companies in generation and retail are exposed to market competition. Transmission networks are controlled by a transmission system operator, which in some countries may be a sole actor. Distribution networks can be owned and controlled by various entities generally in a specific geographic area. Regulations generally prohibit network operators from the generation and retail businesses to hinder cross-subsidising of competitive market segments and obliges them to provide network access to safeguard competition (Batlle and Ocaña, 2013). Such competition in power generation and retail supply differs significantly from electricity systems with vertically integrated monopolies, in which a single company controls all segments of the value chain.

actively seeking to streamline permitting processes for EVSE. Since 30 September 2017, all cities or counties need to have adopted improved permitting practices (State of California, 2016b). More than ten other states such as Illinois, Colorado and Ontario also have legislative exemptions on EV charging infrastructure (Chavez-Langdon and Howell, 2013; Stevens, 2016).

Depending on the specific regulatory approach of a country, and whether legislation considers EV charging stations as retailer or as distributor of electricity, the regulatory environment can facilitate or hinder investments by actors in the electricity sectors and private companies. The ICCT (2017d) describes how regulatory reform can promote EVSE investments:

In a number of countries, the regulatory environment limits the possibilities for utilities to invest or own EVSE. This is because they receive regulated revenues from network operations, which bestows an advantage when competing with companies that do not have a regulated income stream in the market for charging infrastructure. Relaxing some of these restrictions and allowing utilities to invest in the development of EVSE can promote the expansion of charging infrastructure, as seen in the case of regulatory reform in California. An even more progressive approach described by ICCT (2017d) is rate basing, in which utilities levy investment costs for charging infrastructure across all network users. The possibility to integrate charging infrastructure in demand-side management (DSM) can reduce overall system costs, lower the network charges and benefit all network users regardless of whether they are EV owners.

Generally, revenue caps under profit regulations for utilities limit incentives to investment in infrastructure that has the capacity to reduce system costs, as utilities cannot retain incremental profits. The International Council on Clean Technology (ICCT) (2017d) recommends reform of the regulatory environment to reward actors making investments enabling lower system costs, referring to V2G applications in which utility and EV owners can share investment costs and profits. The ICCT suggests also that market regulation must provide access to EV owners or groups of owners so that they can offer the load capacity of their EV in the market to promote possible V2G integration in future DSM portfolios.

Recent investments in charging infrastructure by utilities focus on public charger programmes. Promoting investment or ownership by utilities in home chargers can maximise their contribution to DSM. This is because distribution system operators (DSOs) have the system insight needed to integrate chargers through smart charging or delayed charging, and are able to offset investment costs through increased system performance. EV users have less incentive to adjust charging patterns to system optimisation and therefore do not prioritise system costs when investing in home chargers.

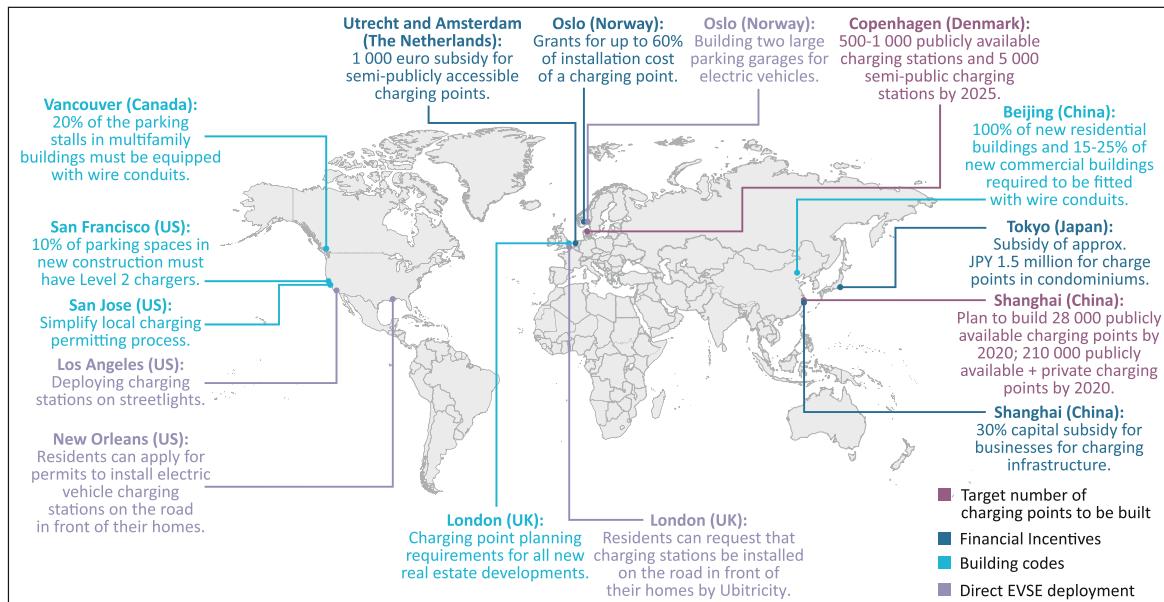
Local policies

Given their competence in land use and traffic regulations (including parking ordinances and zoning actions), local authorities are often best placed to ensure that the deployment of EVSE matches the characteristics of the urban mobility patterns and local geography. In some cases (e.g. China, United Kingdom), cities also have the capacity to distribute national financial support for EVSE (ICCT, 2017c).

Examples of local policy instruments that have a clear impact on the development of urban EVSE networks are discussed in the *Global EV Outlook 2017* (IEA (2017a) and EVI reports, such as the EV City Casebook (Urban Foresight, 2014). Two reports from the ICCT also focus attention on major initiatives being promoted in global EV capitals (ICCT, 2017e; ICCT, 2017f). Figure 3.6 builds on the information in these reports and highlights examples of recent measures that have been adopted for promoting EVSE deployment in major cities.

Figure 3.6 • Examples of recent policy instruments promoting charging infrastructure deployment in major cities

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This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Note: This is not an exhaustive list of policies, but an illustration of examples of cities where EVSE policies have been implemented.

Sources: ICCT (2017e); ICCT (2017f); Japan News/ANN (2018); Lambert (2017); Miller (2018); PluginBC (2018); Urban Foresight (2014); Xiaowen (2018).

Key point: Cities are using a variety of measures to promote the development of charging infrastructure.

Figure 3.6 indicates that there is a variety of policy instruments used to incentivise the development of charging infrastructure in big cities. The policies clearly fit into four distinct types: targeting the number of charge points to be built; financial incentives for EVSE; changing building codes to enable easier installation (discussed earlier in this section); and directly installing charge points. It is evident that building codes are one of the more widely employed options, with cities in all the key regions mandating quotas for new residential units to facilitate the expansion of EV charging outlets.

The increasing use of access restrictions, circulation bans and other regulatory arrangements (e.g. restrictions on registration of new ICE vehicles) applying to urban environments were discussed earlier in Chapter 2. Regulatory frameworks have relevance not only for EV uptake, but also indirectly for the development of EV infrastructure.

Initiatives from private sector stakeholders

In addition to government targets and development plans, individual companies and consortia of OEMs are actively engaged in the development of fast chargers along highways (Table 3.2).⁹ These announcements indicate that an increasing variety of players are entering the charging infrastructure market. Aside from utility companies, many vehicle manufacturers recently have created consortia to deploy highway charging outlets. Evidently, these OEMs aim to bridge the gap

⁹ Note that many of the European projects described here e.g. FastNed project, Mega-E and Ultra-E are subsidised by the European Commission (EC, 2018d; EC, 2018e).

of limited publicly accessible infrastructure for long distance trips or for high-intensity users to be a barrier to adoption of their EV models. To address this issue, they are developing charging stations strategically along highway corridors.

Table 3.2 • Publicly accessible highway charging deployment objectives by selected companies and manufacturing consortia

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Company	2018	2019	2020
Enel			180
E.ON/CLEVER			180
FAST-E			256
Ionity (EU)		400	2 400
Ionity (USA)			290
Mega-E			27
NEXT-E			252
Porsche		500	
Shell / Ionity		80	
Ultra-E	25		

 No. of target stations

 Total no. of target charge points

Notes: This table is based on available data may not be complete. The listed companies have stated that their highway chargers will have fast charging capacity. Targets in the table are only for highway charging infrastructure: many other announcements have been made which include both highway and urban but do not detail the split between charging types and therefore are not included in this table. Ionity is a joint electric car charging network including BMW, Mercedes, Ford and Volkswagen. Shell has now joined the network pledging to build the additional stations specified above. The Ultra-E charging network consists of Allego, Audi, BMW, Magna, Renault and Hubject. The Mega-E network is a partnership between Allego and Fortnum. The NEXT-E charging network consists of MOL, E.ON, Hrvatska elektroprivreda (HEP), Nissan and BMW. In the UK, National Grid have pledged to build 100 highway stations (Hanley, 2018), but the target deployment date is unspecified. SMATRICS (Austria) have a target to build an additional 20 stations under the eva+ project (enel and SMATRICS, 2017), but the target deployment date is unspecified.

Sources: Enel and SMATRICS (2017) for Enel; E.ON (2017) for E.ON/CLEVER; Allego (2018) for FAST-E; Lambert (2018) for Ionity EU/USA and Mega-E; Balkan Green Energy News (2017) for NEXT-E; Kane (2018) for Porsche; Bousso (2017) for Shell/Ionity; EC (2016) for Ultra-E.

Key point: Private sector stakeholders – including car manufacturers, oil companies and utility companies – are planning to deploy fast charging points on highways.

Many of the targets detailed in Table 3.2 have short time horizons, indicating that the roll-out is imminent. With multiple charging outlets per station, it is clear that these stations will cater to multiple vehicles with the potential to expand as the numbers of EVs grow. The announcements highlighted are mainly from European companies for deployment across the European Union. There are also key players in other markets such as Tesla in the United States and utility companies in China. Other developments include the roll-out of EVSE in workplaces (Box 3.2).

Box 3.2 • Workplace charging stations

Workplace chargers are being promoted at a global scale, with an increasing number of companies signing up to the EV100 initiative of The Climate Group. Initiatives developed under this framework include examples such as: HP Inc. and Unilever are offering charging stations at many of their offices; the IKEA Group has installed EV charging at over half of its stores and Chinese internet giant Baidu has invested in workplace charging as well as electric buses for staff transportation at its campuses (The Climate Group, 2018).

In the United States, a number of private and public initiatives are considering the development of workplace chargers. In California, this has likely been driven by the presence of many tech firms (ICCT, 2017f). For example, Tesla has started to offer free workplace chargers for Tesla users to companies and commercial property owners (Bloomberg, 2018b). San Diego Gas & Electric developed the programme Power Your Drive to support up to 3 500 chargers in multi-family buildings and workplaces (SDG&E, 2018).

4. Energy demand and emissions

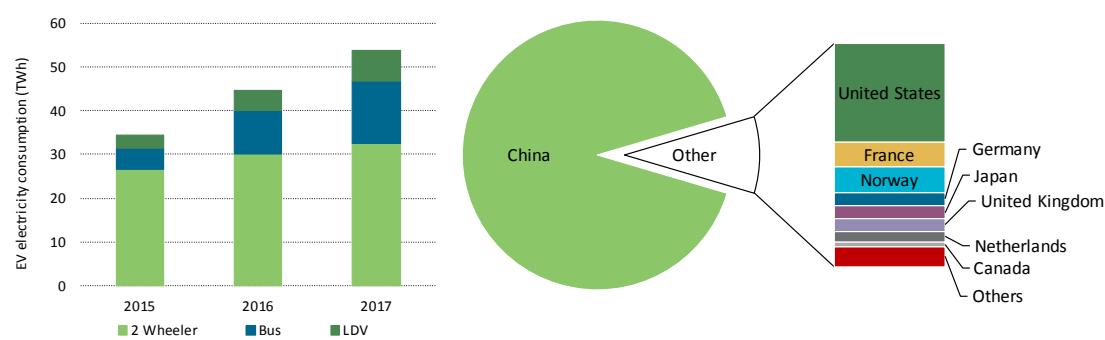
Current impact of EVs on energy demand

Energy demand and change in oil demand

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In 2017, the estimated global electricity demand from all EVs was 54 terawatt-hours (TWh) (Figure 4.1), an amount which is equivalent to slightly more than the electricity demand of Greece. Most demand (91%) is located in the People's Republic of China ("China") where the consumption is mostly due to two-wheelers and buses. These two modes combined accounted for 87% of EV electricity demand worldwide. Yet, electricity demand for LDVs has increased the fastest since 2015 (143%), followed by buses (110%) and two-wheelers (13%).¹

Figure 4.1 • Total electricity demand from EVs by country, 2017



Notes: TWh = terawatt-hours. The pie chart refers to 2017 data. The assumptions are: passenger vehicle consumption 20-27 kWh/100 km, annual mileage 8 500-18 800 km; two-wheeler consumption 3-5 kWh/100 km, annual mileage 5 900-7 500 km; electric urban bus consumption 135-170 kWh/100 km, annual mileage 28 000-47 000 km, (the range indicates the variation across countries). The share of electric driving for PHEVs is assumed to be 36% of the annual mileage. Charging is assumed to have an efficiency of 90%.

Source: IEA analysis based on country submissions; IEA (2018b).

Key point: China dominates global electricity demand for EVs. Largest year-on-year growth in electricity demand comes from LDVs.

The estimated electricity demand from EVs in 2017 increased by 21% compared with 2016. Electricity demand from EVs was equivalent to 0.2% of the total global electricity consumption in 2017 (IEA, 2018c). In China and Norway, the countries that have respectively the largest fleet and the largest market share of EVs, EV electricity demand is 0.45% and 0.78% of the total demand.

So far, the expanding numbers of EVs have had limited impact on electricity demand thus providing encouraging signs for the transition to greater electric mobility. As electric vehicles are increasingly deployed they will increase electricity demand and impact transmission and distribution grids. Box 4.1 highlights potential issues and solutions to integrate EV electricity demand in power grids.

¹ In this section electricity demand and CO₂ emissions are only calculated for two-wheelers. Available data about three-wheeler yearly mileage and fleet numbers is deemed not sufficiently reliable to be included in the analysis.

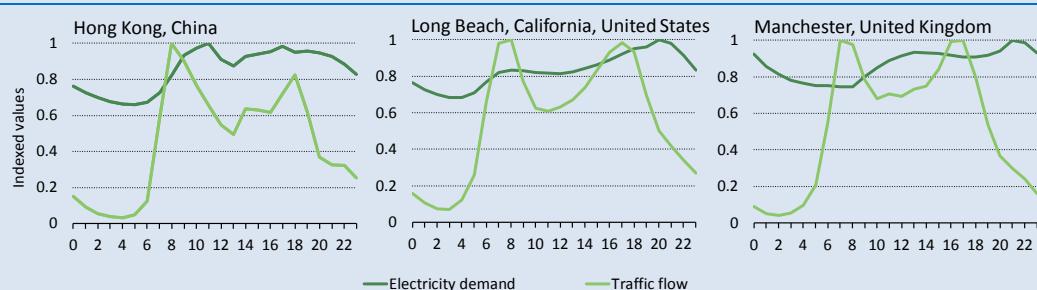
Box 4.1 • Grid implications of EVs

Impacts of EV charging

The structure of transport demand has strong peaks in the morning and evening on weekdays, with limited variations across modes. Power demand also displays a morning and an evening peak in most regions while demand is lower during the night and in the afternoon. The low period of power demand during daytime is less visible for summer days in warm climates, where there is high electricity demand from cooling appliances, or in winter days in cold climates, due to higher power demand for heating purposes.

Figure 4.2 displays day variations in traffic flow in three cities (Hong-Kong [China], Long Beach [California, United States] and Manchester [United Kingdom]) as well as the electricity load curve of each region.

Figure 4.2 • Road traffic and power demand profile during an average weekday



Notes: The two lines aim to describe the variation of road traffic, using a 0 to 1 index profile, and power demand during an average weekday, as a fraction of the maximum daily road traffic and power demand respectively. This figure uses data from three studies for which road traffic measurements were conducted and load curves which are representative for the power demand of the respective city. Power demand curves refer to April for Long Beach and Manchester, and are yearly averages for Hong Kong.

Sources: IEA analysis based on CAISO (2018); Chinkin et al. (2003); ENTSOE (2018); Smith, Lindley, and Levermore (2009); Xia and Shao (2005).

Key point: Power demand and road mobility demand are both characterised by two peaks during morning and evening hours and a period of low demand during night time.

In all three cities, there is a peak in traffic activity in the morning hours after a period of low electricity demand during night time. These characteristics of electricity demand and transport activity suggest that overnight charging of EVs is well timed before they are used in the morning. This has the added benefit of minimising the need for incremental electricity generation capacity and investment in distribution infrastructure upgrades.

In the evenings, the peak in electricity demand often follows the traffic peak. Plugging EVs to the grid after the evening traffic peak may exacerbate the peak in power draw. This couples with a higher risk of overloading of the power distribution network, requiring grid upgrades such as the replacement of distribution transformers and cables.² If not properly managed, increased power draw at peak times could also require additional generation capacity. To avoid economic and environmental effects of increased peak load demand in evenings, shifting the load to the night is desirable.

² For example, the US utility company Xcel Energy concluded that with 5% stock share of EVs, if charging is aligned with peak load, around 4% of the distribution transformers dedicated to residential customers could be overloaded (Xcel Energy, 2015). Other events that require anticipation of possible criticalities include concentrated increases in power demand from EV charging due to concentration in “EV clusters” (Muratori, 2018). EV-induced issues for the local power supply areas may also change over time, given that EVs, in contrast with other loads on distribution networks, are not stationary (IEA, 2017a).

Managing the impacts of EVs on the power system

Demand-side management (DSM), also referred to as demand-side response, is an important instrument that can significantly reduce the need for grid upgrades and additional generation capacity due to electrification of road transport, as well as to facilitate the integration of renewables (IEA, 2018d).

Regulators, utilities, transmission system operators, distribution system operators and retailers are already taking DSM measures and designing policy mechanisms to ensure that the EV uptake will not overload the power grid. For EVs, DSM largely consists of the optimisation of the charging time of the vehicles, shifting loads to ensure a good match between power supply and demand with the aim to move the bulk of the EV charging related power demand from the evening peak to the night. In addition to relieving the load on the distribution grid and reducing investment needs for grid reinforcements, achieving this has the capacity to deliver a number of potential benefits, including:

- Reducing the need for additional generation capacity by shifting charging loads to periods with lower demand (which could translate in lower electricity prices thanks to the possibility to rely on power produced by generation assets with lower marginal price).
- Optimising the utilisation of the grid assets during the day, increasing their utilisation factor and maximising their profitability, therefore reducing their cost per kWh.
- Reducing curtailment of renewable generation by aligning EV charging with periods of high output from renewables, such as night time charging when generation from wind generators is often highest or mid-day when photovoltaic generation peaks (IEA, 2018d).

Realising these benefits with DSM is facilitated by dynamic tariffs such as time-of-use (TOU) pricing or real-time pricing (RTP).³ TOU pricing incentivises consumers to charge EVs in a way that maximises the power draw when electricity prices are low and minimises it when they are high. Typically, dynamic pricing aims to discourage EV owners from charging their vehicle at peak times. However, it can also be used to shift demand towards times when electricity production from renewable energy sources is abundant, or to get all these benefits concurrently.

The charging process may be assisted by smart charging applications. Manufacturers such as BMW already have developed products to automatically optimise home charging to benefit from low electricity rates (BMW Group, 2018). DSM products may also be used to optimise usage patterns of other residential appliances (e.g. heating and cooling) that contribute to electricity peak loads. Integrated systems may enable consumers to prioritise appliances, for instance by temporarily reducing electric heating to offset additional load from charging an EV during peak load.

DSM can also provide valuable ancillary services to the power grid, including frequency regulation, voltage support and power factor correction, as well as the possibility to balance loads across the distribution network. The effectiveness of DSM measures could be further enhanced by bi-directional “vehicle-to-grid” (V2G) capability. V2G is a bi-directional connection between the EV and the grid through which power can flow from the grid to the vehicle and vice-versa.⁴ The implications and potential of the expanding uptake of EVs and DSM will be analysed in the upcoming electricity focus in the *World Energy Outlook - 2018*.

EVs provide fuel efficiencies (in final energy terms) that are two-to-four-times higher than ICE powertrains. This is due both to the higher efficiency of the powertrain and the EVs' ability to

³ The European Commission's (EC) Electricity Directive defines “dynamic electricity price contract” as an electricity supply contract between a supplier and a final customer that reflects the price at the spot market or at the day-ahead market at intervals at least equal to the market settlement frequency (art. 2(11), Electricity Directive) (Eurelectric, 2017).

⁴ There are technical barriers to this, as V2G requires conversion from DC from the battery to AC in the distribution grid.

regenerate kinetic energy when braking. It is estimated that EVs operating worldwide in 2017 displaced 0.74 exajoules (EJ) (17.5 million tonnes of oil equivalent [Mtoe], 0.38 million barrels per day [mb/d]) of diesel and gasoline demand.⁵ The majority of the displacement is attributed to two- and three-wheelers (73%), the rest to buses (15%) and LDVs (12%).

Emissions

Greenhouse gases

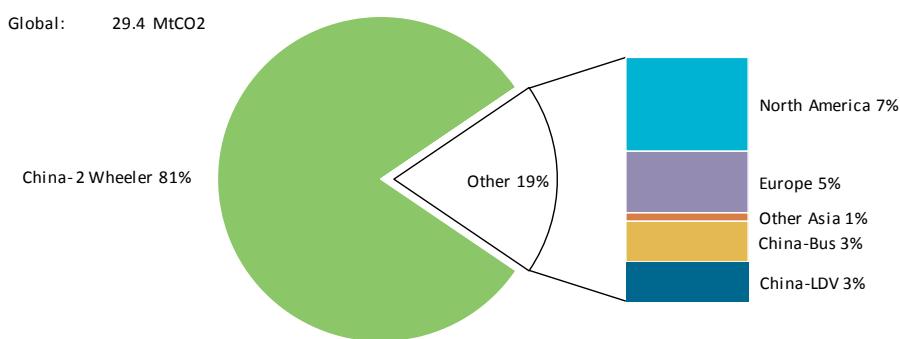
The country specific power generation mix and the carbon intensity of vehicle manufacturing determine the CO₂ intensity of BEVs. The combination of the high energy efficiency of electric motors and low-carbon electricity potentially allows EVs to significantly cut CO₂ emissions with respect to ICEs. The IEA (2017a) observed that in 2015 electric cars in Europe, on a well-to-wheel (WTW) basis, emitted about 50% less CO₂ than gasoline cars and 40% less than diesel cars. When emissions associated with the vehicle manufacturing are also included, the resulting CO₂ emission savings are lower. However, Ellingsen et al. (2016) clarified that when taking into account the entire life cycle of the vehicle (manufacturing, use and disposal), the current European generation mix enables BEVs to deliver roughly 30% GHG emission savings compared with gasoline ICE vehicles. These savings are lower in the United States and Japan, where the carbon intensity of power generation is higher than in Europe. EVs offer only limited advantages with respect to ICE vehicles in terms of WTW CO₂ emissions, and they may even result in net increases when considering life-cycle emissions in countries with a carbon-intensive power generation mix (e.g. India and China). To ensure that EVs have lower climate change impact than ICEs in countries with carbon-intensive power generation, it is of primary importance to reduce the CO₂ intensity of power generation, and to reduce the impact of the battery production and vehicle manufacturing phases (Ellingsen and Hammer Strømman, 2017).

In 2017, EVs in operation worldwide emitted around 35.7 million tonnes of CO₂ (MtCO₂) and avoided emissions of 29.4 MtCO₂.⁶ China stands out as first contributor to the total emissions avoided (Figure 4.3). This result is obtained due to the very high EV stock of two wheelers, rather than through a significant comparative advantage in terms of WTW CO₂ emissions compared to ICEs. This is exemplified by the fact that electric LDVs in China only accounted for 3% of global CO₂ savings despite accounting for 42% of global stock of electric LDVs.

Almost all countries in the world have committed to reduce their GHG emissions in their pledges to the Paris Climate Agreement (UNFCCC , 2018). These measures are expected to reduce the CO₂ intensity of power generation over time, which translates to lower CO₂ emissions for electric mobility. To guarantee that such EVs decarbonisation starts in the short term, countries could introduce a “hard coupling” policy framework that aligns EV stock shares with renewable energy production targets (IEA-RETD, 2015). A review of such cases of implementation of such hard couplings is provided by IRENA/IEA/REN21 (2018).

⁵ The oil demand displacement is estimated by calculating the fuel that would be consumed if all EVs on the road were powered by ICEs with a fuel economy representative of the regional fleet average.

⁶ Emissions are calculated by multiplying the electricity consumption by the average CO₂ emission intensity in each country. The avoided emissions are estimated by calculating the CO₂ that would have been emitted if the EV fleet was powered by ICEs with a fuel economy representative of the country average.

Figure 4.3 • CO₂ emissions avoided due to EVs worldwide, 2017

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Notes: LDV refers to light-duty vehicle. Unless stated otherwise, emissions savings refer to the entire EV fleet. Mileage and fuel economy assumptions here are the same as in Figure 4.1. CO₂ intensities are elaborated from *World Energy Outlook 2017* (IEA, 2017b).

Source: IEA analysis based on country submissions; IEA (2017b).

Key point: Global CO₂ emissions savings related to electric vehicles are largely in China where the number of EVs is high, even though power generation is carbon-intensive.

Local air pollutants

EVs emit no tailpipe emissions and therefore have significantly lower NO_x emissions than conventional diesel ICEVs. Thanks to regenerative braking, EVs can also reduce non-exhaust emissions from road traffic.⁷

The lower emissions of local air pollutants are one of the main drivers of interest in electric mobility in rapidly developing countries, such as India and China, where there are rising concerns about air quality in megacities.⁸

Local air pollution is also a driver for the shift to electric mobility in Europe, where dieselisation, combined with loopholes in the vehicle test procedures and the attempts from automakers to exploit them, has been one of the primary causes of dangerous levels of urban air pollution (Cames and Helmers, 2013).⁹

⁷ Despite the advantage due to regenerative braking, it is important to mention that EVs are typically heavier than equivalent ICE vehicles, and that vehicle weight tends to correlate with an increase in non-exhaust emissions of particulate matter (Achten, 2017a; Achten, 2017b). Increased weight may offset benefits delivered by regenerative braking, limiting EV advantages in terms of reducing PM emissions. Particulate matter from road traffic also comes from vehicle-induced resuspension of road dust. EVs offer little advantages over ICE vehicles in this respect.

⁸ Fully addressing these issues requires also the reduction of emissions occurring in the electricity generation, especially in regions with a coal-intensive power generation profile, like China and India.

⁹ Studies have shown that Euro 5 and Euro 6 diesel ICEVs emit between four and twelve times the regulated test cycle limit values when driven on the road (ICCT, 2017g; Chen and Borken-Kleefeld, 2014).

5. Batteries

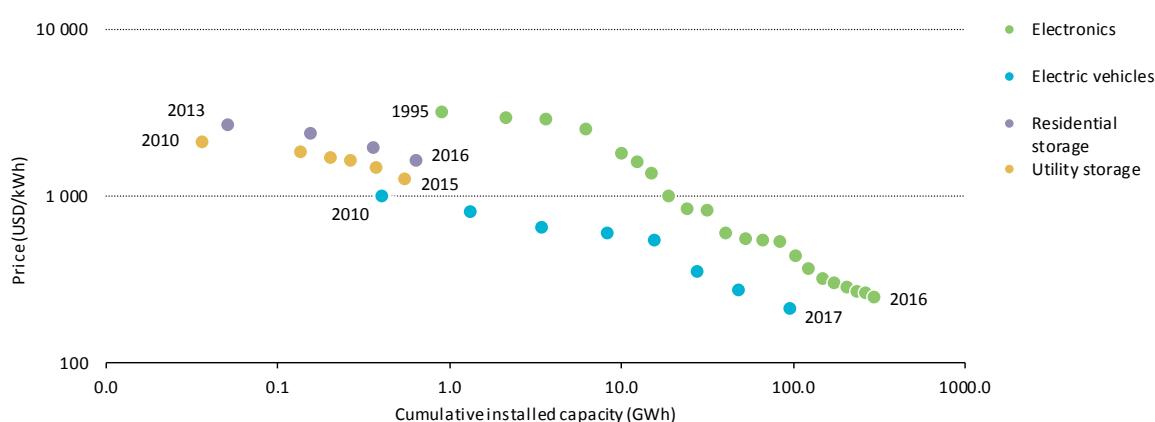
Current status

Figure 5.1 illustrates the cost reductions relative to cumulative manufactured capacity across lithium-ion (Li-ion) storage technologies used in various applications. It shows that Li-ion batteries have experienced significant cost reductions since their market introduction in the 1990s.

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The early development of batteries for consumer electronics provided invaluable experience in the production of Li-ion cells, underpinning the attainment of cumulative production capacity of 100 gigawatt-hours (GWh) by 2010 (Schmidt et al., 2017), enabling the achievement of very significant cost reductions and performance improvements over the past decade. These same developments made the development of Li-ion battery packs for EVs increasingly viable. Over the last five years, cost and performance improvements for EV battery packs supplemented continued technology developments in consumer electronics to become a major driver in the competitiveness of Li-ion storage systems for stationary applications.

Figure 5.1 • Lithium-ion storage technology price developments



Notes: Axes are on a logarithmic scale. Electronics refer to power electronic batteries (only cells); electric vehicles refer to battery packs for EVs; utility and residential storage refer to Li-ion battery packs plus power conversion system and includes costs for engineering, procurement and construction.

Source: Adapted and updated from Schmidt et al. (2017).

Key point: Lithium-ion storage technology prices have decreased as manufacturing volumes increased. Experience in manufacturing batteries for consumer electronics has driven cost reductions to the benefit of EV packs as well as stationary storage.

Today typical batteries used in EVs are based on the lithium-ion technology which has reached a development level enabling the design of vehicles that begin to match the performance of ICE vehicles. Current battery packs for light-duty applications have gravimetric energy densities of 200 Watt-hours per kilogram (Wh/kg) (Meeus, 2018) and volumetric pack energy densities of 200 - 300 Watt-hours per litre (Wh/l) (ANL, 2018). The lifetime of the battery is another important parameter. For EV batteries, a good proxy is the expected mileage associated with a battery's lifetime and its ability to retain a good share of its initial capacity (usually 80%). Available literature suggests that modern Li-ion chemistry for EV batteries can withstand 1 000 cycle degradation (Warner, 2015). Assuming a battery capacity of 35 kWh and an average consumption of 0.2 kWh/km suggests that

this cycle life threshold would not be attained over the first 175 000 km of driving and indicates that the lifetime of the battery is compatible with the expected lifetime for a car.

Cost and performance drivers

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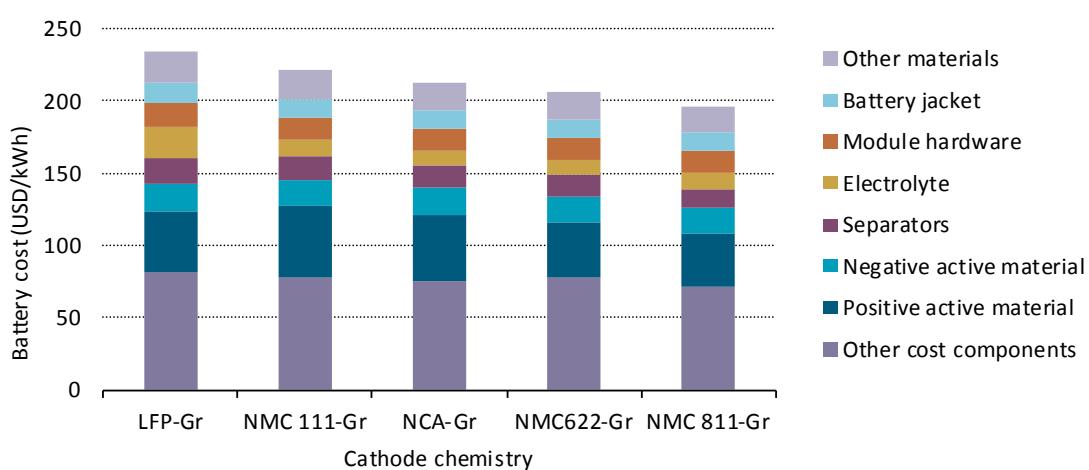
Notwithstanding the complexity of battery design and manufacturing, four key cost and performance drivers have been identified for Li-ion batteries: chemistry; capacity; manufacturing capacity; and charging speeds.

Battery chemistry

Battery cells are composed of a cathode (positive pole) and an anode (negative pole), and the cell's performance is influenced by the chosen chemistry. For the cathode, these include lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminium oxide (NCA), lithium manganese oxide (LMO) and lithium iron phosphate (LFP). In most current designs, the anode material is graphite but lithium-titanate (LTO) is also being used, especially in heavy-duty applications, because of its capacity to extend cycle life (Warner, 2015).

The main benefit of NMC and NCA technologies is their higher energy density compared with other chemistries, which is vital in LDVs and thus dominate the light-duty battery market. LFP is the main chemistry adopted for heavy-duty EVs (namely buses), despite lower energy density than NMC and NCA, as it benefits from higher cycle life and safety performances.

Figure 5.2 • Effect of change in battery chemistry on costs



Notes: Gr = graphite. Battery costs are evaluated for a 35 kWh electric vehicle battery produced at 100 000 packs per year using BatPaC V3.1. The software default settings were used for cost shares and cathode cost (USD 20/kg). Cathode costs imply metal prices around: USD 9/kg for nickel, USD 2/kg for manganese, USD 30/kg for cobalt, and USD 8/kg for Li₂CO₃. NMC 811 technical parameters are based on expert judgement and were developed on the basis of personal communications with S. Ahmed (Argonne National Laboratory).

Source: IEA analysis based on ANL (2018a).

Key point: The cost per kWh of currently available battery chemistries varies due to different energy densities and material needs.

The energy density of NMC based cathodes is proportional to the nickel content (HJ Noh, 2013). A higher energy density increases the amount of energy stored for a given quantity of active material. All else being equal, this reduces the production cost when measured per unit of energy stored. For example, moving from a cathode of uniform content of NMC 111 to one where the nickel atoms account for 60% of the cathode (NMC 622) can bring a cost decrease of 7% (Figure 5.2). An increase in nickel content also determines a decrease in the thermal stability of the battery cells: a challenge that must be overcome before the cost benefit of these novel chemistries can be harnessed.

The nickel content also influences costs as it determines the materials found in the active material. For example, battery chemistries that rely less on critical and expensive materials, such as cobalt, can enable cost reductions and reduce the sensitivity to cobalt prices (Figure 5.2). A cobalt price increase from USD 80 /kg to USD 120 /kg determines a 9% increase in battery pack cost for an NMC 111 while only a 2.5% increase in NMC 811 (ANL, 2018a).

Manufacturing capacity

The scale-up of industrial facilities for the production of batteries has a beneficial effect on costs, as the investment costs can be spread over a bigger production of batteries, enabling economies of scale. Our analysis suggests that current typical factory capacity range from about 0.5 GWh/year to 8 GWh/year, but most of the largest factories have capacities around 3 GWh (Table 5.1). Considering a typical battery capacity range of 20-75 kWh, these factory capacities translate to yearly production volume ranging between 6 000 to 400 000 packs.

Table 5.1 • Sample of main operational and announced Li-ion battery factories

Country	Manufacturer	Production capacity (GWh/year)	Year of commissioning	Source
Operational				
China	BYD	8	2016	TL Ogan (2016)
United States	LG Chem	2.6	2013	BNEF (2018)
Japan	Panasonic	3.5	2017	BNEF (2018)
China	CATL	7	2016	BNEF (2018)
Announced				
Germany	TerraE	34	2028	TerraE (2017)
United States	Tesla	35	2018	Tesla (2018b)
India	Reliance	25	2022	Factor Daily (2017)
China	CATL	24	2020	Reuters (2017f)
Sweden	Northvolt	32	2023	Northvolt (2017)
Hungary	SK innovation	7.5	2020	SK innovation (2018)

Note: CATL = Contemporary Amperex Technology Limited.

Key point: Today's battery factories have capacities of up to 8 GWh/year while factories announced to come online by 2030 will have capacities of up to 35 GWh/year.

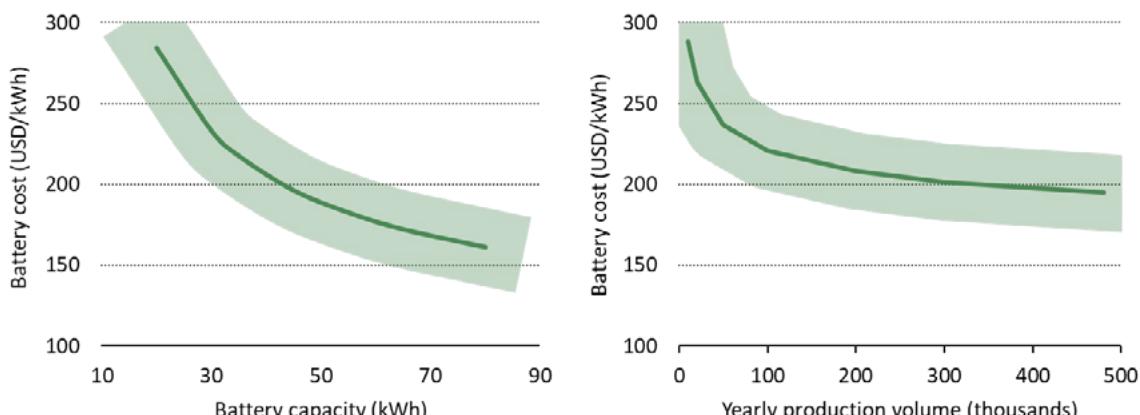
Using the BatPaC model with a range of assumptions on battery manufacturing capacities allows an estimation that the shift from an annual production of 10 000 packs to 50 000 packs could decrease battery costs by 9% (Figure 5.3) while an increase from 100 000 to 500 000 would imply a cost decrease of 12%.

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Battery size

- Battery sizes found in today's EVs vary considerably. For light-duty BEVs the range is about 20-100 kWh. The three bestselling Chinese EVs have battery sizes ranging between 18.3-23 kWh, mainly because they are small vehicles and their design focuses on affordability. Mid-sized cars in Europe and North America have battery capacities ranging between 23-60 kWh. Larger cars and SUVs have battery capacities between 75-100 kWh.
- Large batteries tend to have lower specific costs. A 70 kWh battery is expected to have a 25% lower cost per unit energy stored than a 30 kWh battery, all else being equal (Figure 5.3). This is because large batteries have a higher cell to pack ratio. The cost of the battery management and cooling systems is also spread across a larger energy capacity, reducing their significance per unit of energy stored. However, such an effect would be mitigated in cases where specialty cells with a higher specific cost were used. Figure 5.3 (left) provides an overview of the impact that changes in assumptions on battery size have on the cost per kWh based on results obtained for BatPaC runs.

Figure 5.3 • Effect of changes in size and manufacturing scale on battery costs



Notes: Battery costs refer to a mid-sized car battery evaluated using the BatPaC model (Version 3.1) of the ANL. When not subject to sensitivity, the technical specifications for the battery are: power of 100 kW, capacity of 35 kWh, production volume of 100 000 packs per year and NMC 111-Graphite chemistry. The shaded area represents the 15% uncertainty associated with BatPaC's cost estimates.

Source: IEA analysis based on ANL (2018a).

Key point: Battery size and manufacturing capacities have sizeable impacts on the cost of batteries per kWh.

Charging speed

Current charging speed enables 80% recharging in about 40-60 minutes in a fast charger. Such charging speed does not constitute a challenge for current battery design. While charging practices differ around the world, increasing the maximum speed of charging to ultra-fast charging (300-400 kW) is a desirable feature that would decrease the performance gap of EVs compared to ICE vehicles.

Designing batteries for ultra-fast charging increases the complexity of their design and shortens their lifetime. Accommodating fast charging requires specific battery design considerations, such as decreasing the thickness of the electrodes. These added design constraint tend to increase the cost of the battery and to decrease its energy density.

With an appropriate design and appropriately sized thermal management system, increases in fast charging are not expected to impact the battery's lifetime. On the other hand, an analysis conducted for the US Department of Energy suggests that the change in battery design to accommodate 400 kW charging would nearly double the cell costs (US DOE, 2017).

Technology development prospects

Indications from recent assessments of battery technologies suggest that lithium-ion is expected to remain the technology of choice for the next decade (Figure 5.4).

The main developments in cell technology that are likely to be deployed in the next few years include:

- For the cathode, the reduction of cobalt content in existing cathode chemistries, aiming to reduce cost and increase energy density, i.e. from today's NMC 111 to NMC 622 by 2020, or from the 80% nickel and 15% cobalt of current NCA batteries to higher shares of nickel (Meeus, 2018; Nitta et al., 2015; Chung and Lee, 2017).
- For the anode, further improvement to the graphite structure, enabling faster charging rates (Meeus, 2018).
- For the electrolyte, the development of gel-like electrolyte material (Meeus, 2018).

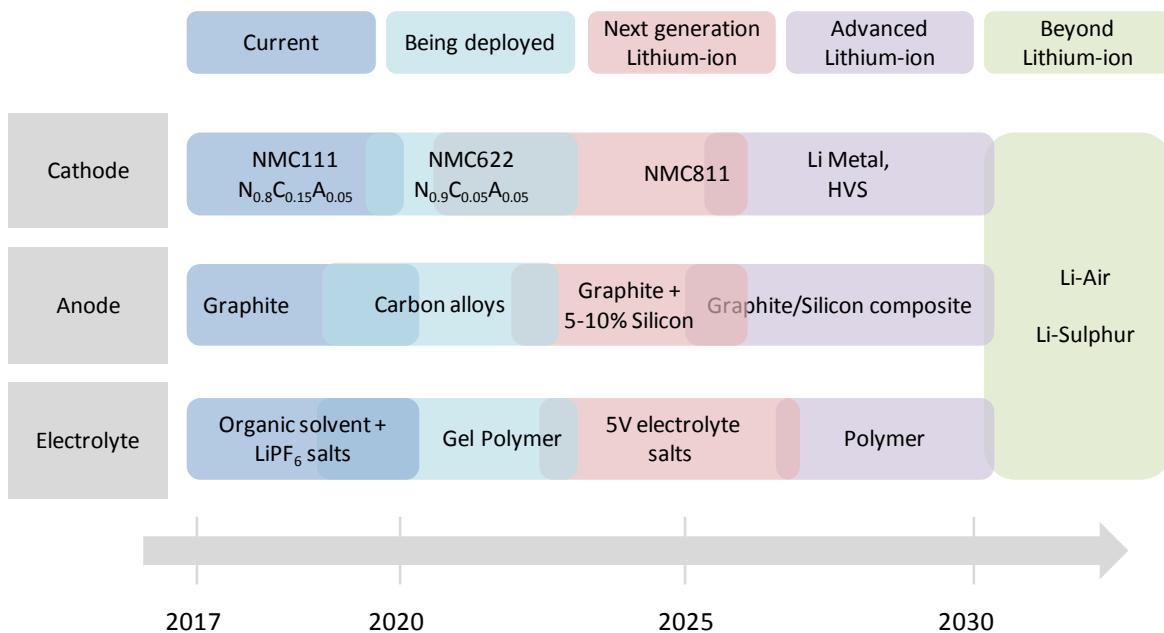
The next generation of Li-ion batteries entering the mass production market around 2025 is expected to have low cobalt content, high energy density and NMC 811 cathodes. Silicon can be added in small quantities to the graphite anode to increase energy density by up to 50% (Meeus, 2018), while electrolyte salts able to withstand higher voltages will also contribute to better performance.

In the 2025-30 period, technologies that promise significantly higher energy densities are likely to begin entering the market and would push the limits of Li-ion batteries (advanced Li-ion). For example, lithium metal cathodes are a promising avenue for Li-ion batteries with improved performance without relying on cobalt and anodes made of silicon composite might enter the design. In this period, solid state electrolytes might also be introduced and further improve energy density and battery safety.

The Li-ion technology might be overtaken by other battery designs that boast higher theoretical energy densities as well as lower theoretical costs. Examples include Li-air and Li-sulphur batteries. However, their technology readiness level is very low, practical performance has yet to be tested and the performance advantage over lithium-ion is still unproven.

Even if battery cells with substantially different designs were to become available in the market by 2030, a time lag due to the need to build up production capacity would delay wide availability on the market for these advanced technologies. This is why most batteries are expected to belong to the "Next generation" technology class in 2030.

Figure 5.4 • Expected battery technology commercialisation timeline



Notes: HVS = high voltage spinel. The diagram shows the likely beginning of commercialisation of a given technology.

Sources: IEA analysis based on Howell (2016); Meeus (2018); Nationale Plattform Elektromobilität (2016); NEDO (2018); Pillot (2017).

Key point: Lithium-ion is expected to remain the technology of choice for the next decade, when it is expected to take advantages of a number of improvements to enhance battery performance. Other technology options are expected to become available after 2030.

Cost estimates

Light-duty vehicles

In light of current technological and market conditions, it is possible to estimate a cost range for batteries produced in 2017 using BatPaC. Using a range of battery capacities between 20 kWh and 75 kWh and a production capacity between 0.5 GWh/year and 8 GWh/year, the model returns a range of costs that varies between 360 USD/kWh for small batteries produced in small volumes to 155 USD/kWh for large batteries produced in large volumes.

The mid-range of the spectrum is compatible with a battery pack price of 274 USD/kWh that can be implied by comparing vehicle models available with both an ICE and a EV powertrain (such as the Volkswagen e-Golf). Cost announcements made by General Motors of cell prices of 145 USD/kWh (Reuters, 2017g) are consistent with the lower end of the cost spectrum presented here.

Once battery costs are averaged based on production volumes, the result is expected to lean towards the lower end of the USD 155-360/kWh range. This is because of the larger production volumes associated with the lower cost packs.

While at a cell level plug-in hybrid electric vehicles can benefit from the same economies of scale enjoyed by BEVs, battery packs for PHEVs are expected to be more expensive on a per unit energy basis because of their higher pack to cell ratio. As a result, typical PHEV batteries would cost 20% more than BEV batteries.

Cost reductions for batteries over the period to 2030 are likely to stem from three main drivers:

- Battery capacities will increase to serve large all-electric driving ranges.
- Battery manufacturing will take place in plants with large production capacities that provide economies of scale.
- Battery chemistries will evolve to options with higher energy density and lower reliance on cobalt.

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Assuming NMC811/graphite chemistry, production capacity range of 7.5-35 GWh/year and battery capacity range of 70-80kWh, the costs resulting from the use of the BatPaC model range from USD 100/kWh to USD 122/kWh. This is aligned with EV battery cost reduction targets in 2030 for the European Union at USD 93/kWh (Omar, 2010), the People's Republic of China ("China") at USD 116/kWh (Hao et al., 2017) and Japan at USD 92/kWh (NEDO, 2018).

Other transport modes

Two-wheelers

Battery capacities able to guarantee sufficient travel distances for two-wheelers are likely to range between 1.5 kWh to 4 kWh. If these capacities were to be coupled with the results shown in Figure 5.3, battery costs for two-wheelers would be subject to very high costs per kWh. However, Figure 5.3 has a focus on packs suitable for cars and cannot not be directly applied to two-wheelers. This is because battery packs for cars have components, such as a cooling system, that would not be necessary for batteries that have power ratings suitable for two-wheelers. Power requirements for two-wheelers are comparatively low and there is no need for fast charging since their charging time is relatively short even on slow chargers.

The simpler characteristics of battery packs for two-wheelers suggest that their structure would be subject to a lower degree of complexity compared with battery packs for cars. As a result, the battery cost for two-wheelers (USD 240-550/kWh) is likely to fall roughly 50-60% more than the range estimated for electric cars, assuming that the cells can be produced at similar costs, even if battery capacities for two-wheelers are significantly lower.¹ This means that the economies of scale driven by the electrification of LDVs are likely to have positive spill over effects on two-wheelers, opening significant opportunities for the use of Li-ion batteries in two-wheel vehicles.

Heavy-duty vehicles

For heavy-duty vehicle applications, very large battery packs have the advantage of increasing the cell to pack ratio compared with LDV batteries. This has positive effects on the possibilities to achieve cost reductions. However, battery cells for HDV applications must have a higher cycle life. This usually involves using LFP cathodes, having higher specific costs than typical NMC designs. In addition, HDV batteries must be designed to sustain high charging loads to enable reasonable charging times. This is an element that contributes to increased costs per kWh, both due to chemistry (LTO is often used instead of graphite) and due to more complex thermal management systems. As a result, there are good reasons to consider that opposing divers (larger batteries and therefore lower costs per kWh, but also tighter requirements in

¹ The 50% assessment used here is based on an average of 10%, corresponding to a case where two-wheeler battery costs per kWh are assumed to be equal to those of a single module for a car pack (lower bound) and 110% resulting from the use of the BatPaC model (developed for cars) with a battery capacity limited to 3 kWh, 14 cells and two modules.

terms of durability and charging power) lead to pack costs per unit energy for HDVs that may not deviate significantly from the cost range discussed for cars.

Implications of battery technology developments for EV uptake

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The section looks at three main transport modes, LDVs, two-wheelers and urban buses, with the aim to identify cases that result in favourable conditions for a transition to electric mobility.

Building on the earlier discussion about battery costs, a cost range of USD 100-350/kWh is used to evaluate the impacts that changes in battery prices could have on the evolution of the purchase price and the total cost of ownership (TCO) for BEV cars and bus batteries that are discussed in this section. While this assessment is primarily aiming at the evaluation of the cost competitiveness of EVs in current market conditions, the inclusion of a cost estimate as low as USD 100/kWh helps understanding what could be happening in the 2030 framework.²

In this evaluation, batteries for PHEVs are assumed to cost 20% more than BEV equivalents. Batteries for electric cars and heavy-duty vehicles are assumed to be in the cost range discussed in the previous section, while batteries for two-wheelers are assumed to be 50% more expensive per kWh. An increment of 10-15% has been added to all cost estimates to account for the difference between production costs and sales price. Figure 5.5 and Figure 5.6 compare TCO of electric LDV types with ICE cars at three battery price levels. These views enable an “apple-to-apple” comparison of battery technologies across modes and vehicle types, despite price differences due to the technical characteristics (primarily battery size and storage capacity) of the batteries.

LDVs

The total cost of ownership for an electric car is higher than for a conventional ICE car; currently this is the most significant factor limiting consumer’s uptake of electric cars. Today’s purchase price of an electric car is significantly higher than an ICE one, and, in most cases, this price difference outweighs the appreciably lower fuel and maintenance costs for an electric car. However, declining battery prices will have substantial impacts on how these parameters evolve. Therefore, it is useful to better understand whether, and under what circumstances, electric and ICE cars may reach cost parity.

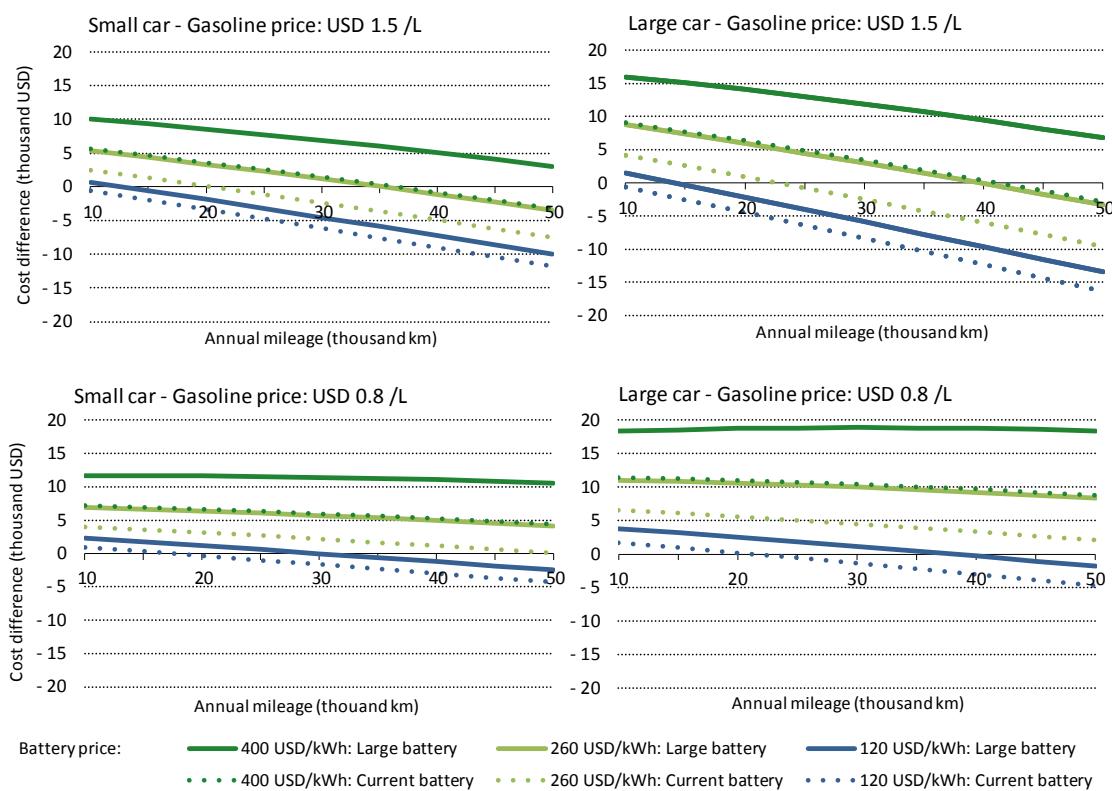
The TCO gap for an electric car, benchmarked against the ICE (i.e. the incremental cost of a battery electric car if compared with an internal combustion engine car), is shown in Figure 5.5. The figure highlights the impacts of varying with four key parameters: battery price; car size (affecting the fuel economy and the size of the EV battery); fuel prices and annual mileage. The battery price assessment is detailed in two cases: current and large, in order to reflect an additional dimension to optimise BEVs. The analysis uses first-owner parameters.³

The vehicle characterisation used for this TCO analysis is also intended to reflect specifications (e.g. in terms of battery size and vehicle power) that, depending on the assumptions used, could be reasonable either for the near term (current batteries, higher prices/kWh) or for a 2030 framework (large batteries, lower prices/kWh).

² These indications are an approximation that does not take into account of improvements in the energy consumption per km of ICEVs and EVs. Should these changes be taken into account, EVs would have significant cost advantages from lower battery costs, while ICEVs would see their operational costs decline more than EVs. Improvements in the energy use per km of EVs result in a downward shift of the curves shown in the TCO figures 5.5-5.9 (this shift is greater for BEVs, given the larger batteries they require), while improvements for ICEVs result in lower reductions of the cost gap with increasing mileages.

³ This is assuming 3.5 years of ownership and accounting for residual value after depreciation with annual depreciation rates in line with those observed historically, and conservatively assuming faster depreciation for battery components.

Figure 5.5 • Comparative total cost of ownership of a different sized BEV and ICE at three battery price levels



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Notes: High fuel price level: USD 1.5 per litre of gasoline equivalent (Lge). Low fuel price level: USD 0.8/Lge. Assumptions used for the small car example: power of 85 kW, 60 kWh for the large battery case, 40 kWh for the current battery, electric vehicle fuel economy of 0.20 kWh/km and ICE vehicle on-road fuel economy of 6.6 Lge/100 km. Assumptions used for the large car example: power of 172 kW, 93 kWh battery for the large battery example, 62 kWh for current battery case, electric vehicle fuel economy of 31 kWh/100 km and ICE vehicle on-road fuel economy of 10.3 Lge/100 km. These assumptions are consistent with a range of about 300 km for both car sizes. The calculations assume an electricity price of USD 0.12/kWh and an additional charging cost of USD 0.04/kWh. The capital costs of buying the vehicle are differentiated between a BEV and an ICE vehicle according to the difference in powertrain costs. These costs are subject to an annual depreciation rate that is variable depending on the annual mileage level (higher levels experience higher annual depreciation rates). An average ownership time of 3.5 years is assumed. Annual maintenance costs of a BEV are approximately 20% of the costs for an ICE vehicle. The cost of tyres per km is nearly double for a BEV compared with an ICE vehicle. The large battery case represents the battery sizes we anticipate around 2030. The current battery case reflects battery sizes expected around 2020. Results shown here assume constant energy use per km for ICEVs and BEVs.

Key point: Choosing a BEV over an ICE vehicle is more attractive for small cars if battery costs are low, fuel prices are high and daily distances driven are high.

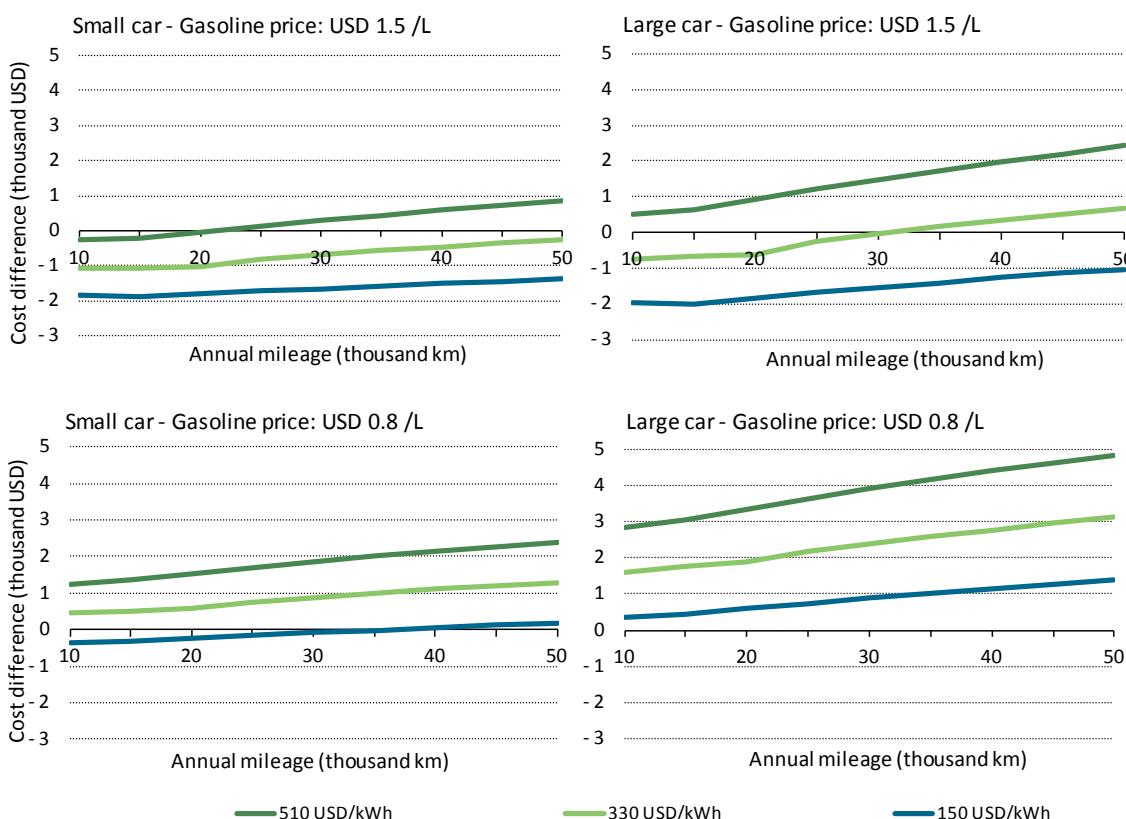
A number of lessons can be drawn from Figure 5.5⁴, including:

- The TCO gap between BEV and ICE cars reduces significantly for vehicles with high annual mileage.
- Battery and gasoline prices have a larger influence on the TCO gap than the size of the car.
- With a battery price of USD 120/kWh and a high gasoline price (comparable to today's price level in Europe), a BEV is an economical choice for all driving mileage profiles.

⁴ Note that these considerations do not change even when accounting for a 30% reduction of the energy use per km of an ICE vehicle and a contextual 20% reduction for a BEV (a case not shown in Figure 5.5).

- With a battery price of USD 260/kWh, BEVs are competitive in cases of high annual mileage and high gasoline prices.
- Although small BEV cars are more competitive with ICEs cars, large electric cars also have potential to become competitive with similar ICE cars, especially with high annual mileage and high gasoline prices.
- When battery prices are higher, (e.g. in the ramping up phase of production), limiting the battery capacity (and therefore the driving range) can have significant impact to lower the TCO parity threshold between battery electric and internal combustion engine cars.
- This analysis also confirms that fuel taxes and purchase price incentives can have a large influence on the TCO gap between an ICE and electric car, lowering the cost gap between the two technologies.

Figure 5.6 • Comparative total cost of ownership of a PHEV and ICE at three battery price levels



Notes: Most assumptions used in this figure are the same as in Figure 5.5 (see notes). However, the assumed size of the battery is lower: 12 kWh in the case of a large car, and 8 kWh in the case of a small car. The electric driving capability for PHEVs is assumed to be fully exploited in the figure. The assumed annual maintenance costs for a PHEV is around 40% that of an ICE, and the costs of a tyre/km is the same for a PHEV and ICEV. Results shown here assume constant energy use per km for ICEVs and BEVs.

Key point: Choosing a PHEV over an ICE vehicle is more attractive for small cars if battery prices are low and fuel prices are high. The cost gap also is significantly influenced by the share of electric driving for PHEVs.

Figure 5.6 shows the TCO gap when a PHEV is compared with an ICE car. Key insights stemming from Figure 5.6⁵ include:

- The slope of the curves outlining the TCO parity is reversed when compared with Figure 5.5. At low annual mileage, and provided that they can maximise the portion of driving in electric mode, PHEV are competitive with ICE cars. On the other hand, the competitiveness case for a PHEV is weaker with high levels of annual mileage. This is due to limits of available battery capacity such that the portion of electric driving is likely lower for high mileage usage. This limitation suggests that large cars in low fuel price contexts struggle to be cost competitive on a first-owner economics basis, unless their electric driving range is increased.
- TCO parity thresholds are also dependent on the fuel taxation regime for PHEVs, with much lower values in cases of higher taxes on petroleum fuels.
- Cost parities for PHEVs are reached at higher battery costs per kWh for PHEV packs (than for BEVs), even accounting for the 20% incremental cost due to higher pack to cell ratio.
- In addition, it is important to note that the cost competitiveness of PHEVs is significantly reduced if the fuel economy of ICEs improves faster than the energy use per km of electric motors.

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Several variables affecting the TCO gap between electric and ICE cars are region-specific and affect the average TCO levels observed in those regions (IEA, 2017a). The high gasoline price level indicated in Figure 5.5 and Figure 5.6 is comparable to the gasoline price level in Europe today, and the low gasoline price level is comparable to today's level in the United States. In North America, cars, on average, are larger than in Europe and Asia, and annual miles driven are higher. Vehicle size and power vary in other regions too. LDVs in countries such as Brazil, China and South Africa have sizes and power ranges that are comparable to those of Europe, Japan and Korea. In contrast, vehicles in India are characterised with small average size and power ratings (GFEI, 2017). Climate conditions can also have an impact on the case for electric cars. For example, winter tests carried out in Nordic countries show that BEVs have a range that is on average 27% lower on very cold days because of the need to use energy for interior vehicle heating (Haakana et al., 2013). Similarly, countries with hot climates and a high need for air conditioning require larger batteries to cover the same distance.

The implications of this cost assessment, combined with the regional differences and the varying policy frameworks characterising various regions are discussed in Chapter 6 of this report.

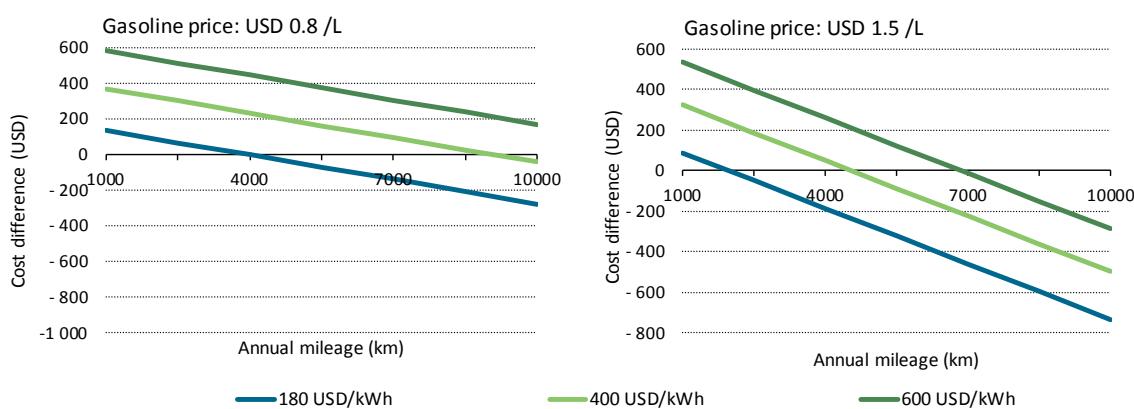
Two-wheel vehicles

Figure 5.7 shows that the TCO gap between an ICE two-wheeler and an electric model is small when accounting for 3.5 years of vehicle ownership and indicates that electric two-wheelers with a range of 70 km and a power rating of 6.5 kW (in line most current ICE two-wheelers) are a more economical choice for first owners travelling more than 7 000 km/year (i.e. 27 km /weekday) and in countries with high gasoline taxes (similar to current levels in Europe), even with battery pack prices of USD 600/kWh. The breakeven mileage falls to roughly 5 000 km/year (19 km/weekday) if the battery pack cost is USD 400/kWh. The same battery prices make electric scooters competitive with ICE models also in places with low gasoline taxes for mileage exceeding 9 000 km/year (35 km/weekday). Pack prices of USD 180/kWh make electric scooters economical for annual

⁵ Note that these considerations do not change even when accounting for a 30% reduction of the energy use per km of an ICE vehicle and a contextual 20% reduction for a PHEV (a case is not shown in Figure 5.6).

mileage lower than 2 000 km/year (8 km /weekday) in places with gasoline taxes similar to Europe, and for mileages around 4 000 km/year (15 km/weekday) in other regions. Since average mileage for two-wheelers typically exceeds 6 000 km/year even in densely populated urban areas, these results suggest that the economic case for electric two-wheelers is strong, especially in regions with high fuel taxation on gasoline if cost reductions due to the scale-up of battery manufacturing are effectively achieved.

Figure 5.7 • Comparative total cost of ownership of an electric and an ICE two-wheeler



Notes: High fuel price level: USD 1.5 per litre of gasoline equivalent (Lge). Low fuel price level: USD 0.8/Lge. For the calculation of engine costs, both models are assumed to have a power rating of 6.5 kW, with on-road fuel economy of 2 Lge/100 km for ICEs and 0.04 kWh/km for electric two-wheelers. For the electric model, the size of the battery is 2.5 kWh, enabling a range of 70 km. The calculations assume an electricity price of USD 0.12/kWh and no additional charging cost. Powertrain and fuel storage costs are assumed to be the only determinants of the difference in the purchase cost between the battery electric and ICE two-wheeler versions. Purchase costs are subject to an annual depreciation rate. All calculations are performed taking into account an average ownership of 3.5 years.

Key point: The economic case for electric two-wheelers is strong: in countries with high fuel taxes electric two-wheelers are already cost competitive with gasoline models.

Urban buses

The total cost of ownership comparison of electric buses versus conventional buses is shown in Figure 5.8.⁶

The TCO comparison indicates that electric buses that average 45 000 km/year (corresponding to nine hours use every weekday with an average speed of 19 km/h) and use overnight charging are cost competitive in high and low income regions with diesel taxation levels comparable to Europe, when battery packs are available at a price lower than USD 260/kWh.

The mileage threshold for buses operating in regions with lower diesel taxes is much higher, all else being equal. Figure 5.8 also shows that the breakeven point is similar in countries with different income levels. The small difference is consistent with the assumption that the investment cost gap between a diesel and an electric bus is not heavily dependent on income.

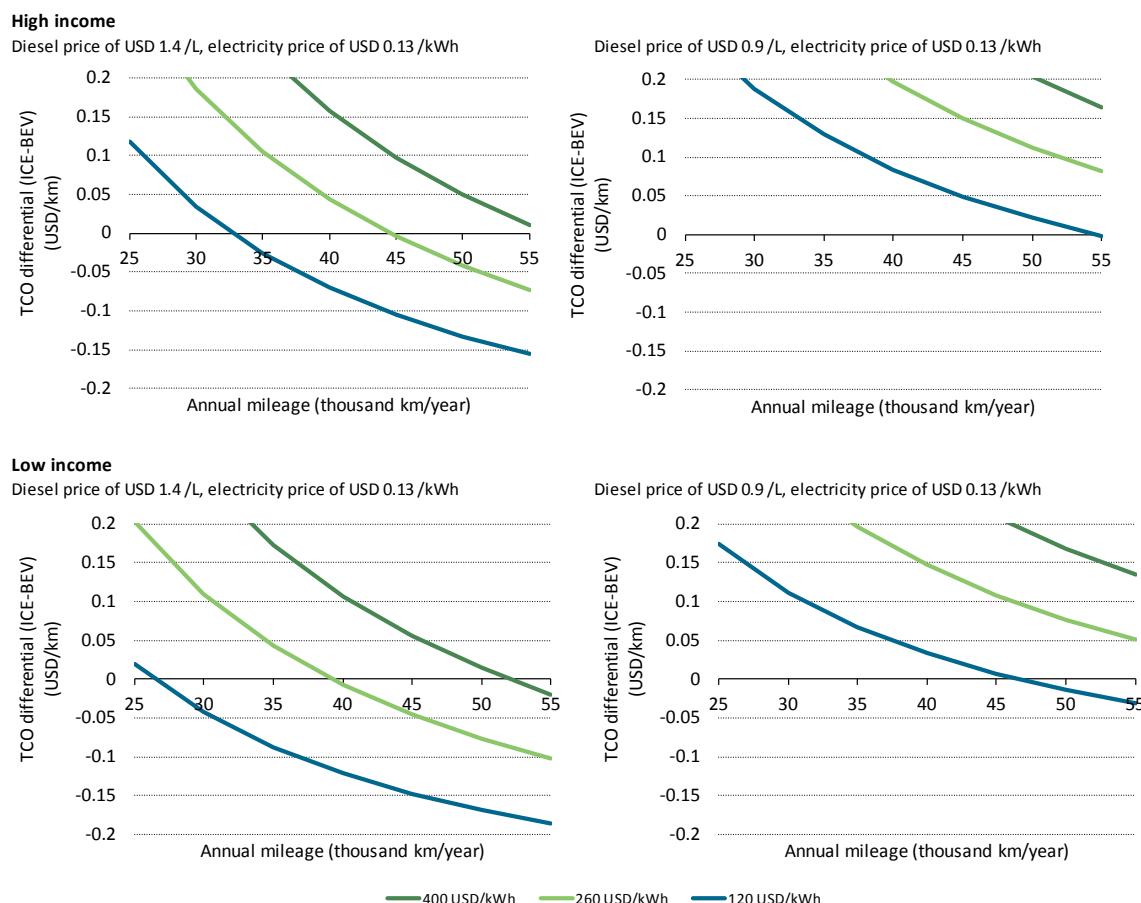
Given that China applies taxation rates that are at the low end of the range used for Figure 5.8; these results support the conclusion that China's recent surge in electric bus penetration has been driven by subsidies and regulations, rather than by economic drivers.

⁶ This assessment for electric buses is solely focused on overnight charging, which currently is the common practice; it does not include a discussion of opportunity charging. TCO for opportunity charging are estimated to be lower than for overnight charging (due to lower battery requirements on buses and charging infrastructure shared across vehicles) (Lajunen, 2018).

Cost reductions resulting from battery technology improvements and ramping up production clearly result in negative TCO/km gaps with ICE buses in countries with fuel taxes comparable to Europe. This demonstrates that there is a compelling case for bus electrification in the European context.

Figure 5.8 • Total cost of ownership gap between ICE (diesel) and electric buses

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Notes: The electric bus modelled is equipped with a 330 kWh battery, which provides a range of around 240 km. Electric buses are assumed to recharge at night with a plug-in 50 kW charger. The difference in TCO is evaluated over a ten-year lifetime, taking into account the depreciation of vehicles (25% per year) and batteries (35% per year), and using a 5% discount rate to account for future costs. Diesel and electric bus body and component costs vary with income levels: buses used in high income regions are assumed to have body components with higher prices. Price gaps have been estimated to reflect the local market conditions. A bus body in a high income region is assumed to cost USD 250 000 for a diesel configuration and USD 290 000 for an electric one. The body component costs assumed for a low income region are USD 120 000 for diesel buses and USD 160 000 for electric buses. High fuel taxes are assumed to result in diesel prices of USD 1.4/L and low fuel taxes in diesel prices of USD 0.9/L. Maintenance costs for the electric buses are assumed to be half those of diesel buses as there are far fewer parts that are susceptible to wear. Costs associated with the charging infrastructure (one fast charger per each electric bus) are included in the assessment.

Key point: Electric buses travelling 40 000-50 000 km/year are cost competitive in regions with high diesel taxation regimes if battery prices are below USD 260/kWh. Expected reductions in battery prices make a compelling case for bus electrification in these regions.

Trucks

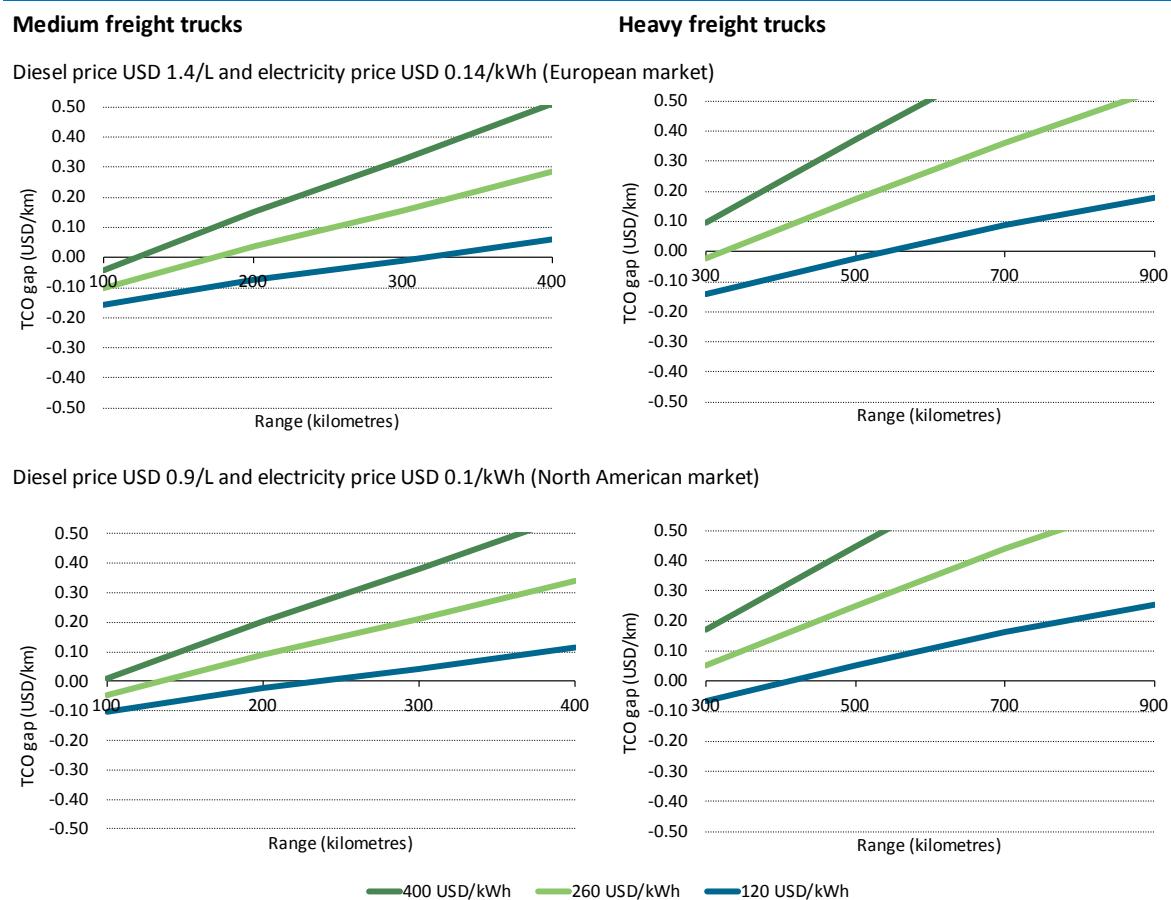
The key elements in the assessment of the breakeven costs for medium freight trucks (MFTs) and heavy freight trucks (HFTs) are the following:

- Cost differential between diesel and electricity.

- Annual mileage, which varies between trucks used for urban delivery, regional missions and long-haul duty cycles.
- Autonomy (driving range on a single charge) of battery electric trucks.

Figure 5.9 shows the impacts of these three factors on the driving range at which battery electric MFTs (trucks with a gross vehicle weight [GVW] in the range of 3.5-15 tonnes) and HFTs (GVW greater than 15 tonnes) under a range of battery pack costs.

Figure 5.9 • Total cost of ownership versus driving range at various battery pack costs for medium and heavy freight trucks



Notes: The TCO is compared over ten years, which is the typical duration of ownership, with a 10% discount rate and includes the salvage value of trucks after depreciation over the period (assumes that both ICE diesel trucks and BEV trucks depreciate at the same rate). The figure assumes an annual average mileage of 45 000 km for MFTs and 90 000 km for HFTs, but with higher mileage in the initial years of operation and declining mileage over time, as is common for trucks. The TCO curves consider driving ranges, which coupled with fuel use per km, determine the capacity sizing in kWh of the battery. Two price regimes are shown and are meant to be representative of European prices (USD 1.4/L for diesel and USD 0.14/kWh for electricity) and North American prices (0.9 USD/L for diesel and 0.10 USD/kWh for electricity). All other parameters are held constant. Charging infrastructure costs (assuming the use of a mega-charger of 1 200 kW and USD 860 000 for heavy freight trucks, and a fast charger of 180 kW and USD 130 000 for medium freight trucks), 30% daily usage rates, ten-year lifetime and a 10% discount rate to amortise costs) are included.

Key point: The autonomy (driving range on a single charge) of battery electric trucks is a crucial determinant of their cost competitiveness against ICEs.

For the energy price levels that characterise the examples used for the analysis, trucks only begin to become viable competitors once battery prices are lower than USD 260/kWh. At this price

threshold⁷, MFTs with maximum driving range of roughly 180 kilometres become competitive in Europe and those with a range of less than 150 kilometres become competitive in the United States. At USD 260/kWh battery prices, HFTs become competitive over ten years of ownership in Europe if they operate with a very limited all-electric range (close to 300 km). Electric HFTs operating with daily ranges of 300 km will only become competitive in a price regime like that of the United States once battery pack prices fall below USD 170/kWh.

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This analysis shows that battery electric trucks might have a potential use for urban and regional deliveries in regions where diesel prices are high. As the payback accrues only after many years of operation, electric trucks are likely to be purchased first and primarily by large fleets that have low discount rates and can accept long payback periods. Indeed, large carriers account for nearly all of the orders of prototypes and marketed battery electric trucks to date. But even in developed markets like Europe and the United States, road freight is a very unconsolidated industry; the majority of trucks are owned and operated by individuals or business with fewer than five trucks (IEA, 2017c).

⁷ This assessment is based on the assumptions considered in the note to Figure 5.9, and is subject to significant sensitivities to the values retained there.

6. Outlook to 2030

Definition of the scenarios

This section presents the outlook for the deployment of electric vehicles in the period to 2030 in two scenarios:

- The New Policies Scenario (NPS) is the central scenario of the IEA's *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 policies that are expressed in official targets or plans. In particular for this report, it includes key policies in place as well as recent updates as presented in the sections on Vehicles and Electric vehicle supply equipment (Chapters 2 and 3) of this report.
- The EV30@30 Scenario, which is consistent with the ambitions pledged by EVI countries in the EV30@30 Campaign Declaration (CEM-EVI, 2017). In this scenario, the EV30@30 target – the 30% market share of EVs for LDVs, buses and trucks collectively – is met at the global level. If accompanied by a reduction of the carbon intensity of power generation exceeding 50% by 2030, this goal is in line with the Paris Agreement, as growth in the market uptake of EVs continues after 2030 (IEA, 2017d).¹

Electric vehicles

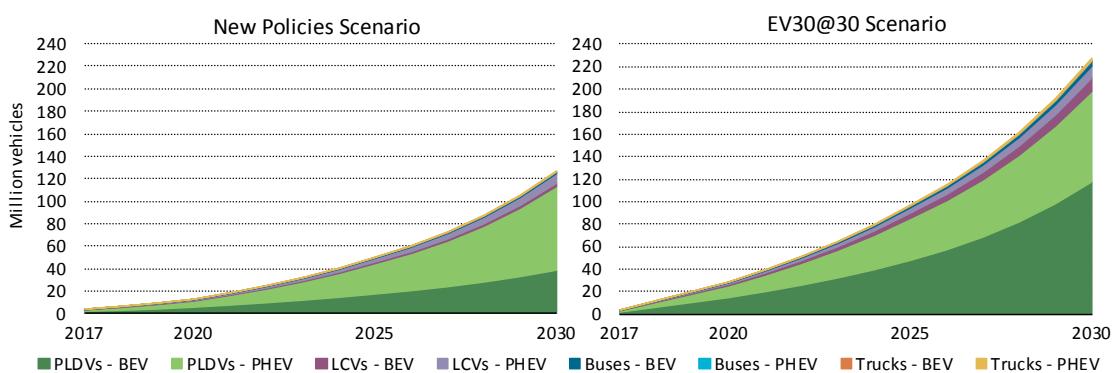
Global results

The New Policies Scenario projects a global stock of EVs of 13 million vehicles by 2020 (up from 3.7 million in 2017) and nearly 130 million vehicles by 2030 (excluding two- and three-wheelers) (Figure 6.1). Sales of EVs in 2020 would be about 4 million (up from 1.4 million in 2017) and expanding to 21.5 million by 2030. This corresponds to a 24% average year-on-year sales growth over the projection period.

The EV30@30 Scenario projects a global stock of 228 million EVs by 2030 (excluding two- and three-wheelers) (Figure 6.1). This is roughly 100 million more in 2030 than in the New Policies Scenario. Achieving these levels requires a rapid scale up and geographical expansion of policy commitments, starting as soon as possible.

¹ In the EV30@30 Scenario, technological transitions in the transport sector contribute to efforts to reach the targets and goals. In addition, avoid and shift measures play a large role such as encouraging fewer trips by car, reducing average trip distances, improving the operational efficiency of all transport modes and promoting modes such as public transportation, walking and cycling.

Figure 6.1 • Global EV stock by scenario, 2017-30



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2018b).

Key point: The EV30@30 Scenario sees 228 million EVs (excluding two- and three-wheelers), mostly LDVs, on the road by 2030. This is about 100 million more than in the New Policies Scenario.

Two- and three-wheelers

The number of electric two- and three-wheelers on the road increases from around 300 million in 2017 to 455 million by 2030 in the New Policies Scenario, and 585 million in the EV30@30 Scenario. Under both scenarios, the growth in electrification for these modes is significant. By 2030, the number of electric units attains 39% of the global stock of two-wheelers in the New Policies Scenario and 50% in the EV30@30 Scenario. The majority of the two- and three-wheelers entering the market by 2030 are in the People's Republic of China ("China"), India and the ASEAN countries.

These projections reflect the good economic case for a transition to electric two-wheelers and indicate that the expected increase in battery production capacity for automotive applications will also enhance availability of affordable battery cells, suitable for the two-wheeler market (see Figure 5.7). The lower level of two-wheeler deployment in the New Policies Scenario also reflects a policy landscape that is less supportive of the electrification of two-wheelers than for LDVs. Examples include a lack of fuel-economy standards for two-wheelers and little use of access and circulation restrictions in countries other than China.

These projections do not include any penetration of plug-in hybrids among two- and three-wheelers. This is because BEVs are best suited for light-weight, short-range vehicles, as they do not incur costs associated with the use of complex PHEV powertrain architecture.

Light-duty vehicles

In both scenarios, by 2030, electric LDVs (including PLDVs and LCVs) are the second-largest mode in volume terms after electric two- and three-wheelers. If two- and three-wheelers are excluded, LDVs represent over 97% of new EVs on the road in 2030. This reflects the predominance of LDVs in the road vehicle fleet, as well as higher EV market penetration than in medium- and heavy-duty long distance vehicles.

New Policies Scenario

Figure 6.1 shows that the electric LDV stock in the New Policies Scenario reaches 12 million vehicles in 2020, representing almost 1% of the world total LDVs. It reaches close to 6% of the global LDV stock in 2030, with 125 million units. On the sales front, 3.9 million electric LDVs are sold in 2020 (3% of the global LDV market) and 21 million in 2030 (13% of the global LDV market) in the New Policies Scenario. Both the stock and sales growth were observed mostly for passenger light-duty vehicles, which represent 90% of the total of all-electric LDVs in 2020 and 2030.

The increase reflects existing and announced policies at local, national and supra-national levels. The policy-driven growth in EV sales underpins economies of scale and fosters technology development which reduces battery pack costs, increases opportunities to cut the purchase price of electric LDVs and to improve their performance.

The uptake of electric LDVs is expected to be more robust in urban areas, which are characterised by moderate average daily driving distances and available charging outlets. Measures by local and regional authorities to reduce harmful air pollution provide incentives for the diffusion of electric vehicles (Table 2.3 and Table 2.4). Taxis and ride-hailing service vehicles are common in urban areas and they have a good profile for electrification due to their high daily mileage (exposing them to favourable conditions to enhance the competitiveness of electric models on a TCO basis, as shown in Figure 5.5). Taxis and the like are particularly subject to use during traffic peaks (and therefore fairly free to charge at off-peak times). Cities could also be impacted by the development of self-driving vehicles, with notable implications for electrification.²

In the New Policies Scenario, stocks and sales for LDVs are almost equally split between PHEVs and BEVs in 2020, and lean towards PHEVs in 2030. This is the result of regional differences, with some markets having a stronger initial orientation towards BEVs and others being more PHEV focused (primarily reflecting policy measures, particularly fiscal incentives). The electric LDV market evolution outlined here attempts to factor in the following elements:

- Better cost competitiveness for PHEVs at low mileage, playing in favour of PHEV uptake over BEVs for the traditional vehicle ownership mode, especially in households with a single car.
- More flexibility for individuals purchasing a PHEV because of options in terms of use, combined with higher hurdles for BEV owners when travelling long distances, also playing in favour of PHEVs.
- Increased advantages for BEVs at high mileage for vehicles having easy access to overnight charging, and therefore greater suitability for taxi services.
- Better opportunities for cost reductions for batteries with larger capacity (though with higher upfront costs), suggesting that there could be room for BEVs in the high value added segments of the car market, and not only for the small vehicle class (where upfront cost would be lower, due to lower battery capacity requirements).

² Whether EVs will be better placed than conventional ICEVs to fulfil all the operational and technical requirements of shared and/or autonomous vehicles also depends on the progress that will be made to minimise the power demand of the devices enabling self-driving capabilities.

EV30@30 Scenario

Under the EV30@30 Scenario, 100 million more electric LDVs are put in circulation by 2030 in comparison with the New Policies Scenario, reaching 220 million units in 2030, when the electric LDV stock share is 12%. This is in a context where the total number of LDVs on the road in the EV30@30 Scenario is 12% lower than in the New Policies Scenario, due to measures aiming to avoid traffic and shift travel activity to other modes. Electric LDV sales in the EV30@30 Scenario are projected at 38 million in 2030. The penetration rate of BEV and PHEVs differs significantly between the two scenarios: by 2030, one-third of electric LDVs are BEVs in the New Policies Scenario, while BEVs are close to 60% of all electric LDVs in the EV30@30 Scenario. This reflects the assumption of a context with more accessible charging infrastructure, tighter fuel-economy standards with extended timelines, regulatory incentives favouring zero-emission vehicles and more restrictions on ICE vehicle use. The same conditions also lead to a growing share of the annual mileage of PHEVs that makes use of electricity rather than liquid fuels.³ The higher reliance on BEVs in the EV30@30 Scenario is also consistent with a faster depreciation for vehicles fitted with internal combustion engines (including PHEVs), as well as higher taxes on fossil fuels.

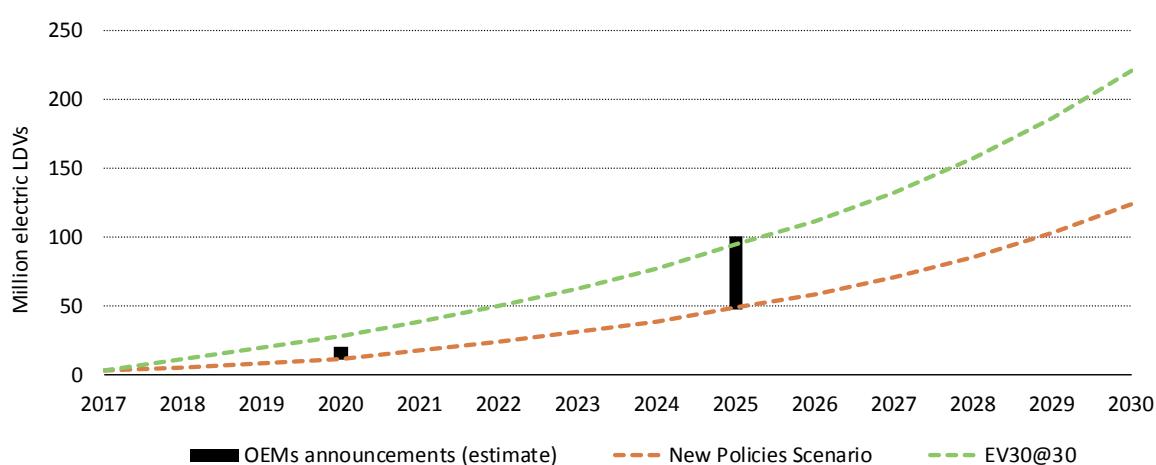
Benchmarking scenario results against manufacturers' targets for LDVs

An important parameter to observe when it comes to projections of EVs is the future availability of models. Many original equipment manufacturers (OEMs) are still in the process of ramping up production, and so an assessment of the extent to which they will be able to supply vehicles to the market is still dependent on OEM announcements (Table 2.5). Most OEMs have typically made announcements that indicate planned production volumes for either 2020 or 2025; stacking these announcements (Figure 6.2) up reveals a number of interesting indications:

- OEM announcements align well with the New Policies Scenario projections in 2020 and have good chances to overshoot them in 2025; if all announcements for manufacturing capacity in 2025 are being met in a timely way, then the projected required market size in 2025 will be available comfortably.
- OEM announcements are generally bolder for 2025 than for 2020, reflecting expectations that EV batteries with larger energy storage capacity become available after 2020.
- EV stock projections in the EV30@30 Scenario exceed the capacity announced by OEMs for 2020, and are estimated to be at the top of the range of the announcements for 2025.
- Meeting the EV30@30 target at the global scale (220 million electric LDV stock by 2030) would not only require a successful market deployment for EV models, but also the addition of new EV production capacity with respect to what has been recently announced, for the period following 2025.

³ By 2030, 65% of the kilometres driven by a PHEV are in electric mode in the New Policies Scenario, up from a 30% share assumed for 2017. The share of electric mode driving for PHEVs grows faster in the EV30@30 Scenario, reaching 80% by 2030.

Figure 6.2 • Comparison of scenario projections and manufacturers' targets for electric LDVs, 2017-30



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Notes: The 2020 and 2025 projections from original equipment manufacturers are based on their announcements as outlined in Table 2.5. The production capacity of OEMs in China has been capped at 5.2 million vehicles both in 2020 and 2025. This cap is calculated considering the 7.7 million vehicle capacity announced for 2020 (Liu, 2018) and a 66% capacity utilisation factor, aligned with the ratio of vehicle production in China and capacity available in recent years (IHS Markit, 2015). The lower bound of vehicle production in China for 2020 was assumed to be 2 million, well below the capacity assessed to become available in the same year. For companies that announced the deployment of a number of models, the assumptions made in this analysis consider a sales-to-model ratio range of 10 000-30 000 in the 2020 timeframe and 30 000-50 000 in 2025.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2018b).

Key point: Estimates based on manufacturers' projections suggest an uptake of electric LDVs ranging in-between the New Policies and the EV30@30 scenarios.

Buses

Both the New Policies and the EV30@30 scenarios include rapid developments for the electrification of bus fleets, primarily through the deployment of BEVs in cities. The number of electric buses reaches 1.5 million units by 2030 in the New Policies Scenario and 4.5 million units in the EV30@30 Scenario, compared with 370 000 electric buses on the road in 2017.

The market share of electric buses in total bus sales is lower than 15% in the New Policies Scenario and 35% in EV30@30 Scenario by 2030. These high shares reflect the cost advantages associated with high bus mileages and the possibility to plan their daily overnight charge (Figure 5.8). Transitioning to electric buses in urban areas brings opportunities to optimise their battery size to the specifics of the charging infrastructure in the service area.

In the EV30@30 Scenario, the transition takes place at a faster pace primarily because of strong policy drivers and concerted planning between public and private stakeholders on EVSE deployment. This would facilitate the installation of high-power charging capacity (50 kW or more) with effective grid connections (that may require reinforcements) in urban areas. The transition to electric buses in this scenario also includes intercity buses, which use both PHEV and BEV technologies.

Trucks

The world's stock of electric trucks reaches close to 1 million in 2030 in the New Policies Scenario and 2.5 million in the EV30@30 Scenario, from just a few hundred in 2017. These projections yield low shares for electric trucks in the total stock of trucks in 2030: 1% in the New Policies Scenario and 3% in the EV30@30 Scenario. Most trucking operations, especially heavy-duty trucks, are on highways and often over long distances. This is a much different landscape than developing electric

vehicle infrastructure in an urban setting as for city buses. As a result, the likelihood for long-range requirements for trucks, combined with their large size and weight, lead to a narrower scope of opportunity for large-scale electrification by 2030 in a cost effective manner given the projected rates of battery price declines. This is reinforced by the technical and economic barriers that exist today with regards to permitting trucks to fast charge along highways, given the high-power requirements for charging a truck battery in a reasonable amount of time.

Regional insights

China and Europe

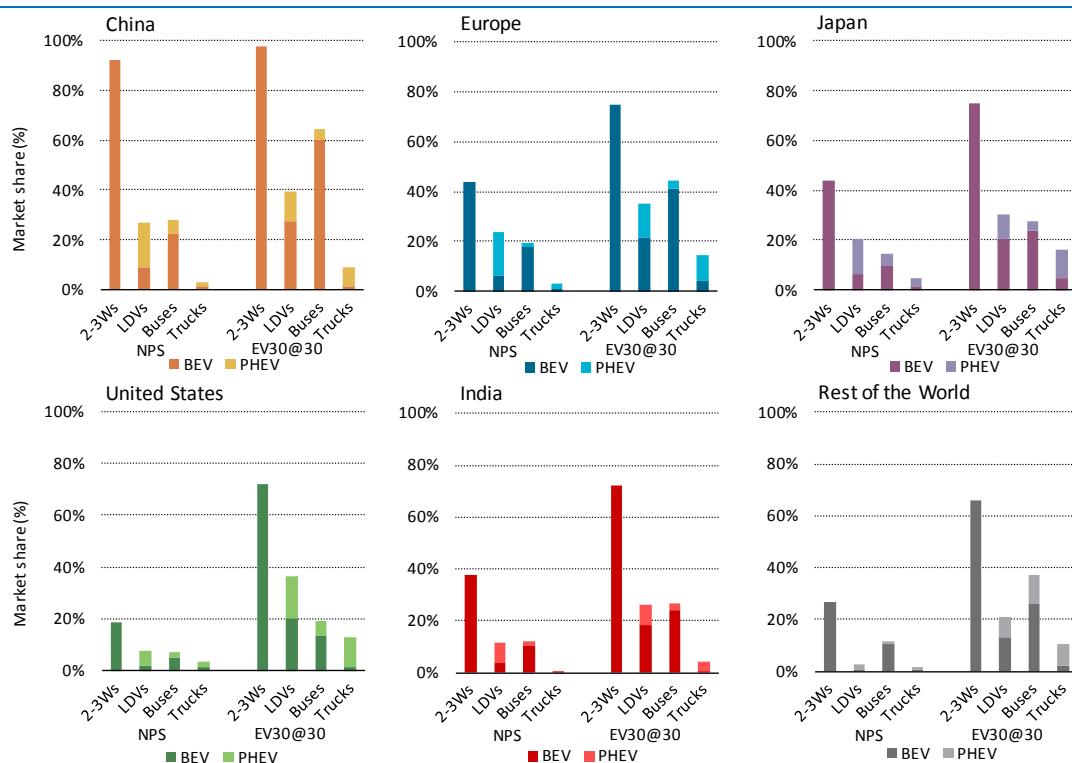
China and Europe are the global regions with the fastest development of EVs in both scenarios and in virtually all modes (Figure 6.3).

In the New Policies Scenario, EVs reach a market share (or sales share) of 26% in China and 23% in Europe by 2030 when accounting for all modes (except two- and three-wheelers).

For LDVs, this is primarily driven by:

- The NEV credits mandate announced in September 2017 and the Electric Vehicle Subsidy Program in China (MIIT, 2017; MIIT, 2018).
- The recent proposal by the European Commission to revise the 2030 CO₂ emissions standard for passenger cars and LCVs (EC, 2018a), combined with the high taxation regime applied to petroleum fuels in Europe.

Figure 6.3 • EV market share by type and scenario in selected regions, 2030



Note: NPS refers to New Policies Scenario; 2-3Ws refers to two- and three-wheelers.

Source: IEA Mobility Model (2018b).

Key point: The EV market is led by China and Europe in both the New Policies and the EV30@30 scenarios.

The market shares of electric buses are also higher in these two regions than elsewhere in both scenarios. In Europe, this is primarily driven by the fuel taxation level that is higher for diesel than anywhere else in the world, making the case for an electric transition economically viable at an early stage. Additional dedicated support in Europe could further increase the projections. In China, this is consistent with the emergence of a local electric bus industry already in 2017 and the strong policy support that started this transformation in major cities. The adoption of urban electric buses is also driven by cities that made clear commitments for the electrification of their bus fleets (C40, 2017) and local governments aiming to implement low- or zero-emission zones (Table 2.3).

In the EV30@30 Scenario, by 2030, China has an EV market share for the total of electric LDVs, buses and trucks combined of close to 40%, and Europe of 35%. In particular, Europe sees a strong market penetration of PHEV and BEV trucks. This is driven by a broader scope for lower TCOs for heavy-duty vehicles that transport goods because of high taxes on diesel in Europe.

Electric two- and three-wheelers in China reach over 90% market share by 2030 in both scenarios, up from 55% in 2017, reflecting a large shift initiated by implementation of strong regulations. Other regions follow, but at a slower pace reflecting less stringent measures. In all regions, spill overs effects from advances in electric LDVs such as batteries costs have a positive spin for two-wheelers too, leading to higher market shares by 2030 than for other modes, in both scenarios.

Japan

Japan is the world's fifth-largest EV market and has stated targets for the future (Table 2.2). The country has strong design and manufacturing experience in vehicle hybridisation, and is home to a number of OEMs that are embracing the electric mobility transition faster than others (e.g. Nissan, Toyota). A number of Japanese manufacturers are also making major investments for the deployment of automotive batteries (such as Panasonic). Japan's dense urbanisation lends also itself to easier deployment of a comprehensive network of charging infrastructure than in other regions. Nonetheless, Japan has slightly lower EV shares in the New Policies Scenario than China and Europe, as the policy environment does not explicitly include regulatory requirements for BEV and PHEVs for light-duty vehicles, does not subsidise electric buses. Japan is also a global leader in the promotion of hydrogen FCEVs as part of a clean transport future.

In the EV30@30 Scenario, EV market shares in Japan approach the values of the European and Chinese markets for LDVs in 2030, consolidating the role of Japan as a global leader in the transition to vehicle electrification.

United States

Electric mobility deployment in the United States occurs at two speeds:

- On one hand, there are market leaders with clearly defined ambitions such as California and the ZEV states, which achieve rapid market penetration (Table 2.2).
- On the other hand, taxes on petroleum fuels are lower than those applied in China, Europe and Japan; vehicle characteristics (power, size, weight and footprint) indicate that cars are much larger than in other areas of the world; and uncertainty about the announced revisions of current CO₂ standards, recently deemed too strict by the federal government (EPA, 2018), lead to lower EV uptake in the United States in the New Policies Scenario than in other countries.

In the EV30@30 Scenario, the United States is assumed to adopt rapidly a broadly supportive policy framework. In this scenario, the market share of electric LDVs reaches similar levels as in China,

Europe and Japan, while the shares of electric buses are lower. This is due to a lower cost competitiveness of BEV urban buses in an environment applying fuel taxes that are projected to remain lower than in Europe.

India

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India reaches an 11% EV market share by 2030 (for all modes combined, excluding two- and three-wheelers) in the New Policies Scenario. This reflects the country's ambitions and actions towards the development of electric mobility, including proactive engagements from the local automotive industry (Mahindra, 2018; The Economic Times, 2018), and actions from the government on the procurement of electric cars (Government of India, 2017b; Government of India, 2018b). Given the need to further develop an integrated policy framework supporting EVs, the projections in the New Policies Scenario consider a lower EV penetration rate for India than in other major world regions (see key policy updates in Chapter 2).

In the EV30@30 Scenario outlook, India boosts momentum for the electric mobility transition, develops a favourable policy environment and achieves a 25% EV market share by 2030 across all modes (except two- and three- wheelers, of which over 70% of sales are electric units by the same year). This transition can be supported with the adoption of car and ride-sharing systems, suggesting that the country to some extent may leapfrog from a low personal vehicle ownership rate to shared mobility while access to motorised road-based mobility is growing.

Other regions

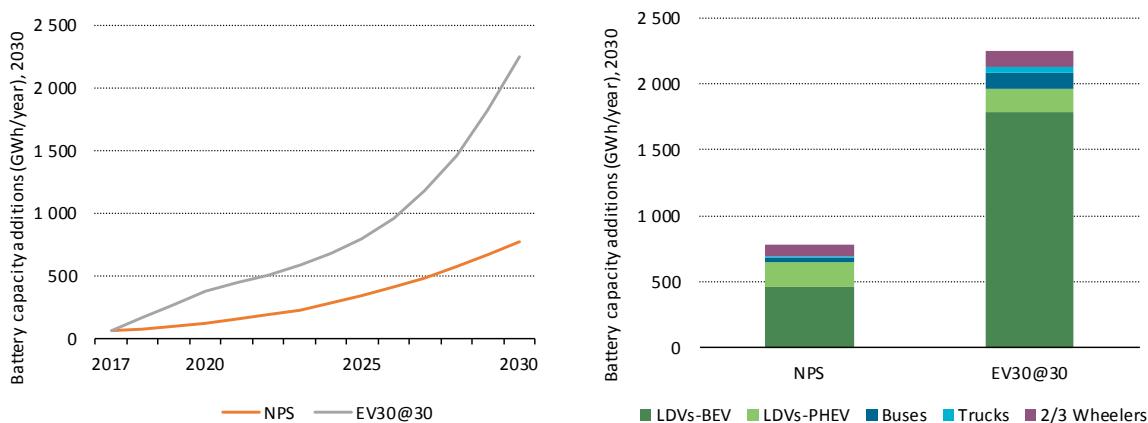
The largest EV markets included under "rest of the world" in Figure 6.3 include Asia (excluding China and Japan), Africa, Australia, Middle East, Canada, Latin America, the Middle East, New Zealand, Turkey and the Russian Federation. Electric LDV shares in these regions on average are lower compared to China, Europe, Japan, India and United States in the New Policies Scenario by 2030. This reflects the fact that most of the major global economies that are at the leading edge of the policy development supporting EVs are included in the subset of regions discussed in greater detail above. Electric bus shares in other regions (taken together) are higher than in the United States, reflecting a stronger economic case in countries that apply higher fuel taxes, despite bigger challenges for the access to capital for electric bus purchases in some of the regions.

Electric LDV shares in the EV30@30 Scenario are similar to India, and therefore reflect a context where swift policy action enables sizeable commitment to the deployment of chargers and a dynamic uptake of EVs. Electric buses are subject to a swift transition too, almost comparable to the case of Europe. This is due to a number of examples where there is potential for lower TCO from bus electrification, and assumes that barriers to increased adoption (including challenges with access to capital) are proactively removed by governments and other stakeholders.

Battery capacity

The deployment of electric vehicles outlined in both scenarios is accompanied by an increase in EV battery production capacity. By 2030, EVs are expected to have longer ranges, between 350 km and 400 km. These ranges translate to battery capacities of 70-80 kWh. Current average battery capacities for LDVs range between 20 kWh in China to 60 kWh in the United States, thus the increase in average battery capacity per car is expected to increase. For PHEVs, ranges are expected to be on average 60-70 km and it is expected that this will lead to higher shares of the annual mileage to be driven using electricity only. The average battery capacity of PHEVs is expected to plateau at around 15 kWh.

- In the New Policies Scenario, the demand for annual battery capacity added to EVs is expected to grow by a factor of 15, from around 68 GWh in 2017 to 775 GWh in 2030. Battery storage is driven primarily (84%) by electric LDVs, with a substantial contribution of PHEVs, followed by two-wheelers (10%) and heavy-duty vehicles (7%) which include buses and trucks. China is expected to retain its leadership in global demand and contribute to half of the global battery capacity demand, followed by Europe (18%), India (12%) and the United States (7%).
- In the EV30@30 Scenario, annual demand for batteries reaches the 2030 value of the New Policies Scenario five years sooner and it reaches 2.25 TWh in 2030, with LDVs contributing 87% of the total (Figure 6.4). China remains the main global region for battery capacity demand, accounting for a third of the total. Europe and North America combined follow with 28% of total capacity. India's battery capacity demand represents 12% of the global total while Japan accounts for 3%.

Figure 6.4 • Battery demand for EVs to 2030 by scenario

Notes: NPS = New Policies Scenario. Battery capacity projections are based on estimated EV sales and region-specific EV battery capacity. For LDVs, battery capacity ranges are 30-70 kWh in 2017 and progress to 70-80 kWh in 2030 for BEVs. For PHEVs, battery capacity ranges are 8-12 kWh in 2017 and progress to 12-15 kWh in 2030. Higher values are applied mainly in North America and the Middle East, due to larger mileage and vehicle attributes (e.g. power, weight and fuel economy) which are well above the global average and values in other regions. Buses are assumed to use batteries of 250 kWh, two-wheelers use batteries of 3-4 kWh. Truck batteries are assumed to range between 150-350 kWh.

Key point: Demand for battery capacity for electric vehicles, primarily for PLDVs, is projected to increase to 2.2 TWh per year in the EV30@30 Scenario and to 0.78 TWh per year in the New Policies Scenario to 2030.

These results imply that the EV battery supply market is expected to undergo a major expansion in the coming years in both scenarios. The New Policies Scenario values confirm that the estimated additions projected for 2025 would require the construction of roughly ten battery manufacturing facilities with the production capacity of the Tesla Gigafactory. There are signs that major battery manufacturers, as well as new market entrants, are scaling up investment in battery production. Manufacturer's announcements about future production facilities with capacities that exceed 30 GW/year are being planned in all global regions (see Table 5.1).

The growth in battery capacity demand is likely to have important implications on the cost of batteries, due to learning-by-doing and capacity expansion, and on the demand for transition metals (cobalt, nickel and lithium) (Olivetti et al., 2017). The implications that the increase in

demand for battery capacity has for material demand are discussed in the next section. (Cost implications for battery capacity scale up are discussed in Chapter 5).

Material demand

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Increased demand for EVs will lead to the increase in demand for materials that have not been specifically associated with road transport (Table 6.1). Three important changes are the increased use of copper (Copper Alliance, 2017), the use of rare earth materials in the electric motor and the use of precious metals in batteries. Neither copper nor rare earth supply is considered to pose a risk to EV deployment; EV demand for copper would only account for a minor share of copper demand and rare earths can be substituted with other materials in electric motors with different designs (Kramer, McCallum and Anderson, 2012). On the other hand, potential risks coming from the supply of battery materials have been identified.

The projections in the New Policies and the EV30@30 scenarios clearly suggest that market shares of electric vehicles will grow. The eight-to-ten-year lifetime of EV batteries, combined with the rapid demand growth for battery capacity outlined in both scenarios also mean that virtually all the material demand for battery capacity increases will have to be supplied by resource extraction, at least up to 2030.⁴

This sort of development bears important implications for the growth of the demand for materials extensively used in lithium-ion batteries, given their importance in automotive applications. Key materials that are subject to an increase in demand include nickel, cobalt and lithium.

Table 6.1 • Overview of critical material intensity of key battery chemistries

kg/kWh	Li	Ni	Co	Mn
NCA	0.10	0.67	0.13	0.00
NMC 111	0.15	0.40	0.40	0.37
NMC 433	0.14	0.47	0.35	0.35
NMC 532	0.14	0.59	0.23	0.35
NMC 622	0.13	0.61	0.19	0.20
NMC 811	0.11	0.75	0.09	0.09
LFP	0.10			

Notes: NCA refers to nickel cobalt aluminium oxide, NMC refers to nickel manganese cobalt oxide (numbers indicate the atomic share of each metal), LFP refers lithium iron phosphate oxide.

Source: ANL (2018b).

Key point: Changes in cathode chemistries have direct implications for the demand of material. For example, the NMC 811 chemistry, in which battery manufacturers have a growing interest, enables significant reductions in cobalt content compared with other NMC chemistries.

⁴ Material supply through recycling can only gain relevance once there is a sufficient amount of materials deployed in the vehicle stock and when these materials become available at the end-of-life of the vehicles and/or their batteries.

Nickel

Nickel is widely used in a range of applications and it has a well-developed supply chain. Today, nickel supply has a magnitude of 2 000 kilotonnes (kt) per year per year and is primarily intended to fulfil the demand of high-grade steel production. Batteries are part of the demand mix, but they only account for a small fraction of the total (Glencore, 2018; Hamilton, 2018). To date, nickel prices are not really affected by changes in EV-related demand, but rather by market dynamics that relate to an oversupply that lasted up to 2015, and market tightness after that, leading to a decline in the stocks accumulated until then (Glencore, 2018; Hamilton, 2018). Even if nickel is subject to be impacted by the structural change in demand expected from growing battery capacity, the impacts will be mitigated by the fact that the integration of this new demand will clearly take place in a broader context. Despite variations in the quality needed for different applications, which may lead to the emergence of a two-tier type of market, nickel is expected to be less impacted by the demand growth for EV battery capacity than other materials (Glencore, 2018; Hamilton, 2018).

Cobalt and lithium

Cobalt and lithium are subject to impacts that are much more significant. Battery capacity increases from EV adoption, as well as speculative stockpiling and strategic sourcing, have already led to sizeable changes in the spot prices of these two commodities over the past two years (As of January 2018, +250% for cobalt and +400% for lithium since January 2015) (Facada, 2018). This does not reflect a lack of sufficient reserves, but rather the much lower scale of the current demand for cobalt and lithium (respectively 110 kt/year and 40 kt/year) if they are compared with nickel, and to the much larger share of demand for these materials attributable to EV batteries. One million EV batteries (close to actual sales in 2017) are estimated to account for approximately 6% of the total demand of cobalt and 9% of the total demand of lithium of 2017. By comparison, the same amount of EVs only represents 0.4% of the global nickel demand (Hamilton, 2018).

Cobalt

Cobalt is currently mostly mined as a by-product of nickel and copper because it occurs in the same ores and because of its limited market size and price. This means that today cobalt supply is structurally linked to the markets for other materials, and subject to limited opportunities to respond quickly to the increase of demand expected from EVs. Just under 60% of the current global production of cobalt is concentrated in the Democratic Republic of Congo (DRC), a region that has not been proven to be stable in the past. Increasing demand is spurring interest in the DRC for the extraction of cobalt by artisanal miners, which has witnessed the use of child labour (Olivetti et al., 2017).

Moreover, the capacity to refine and process raw cobalt is highly concentrated; China has 90% of the refining capacity. These characteristics make the supply of cobalt subject to risks.

Lithium

Lithium is mostly produced in South America and Australia. Price increases since late 2015 are attributed to a lag in supply due to complex constraints in Chile, combined with a surge in demand for EV (Hamilton, 2018). Despite this, a sizeable lithium supply response is expected to become available, due to increased capacity from incumbent Chilean producers and investment in new extraction being made in Australia, Brazil and Argentina.

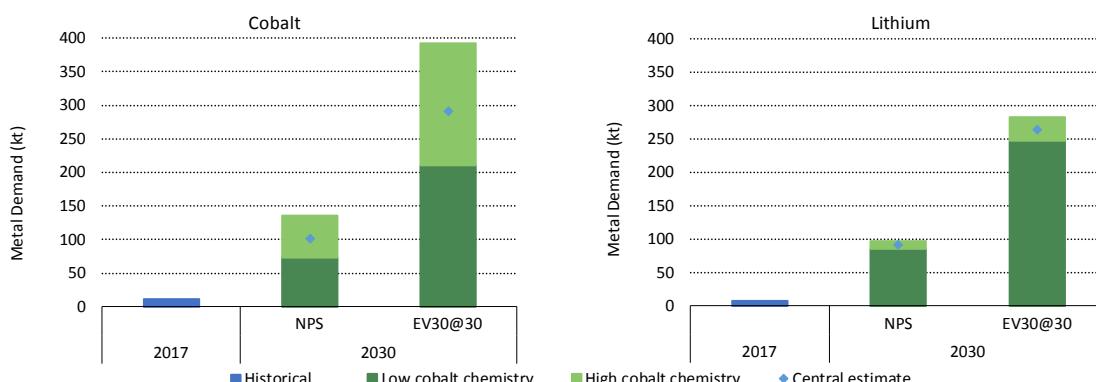
Demand projections

Figure 6.5 shows cobalt and lithium demand projections coupled with the EV deployment rates of the New Policies and EV30@30 scenarios. The projections account for sensitivities due to possible changes in the battery chemistries that will be deployed to equip vehicles in the next decade, taking into account the insights provided in Chapter 5.

Figure 6.5 indicates that both cobalt and lithium demand are expected to experience major increases over the next decade. This is an important signal, pointing out that investment in production is necessary to limit the risk of supply bottlenecks. Figure 6.5 also indicates that future demand for cobalt and lithium is subject to two types of uncertainties: first, how many electric vehicles will be sold and, second, what battery chemistry will be used.

A central estimate where the market share of cathode chemistries in 2030 is 50% NMC 811, 40% NMC 622, and 10% NCA is assumed. According to this assumption, cobalt demand in 2030 is 101 kt/year in the New Policies Scenario and lithium demand reaches 91 kt/year (Figure 6.5). In the EV30@30 Scenario, these values are much higher, with cobalt demand reaching 291 kt/year in 2030 and lithium at 263 kt/year. If NMC 811 cathodes are widespread in 2030, then the demand for lithium is expected to be higher than demand for cobalt. One of the main reasons for the larger increase in lithium demand in the EV30@30 Scenario is the addition of demand from heavy-duty vehicles, assumed to be primarily based on the LFP cathode chemistry and therefore not impacting cobalt demand.

Figure 6.5 • Cobalt and lithium demand, 2017 and 2030



Notes: NPS= New Policies Scenario. Projected battery capacities and sales figures are used to estimate material demand in 2030. Demand figures refer to pure metal contents. In the low cobalt scenario, NMC 811 makes up 90% of battery sales in 2030, with the rest being NCA. In the high cobalt scenario, NMC 622 makes up 90% of sales with NCA the rest. In all scenarios battery demand for HDVs is assumed to be 80% LFP and 20% NMC 622.

Key point: Lithium and cobalt demand from electromobility will increase in both scenarios. For cobalt, uncertainty over future battery chemistries increases variability of demand in 2030.

The results shown in Figure 6.5 suggest that changes in cathode chemistries affect cobalt demand significantly more than lithium. This reflects the fact that battery manufacturer's research and development drive to increase the energy density of cells, by transitioning from NMC111 to NMC622 and NMC811 cathodes, has a major influence on the demand for cobalt. For lithium, on the other hand, only major battery design changes (such as a move to beyond Li-ion technology, which is not expected to become available until after 2030) might have a similar effect.

The rapid ramp up in demand for cobalt and lithium requires investment in the supply of raw materials. However, material suppliers facing high uncertainty over demand might be reticent to

make the needed investments. A potential instrument could be the use of long-term agreements between suppliers and manufacturers given that the demand for cobalt is very unlikely to wane in the next decade. The main role for public policy in this context is to facilitate investment by decreasing the uncertainty of the future of sales of electric vehicles by setting out a clear vision for the electrification of road transport.

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Electric vehicle supply equipment deployment

As EV penetration grows, so do the number of charging outlets installed. Electric vehicle supply equipment (EVSE) will be deployed on private premises, both for individual vehicles (at home and work) and fleets (namely LCVs and taxis or ride-hailing cars), and complemented by publicly accessible chargers. The EVSE deployment will occur initially in cities, expanding over time to major arterials of the intercity road network, including highways.

The scenario results outlined here reflect this by assuming that the future development of charging infrastructure will be bound to the magnitude of the development of electric mobility. They also attempt to account for differences on the choices made on recharging habits, looking at cases characterised by a greater reliance on private chargers, and at other cases where publicly accessible chargers are likely to play a more significant role.

Private charging infrastructure for LDVs

The availability of private charging infrastructure (such as at home and work) currently is estimated to be approximately 1.1 charger per electric car in most global regions. This assumption is corroborated by good evidence in the Nordic region (IEA, 2018a) and in the United States (NREL, 2017) and aims to reflect the fact that nearly each electric car owner, at this early point of the electric mobility transition, benefits from a private parking spot with an installed charging outlet, and that the emergence of workplace charging spots provides an additional private charging opportunity, serving both electric car adopters who can or cannot charge at home.

Available statistics suggest that densely populated areas could represent an exception to this rule. Key indications supporting this statement include the high EVSE/electric car ratios for publicly accessible charging infrastructure observed in China and Japan compared with other regions, especially when looking at fast chargers (Figure 6.6). Similarly, the rate of private EVSE per electric car reported by available Chinese sources for 2017 seems somewhat lower than in the other countries discussed above, at around 0.8 (Sina Technology, 2018; Sohu, 2018b).

Based on this initial (although limited) set of information, and taking into account that, despite a low starting point, China's government aims to provide 0.9 privately accessible chargers per electric car by 2020 (NDRC, 2015), the scenarios on EVSE deployment developed here have been built on the following key assumptions:

- As electric car adoption becomes wider and affects all LDV customer types, including those without a private parking spot at home, the number of electric car owners who charge at home decreases.
- In parallel, charging outlets at workplaces continue to increase worldwide, compensating for the loss of home chargers.
- In all global regions except China and Japan, this helps maintain a ratio of 1.1 private chargers per electric car.

- Given China's intention to pursue its goal of increasing the availability of private chargers, the central assumption considers that by 2030 China attains a ratio of 0.9 private chargers per electric car.

The resulting number of private slow charging outlets (up to 7 kW) deployed globally in the New Policies Scenario would reach 125 million by 2030. Assuming an upper and a lower bound to the previous assumption, of 1.2 private chargers per electric car and 1 charger per electric car respectively by 2030, the total number of private chargers would range between 115 and 135 million outlets in the New Policies Scenario. In the EV30@30 Scenario by 2030, the number of private charging outlets would reach 230 million units as the central estimate within a range between 210 and 250 million units (Figure 6.7).

Publicly accessible LDV and bus charging infrastructure

Similar to the projections for private charging infrastructure, the assessment for the projections of publicly accessible EVSE considers a central case accompanied by an upper and lower bound. It is defined on the basis of three main considerations:

- Norway, the first electric car market globally in terms of market share (39%) had a ratio of 1 publicly accessible charging outlet for 19 electric cars in 2017. Another top market, Sweden (6% market share in 2017) had 1 outlet per 12 electric cars. Both these values are significantly lower than the global average of one charger per seven electric cars observed in 2017.
- The AFI Directive of the European Union (EC, 2014) recommends a ratio of one publicly accessible charger per ten electric cars.⁵
- Countries with densely populated cities such as China and Japan already have a stronger publicly accessible EV infrastructure than others, with one outlet for six electric cars in China and one outlet for seven electric cars in Japan.

The cases evaluated here are defined as:

- A central estimate for EVSE penetration, assuming that all countries converge towards one publicly accessible outlet for ten electric cars by 2030 – as suggested in the AFI Directive. From this basis, densely populated countries such as China and Japan implement 30% of fast chargers in the total number of publicly accessible chargers to compensate for the lower availability of private chargers, while other regions implement only 10% of fast chargers.
- A lower estimate for EVSE penetration, considering that markets converge towards Norway's ratio of 1 outlet for 19 electric cars. In this case, Japan and China implement 40% of fast chargers in the total number of publicly accessible chargers and other countries have 15% fast chargers by 2030.
- A high estimate, in which a ratio of one publicly accessible outlet is deployed for every seven electric cars (which is close to the global 2017 ratio) through to 2030. In this case, Japan and China have 30% fast chargers in the public space and other countries have 10%.

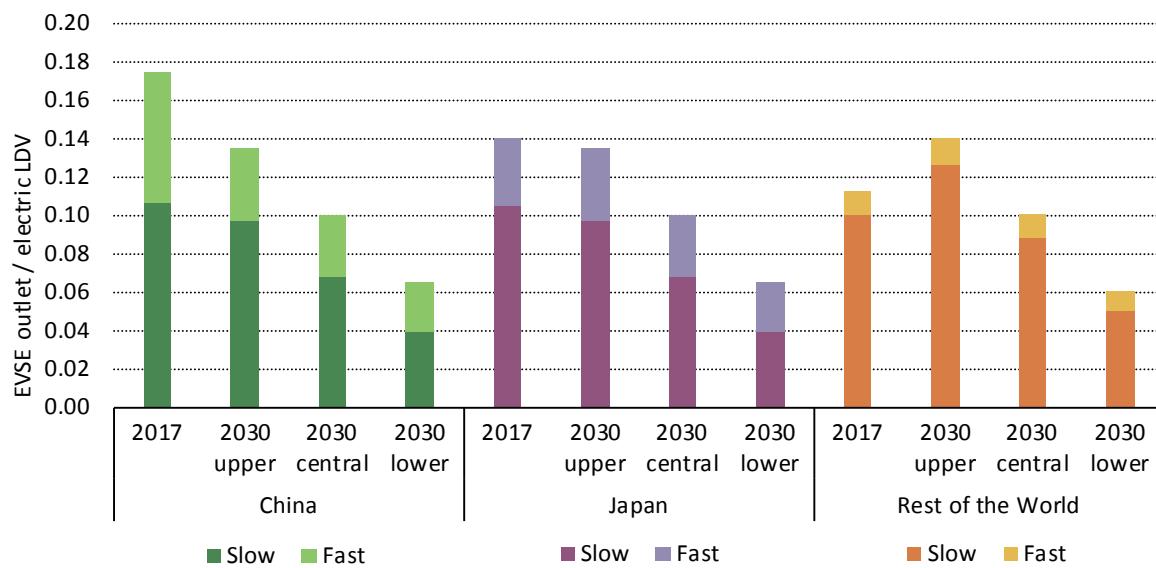
These estimates, summarised in Figure 6.6, aim to provide reasonable ranges for the deployment of publicly accessible EVSE that could accompany the electric LDV market growth projected in the

⁵ The AFI Directive also states that the number of chargers should take into consideration the type of cars, charging technology and number of private charging points. The power rating of charging infrastructure is not prescribed.

New Policies and the EV30@30 scenarios to 2030, acknowledging the significant uncertainties on the data available and thus using a simplified approach.

Figure 6.6 • Publicly accessible charger to electric LDV ratios by region split in lower, central, and upper scenarios (2017 and 2030)

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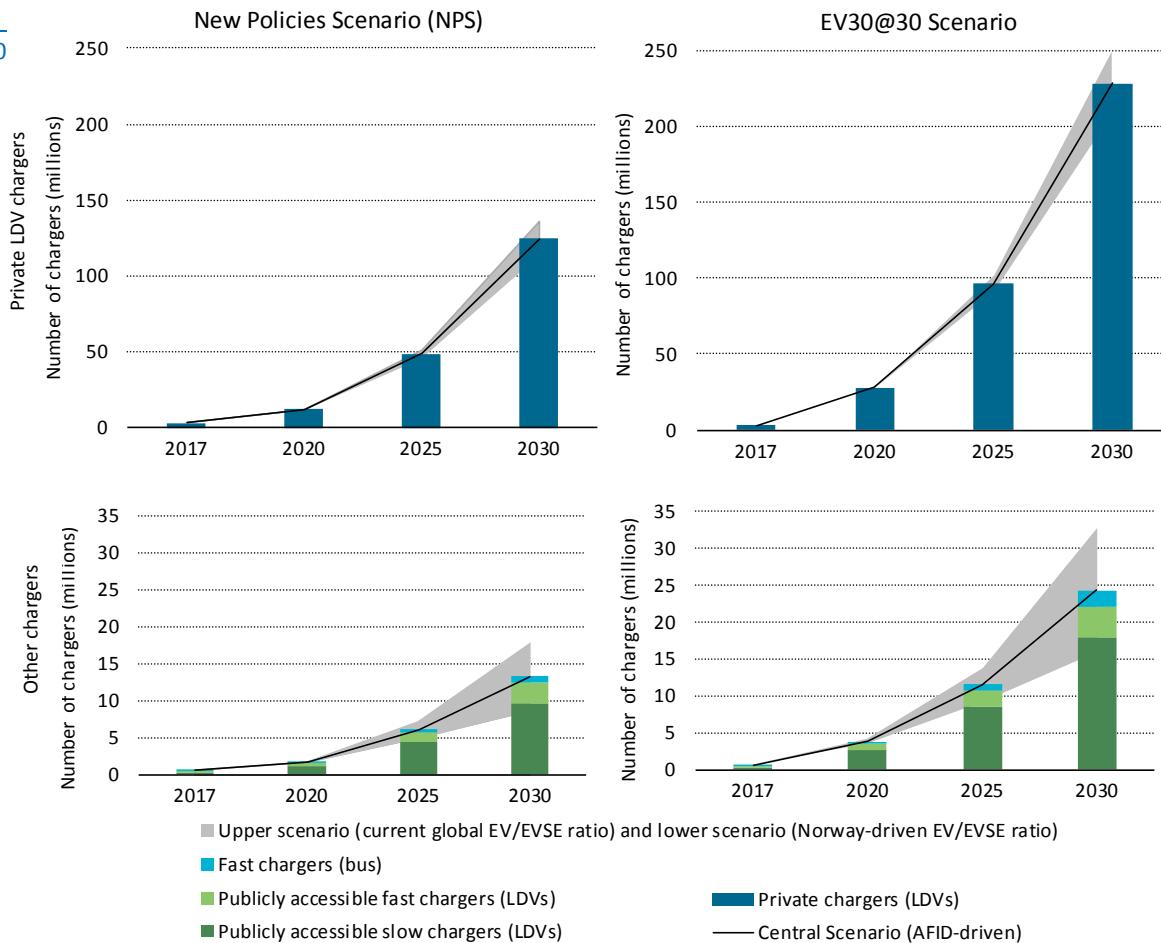
Key point: By 2030, densely populated countries have lower availability of private chargers than other regions and deploy more publicly accessible fast chargers to compensate.

Figure 6.7 indicates that the range of publicly accessible chargers resulting from the application of the lower and upper bound cases to the New Policies Scenario projections for electric LDVs is between 8 and 17 million chargers by 2030, while the EV30@30 Scenario results in a range between 14 and 30 million chargers. The central estimate suggests a total of 13 million publicly accessible chargers, split between 10 million slow and 3 million fast chargers, for a total number of electric LDVs on the road of 125 million by 2030 in the New Policies Scenario. In the central estimate of the EV30@30 Scenario, the number of chargers reaches 18 million publicly accessible slow chargers and 4 million publicly accessible fast chargers (totalling 22 million) by 2030.

The projections of charging infrastructure dedicated to buses, also presented in Figure 6.7, suggest the installation of 0.7 million (New Policies Scenario) to 2.3 million (EV30@30 Scenario) fast chargers in the period to 2030. These assume that chargers dedicated to buses provide a minimum power of 50 kW ("fast"), and that one fast charger is coupled with three electric buses, as observed currently in Shenzhen (China), which is the only city in the world that has fully transitioned to electric buses (Lu, Lulu and Zhou, 2018). By 2020 and up to 2030, bus EVSE implementation barriers (as currently observed in Shenzhen itself), are lifted and the number of bus chargers grow to serve two buses each, which corresponds to charging two buses with 200 kWh per night (4 hours each) at 50 kW.⁶

⁶ This is consistent with the charging needs (at 50 kW) of a bus consuming 1.3 kWh/km and covering 160 km daily (8 hours daily operation at 20 km/hour on average).

Figure 6.7 • Global LDV private chargers and publicly accessible LDV and bus chargers by scenario (2017-30)



Key point: Publicly accessible LDV and bus charging outlets expand from a total of 550 000 units in 2017 to up to 33 million by 2030 in the EV30@30 Scenario.

Impacts on energy demand and CO₂ emissions

The EV activity growth projected in the New Policies and EV30@30 scenarios result in an increase of electricity demand in each region. In 2030, the worldwide electricity consumption from EVs reaches 404 TWh in the New Policies Scenario and 928 TWh in the EV30@30 Scenario. These values represent, respectively, a 7-fold and 17-fold increase when compared with the electricity consumed by EVs in 2017.

Structure of electricity demand: New Policies Scenario

In the New Policies Scenario, EVs are projected to consume approximately 404 TWh of electricity in 2030. Light-duty vehicles overtake two- and three-wheelers and become the main electricity consumer among electric vehicles in 2030 (when they account for 62% of the total EV demand), followed by two- and three-wheelers (20%), buses (13%) and trucks (5%). The geographical distribution of the power consumption from EVs reveals that the EV stock in China remains the largest consumer, even if China's share in global electricity consumption from EVs

declines from 91% in 2017 to 47% in 2030. European countries and the United States follow, representing respectively 18% and 10% of the total electricity consumption. In this scenario, the EV fleet in 2030 is expected to displace 5 EJ (120 Mtoe, 2.57 mbd) of diesel and gasoline demand.⁷

Structure of electricity demand: EV30@30 Scenario

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In 2030, LDVs are the transport mode consuming the highest share of power (64%) in the EV30@30 Scenario, followed by buses (14%), two- and three-wheeler (11%) and trucks (11%). The distribution of the total power consumed by EVs across regions and modes for 2030 indicates that the Chinese EV fleet continues to be the largest consumer, despite a significant drop (from 91% to 29%) with respect to 2017. The EV stock in the United States becomes the second-largest electricity consumer, accounting for around 20% of the total. The third-largest power consumer for EVs is Europe, responsible for around 17%. The electricity consumption from EVs increases significantly in India, which by 2030 accounts for 7% of total electricity consumed by EVs worldwide.

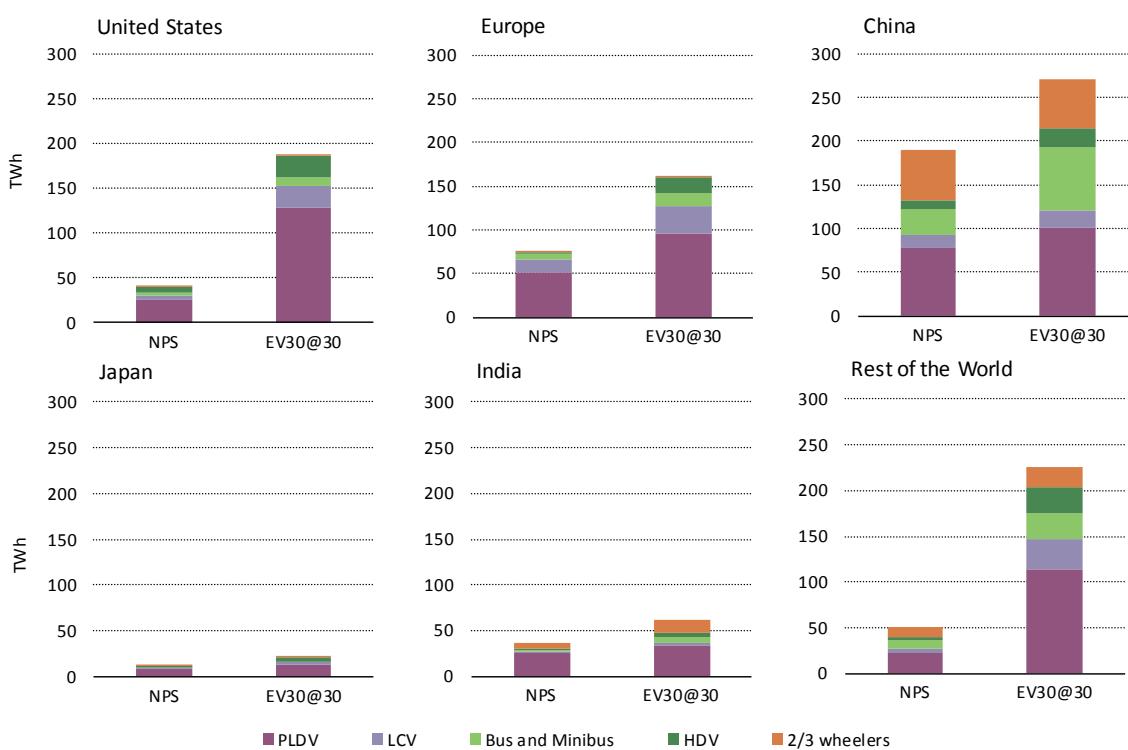
In China, the country characterised by the highest EV stock share, the total electricity draw from EVs in 2030 is five-times larger than today's power consumption from EVs. In the United States, the second-largest EV fleet, the EV power demand in 2030 is around 70% of the value projected for China. In the EV30@30 Scenario, the EV stock in 2030 displaces 9.2 EJ (220 Mtoe, 4.74 mbd) of gasoline and diesel, which is almost double the level in the New Policies Scenario.

Figure 6.8 compares the electricity consumption by mode in New Policies and EV30@30 scenarios for key regions in 2030. It illustrates that the EV fleets in China, United States and Europe account for around 75% of the total electricity consumption from EVs worldwide in the New Policies Scenario and 66% in the EV30@30 Scenario. The largest difference in electricity consumption from EVs between the two scenarios is in the United States. This reflects a wider gap in the EV deployment between the two scenarios compared with China and Europe, where there is sizeable penetration in the New Policies Scenario as well. India is characterised by similar consumption in both scenarios. This is partly because India's strong ambition for electric mobility is factored into the New Policies Scenario, and partly because of the significant portion of the electricity demand attributable to electric two- and three-wheelers, subject to a significant shift towards electrification in the New Policies Scenario.

LDVs are the main contributor to power consumption from EVs in both scenarios for the United States, Europe and Japan. Another indication emerging from Figure 6.8 is the large share of total electricity used by EVs that is attributable to buses and minibuses in 2030 both in the New Policies Scenario (20%) and the EV30@30 Scenario (35%) in China and, to a lower extent, in Europe.

⁷ The diesel and gasoline displacement is calculated as the quantity of oil products that would be consumed if EVs had the same fuel consumption as the average ICEV fleet in that year.

Figure 6.8 • Electricity demand attributable to EVs by mode, region and scenario, 2030



Notes: NPS = New Policies Scenario; PLDV = passenger light-duty vehicle; LCV = light commercial vehicle; Europe includes OECD Europe and EU6 countries. The following assumptions are used and the ranges indicate differences across countries. Fuel consumption: PLDV 20-27 kWh/100 km; LCV 31-53 kWh/100 km; bus 132-170 kWh/100 km; minibus 37-97 kWh/100 km; medium and heavy trucks 113-138 kWh/100 km; two-three wheeler 4-7 kWh/100 km. Annual mileage: PLDV 7 100-18 200 km; LCV 7 300-20 300 km; bus 14 400-49 300 km; minibus 27 000-45 000 km; medium and heavy trucks 18 500-91 100 km; two-three wheeler 3 800-7 600 km. Charger losses assumed to be 10%. Share of electric driving for PHEVs in 2030 is 80% of the annual mileage.

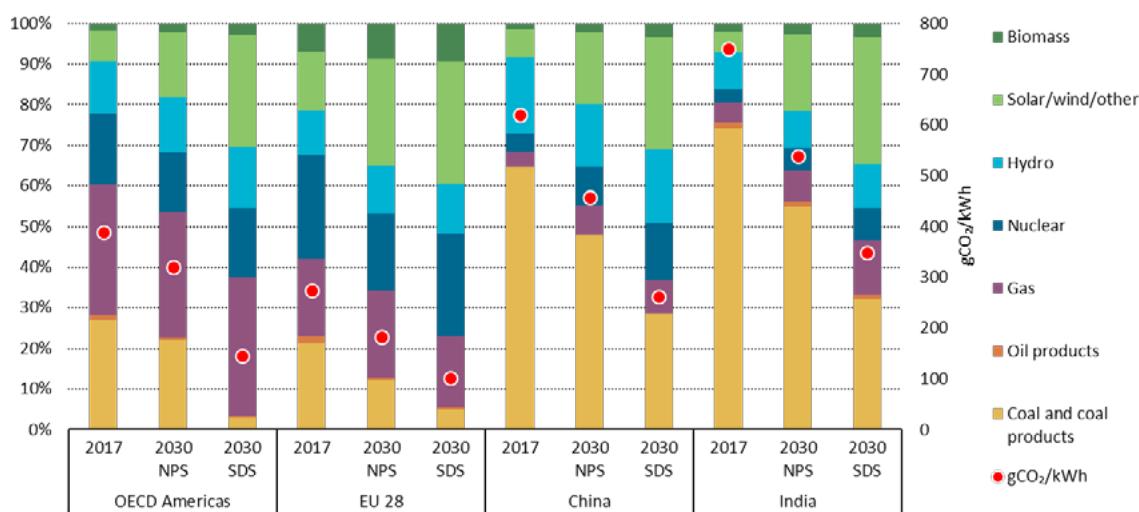
Source: IEA analysis based on country submissions (IEA 2018a).

Key point: Two-wheeler and bus electricity demand make China the highest consumer of electricity for EVs in both scenarios. In the EV30@30 Scenario, electricity demand for EVs is more geographically widespread.

Implications for well-to-wheel GHG emissions

Figure 6.9 shows the evolution of the power generation mix and carbon intensity from 2017 to 2030 in four of the main regions for EV uptake. It indicates that both the New Policies and the EV30@30 scenarios project that the power generation mix will have a lower CO₂ intensity in 2030. Electricity's carbon intensity in the EV30@30 Scenario is assumed to follow the Sustainable Development Scenario pathway (IEA, 2017b).

The reduction of the carbon intensity projected in the two scenarios results in a reduction of GHG emissions per kilometre from EVs in all global regions. These developments are set to further increase the climate benefits associated with EVs. Both scenarios indicate that by 2030, EVs will have lower use-phase CO₂ emissions per km in all regions.

Figure 6.9 • Power generation mix and carbon intensity by region, 2017 and 2030

Note: NPS = New Policies Scenario; SDS = Sustainable Development Scenario.

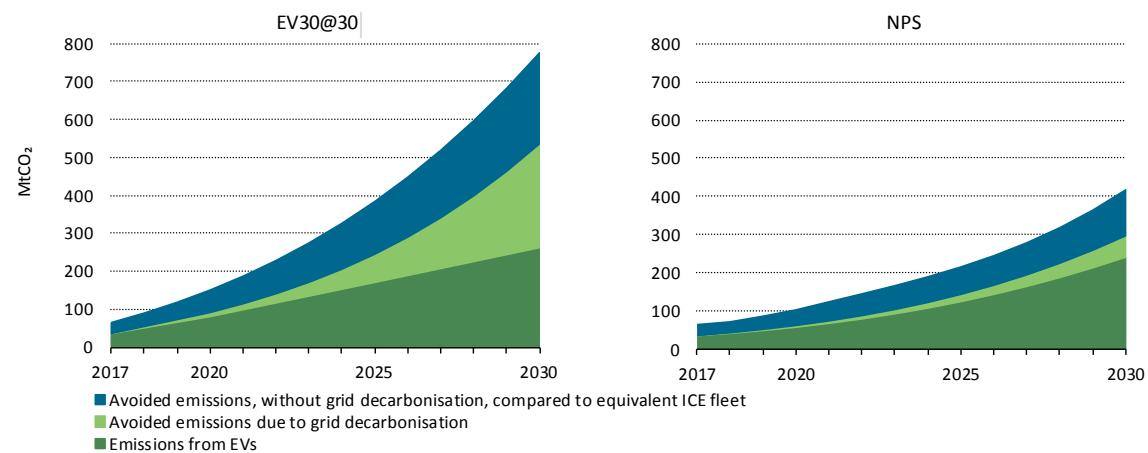
Source: IEA (2017b).

Key point: Today the carbon intensity of power generation differs considerably across regions, but the carbon intensity is projected to decline in each region by 2030.

CO₂ emission estimates and savings

The future CO₂ emissions by the EV stock are determined by the combination of the EV stock evolution and GHG intensity of power generation. In the coming years, EVs are expected to achieve emissions savings thanks to their superior energy efficiency and to decarbonisation of electricity supply. In the New Policies Scenario, if all EVs projected to be circulating were powered by ICE powertrains instead, then they would have emitted 418 MtCO₂ by 2030 on a WTW basis (Figure 6.10). If that EV fleet would be powered by the same generation mix of 2017, then these vehicles would be responsible for 297 MtCO₂ of emissions. That is a 121 MtCO₂ (63%) decrease in WTW emissions, without any further grid decarbonisation. The New Policies Scenario decarbonisation pathway would further contribute to avoid 56 MtCO₂ on a WTW basis. Therefore, in the NPS, higher penetration of EVs in countries with less carbon intensive grids, as well as EV's better energy efficiency, dominate the expected emissions reductions. In the EV30@30 Scenario, EVs avoid 241 MtCO₂ without any change to the generation mix. However, when considering the Sustainable Development Scenario decarbonisation pathway for power generation, the grid decarbonisation contributes to a further 273 MtCO₂ emission reduction. This indicates that, at a global level, the decarbonisation of the power grid of the Sustainable Development Scenario can more than double the WTW CO₂ emission reductions from the electrification of road transport.

Figure 6.10 • GHG emissions from electric vehicles



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Notes: Emissions from EVs are calculated by multiplying the electricity consumption from EVs (using the same assumptions described in Figure 4.3) times each region's CO₂ intensity in the *World Energy Outlook's* New Policies and Sustainable Development scenarios for each year. The avoided emissions due to decarbonisation are calculated by applying the 2017 CO₂ intensity in each region to the projected electricity demand in each scenario. The avoided emissions without grid decarbonisation are calculated as the difference between the emissions from EVs and the well-to-wheel emissions that would have been emitted if the projected EV fleet was powered by ICEs with fuel economy representative of every region in each year.

Sources: IEA (2017c); IEA (2018a).

Key point: In 2030, CO₂ emissions associated with the use of EVs is lower than those of equivalent ICE vehicles at a global scale, even if electricity generation does not decarbonise from current levels.

7. Policy considerations

Introduction and structure

With zero tailpipe emissions, the possibility to rely on the most diversified energy carrier available at a very large scale (electricity) and a very dynamic improvement of battery storage costs, EVs (and especially battery electric vehicles [BEVs]) are emerging as one of the most promising technology among all solutions being pursued today.¹

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A range of policy instruments related to the promotion of EVs have been adopted in major global markets. The People's Republic of China ("China"), Europe, Japan, United States and recently India have spurred EV consumer demand through a combination of instruments including public procurement and investment plans, subsidies and other financial incentives addressing both EV purchase prices and refuelling/charging infrastructure, fuel-economy standards and other measures, in particular including zero-emission vehicle (ZEV) mandates.

The primary focus of this Chapter is to take inspiration from existing policy experiences to indicate how to navigate the transition to mass market adoption of electric vehicles, while meeting economic and environmental sustainability requirements. To do so, this Chapter:

- Outlines the monetary and regulatory policy instruments that spur EV adoption while addressing the main negative externalities incurred by conventional ICE vehicles.
- Underscores that policy instruments will need to provide market certainty and clear, strong signals to all stakeholders: consumers, vehicle and component original equipment manufacturers (OEMs), battery design researchers and manufacturers, electric vehicle supply equipment (EVSE) infrastructure suppliers, utilities and grid service operators, and mining companies.
- Points out pivotal policies that can encourage the transition to widespread adoption of electric vehicles.
- Highlights the fact that policy measures will need to adapt as EV roll-out accelerates and as battery technologies continue to improve the competitive value proposition of electric *vis-à-vis* ICE vehicles. Financial incentives will need to become self-sustaining or else be scrapped, and structural challenges resulting from lower government revenues from taxing fossil fuels will need to be addressed.

The considerations provided in this Chapter stem from our current understanding of a topic that is rapidly evolving, and come with a number of limitations. For example, policy needs may change as the understanding of consumer preferences improves, as battery supply chains and contracts are consolidated, as battery performance and suitability to second-life applications is more fully understood, and as other factors are further clarified. For these reasons, the policies proposed should not be viewed as a recipe, but rather as an opportunity for discussion and critical engagement.

¹ While EVs do not directly address the issue of congestion, they may be synergistic with broader transport strategies, such as investment in (electrified) public transit and shared mobility services that could provide better, less expensive, and more efficient and equitable mobility.

Ensuring that the policy environment is conducive to increased EV uptake

Much of the economic case for plug-in and battery electric cars rests in their lower fuel costs compared with ICE vehicles. Of course, consumers face gasoline and diesel prices that vary depending on their area, even within a country, and similarly for electricity prices. For vehicle fuels this variation often reflects the tax regime applied to fossil fuels. In regions where gasoline and diesel taxes reflect the climate change and local pollution impacts of fuel combustion, the savings for vehicle use from deriving energy in the form of electricity are more evident.

A number of steps should be taken to create optimal circumstances for the uptake of EVs. A first policy priority should be the phase-out and removal of fossil fuel subsidies in countries that still apply them. This is closely followed by the need to establish taxes reflecting the carbon content of fuels, and to reinforce these with taxes that cover other impacts (such as local pollutant emissions) in countries that have already some type of carbon taxation. Other vital measures relate to cutting air pollution emissions from transport through means such as strict fuel quality standards and taxes on poor quality fuels, and setting and enforcing vehicle maintenance requirements. The implications of these measures for electric mobility are important. Such regulatory and financial measures would reflect at least a portion of the negative societal costs induced by the use of ICE vehicles in their fuel costs and the additional costs to mitigate their exhaust emissions in after-treatment systems.

Promoting public procurement

Public procurement programmes for zero-emission vehicles, for instance to populate a municipal vehicle fleet, can provide a pivotal stimulus to market creation and expansion. By underpinning an initial market, public procurement provides some assurance to manufacturers, their international suppliers and local industry to mobilise resources to deploy available models. Further, it increases the visibility of electric vehicles to the public and stimulates the emergence of related expertise and businesses.

When applied to EVs, public procurement supports early development of charging infrastructure and helps taking essential decisions on the standards that need to be adopted to enable EVs to use it.

Public procurement typically takes the form of minimum thresholds for low- and zero-emission vehicles for fleet renewals for a variety of vehicle types – car, vans, light-duty trucks and buses – and generally employs centralised bulk purchases. This approach reduces transaction costs and supports OEMs in developing scale, while also minimising unit costs for the public authorities buying the vehicles. Notable examples of public procurement programmes have been outlined in the Government Fleet Declaration of 2016 by the Electric Vehicle Initiative (EVI) member governments (CEM-EVI, 2016). They are supplemented by recent initiatives of India's Energy Efficiency Services Limited (EESL) (see Box 2.3).

As authorities implement public procurement plans to electrify urban bus and other service vehicle fleets, costs must be weighed against constrained access to capital. Multiple financing mechanisms may address these hurdles. Examples include grants and direct subsidies, battery leasing, operating leases and utility tariffs that shift upfront financing for batteries and charging infrastructure from a vehicle purchaser (e.g. a transport agency) to an electricity provider or a grid operator. Such tariffs can benefit the upfront financing entity (which is in many cases a utility) by adding power storage options, accelerating the deployment of EVs and thus increased electricity sales, and enabling them to recover costs over the warranty period for the battery and infrastructure equipment. For the bus

operator the benefit is a shift from capital financing costs to a capped monthly fee for electricity, which ensures that the total cost of owning and operating the electric bus remains lower than a conventional diesel bus (For an example, see the Pay-As-You-Drive initiative (Clean Technica, 2018)).

Bridging the price gap

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Measures that reduce the purchase price of an electric vehicle have proven to be effective policy instruments to stimulate EV market uptake. This is much in evidence in the Nordic region for the car market (IEA, 2018a) and in China for the bus market. (See Drivers of electric bus uptake in China in Chapter 2.)

As limited public finances should be directed to priority areas with potential for the most effective impact, public investment for electric vehicles is likely to be most effective if targeted to vehicles that are used intensively, such as urban buses and other municipal service fleets.² This is especially relevant in cities in emerging economies that are aiming to address the health-related impacts of local air pollution. Vehicles with high utilisation rates are likely to achieve EV versus conventional ICE vehicle cost parity earlier than others as the market develops and factors such as declining battery costs translate into lower vehicle purchase prices. Therefore incentive schemes need to adjust to changing conditions as markets mature.

Approaches such as competitive procurements for fleets in public service are useful, though they represent a fairly limited volume of vehicles. Policies to support the transition to low and zero-emission mobility need to facilitate the ramp-up and dissemination of alternatives to ICE vehicles, such as BEVs, and plug-in hybrid vehicles (PHEVs), by leveraging the volumes available in the passenger car market. Sales volume potential in the passenger car market is sufficiently large to support a transition to electric mobility with structural changes in the supply chain and at volumes that deliver economies of scale, both of which lead to cost reductions.

Reducing purchase costs

Experience to date, primarily in the Nordic region, demonstrates that taxes on vehicle registration can be a major contributor to large-scale deployment of electric vehicles (IEA, 2018a). In particular, vehicle purchase subsidies and/or exemptions on vehicle purchase taxes that reduce the gap in the purchase price faced by EV buyers have proven to be the single most effective lever for boosting EV sales, especially in cases where they manage to very significantly reduce the purchase price gap between ICE and electric vehicles.

As volumes of electric car sales increase, governments will be compelled to phase out purchase subsidies or find other ways to ensure that the financial support for zero-emission vehicles is provided in an economically sustainable manner. A good example is the use of differentiated taxes for vehicle registration and/or circulation, pegged to vehicle performance in terms of energy use, and emissions of pollutants and greenhouse gases. Such taxes penalise vehicles with poor performance and favour vehicles that meet established thresholds. In addition to being more sustainable from a budget perspective, differentiated taxes based on emissions align fiscal policy with intended outcomes, rather than targeting market uptake of a specific technology. A technology-neutral approach avoids the risk of hindering market competition of

² Reduced GHG emissions and fuel expenditure in fleets with a high utilisation rate improve the public and societal payback calculus. As the competitiveness, in terms of total cost of ownership improves for a given mode, the need for subsidies declines.

alternatives and locking-in particular technologies. Performance-based measures such as feebates can garner broad support across wide constituencies.

The benefits of scale in the production of car batteries are expected to spill over to all other EV modes: first to two-wheelers, buses, taxis and light commercial vehicles (LCVs), and eventually to trucks. These spill overs would be more difficult to achieve without a shift in the passenger car market segment such that OEMs can be successful in building capacity for a large-scale battery production and economies of scale to reduce costs.

Driving down operating costs

Circulation taxes are another fiscal instrument that can favour EV operations. They exert less influence on consumer decisions, however, as consumers tend to pay more attention to the vehicle upfront price than operating costs.

Measures implemented by local/regional authorities that favour EVs, such as free or discounted parking, free charging and access to priority traffic lanes and reduced charges on the use of transport infrastructure, also can effectively complement national regulatory and fiscal policies, and enhance the value proposition for electric vehicles.

Supporting the deployment of chargers

Policy support for EVSE deployment effectively complements measures that promote the acquisition of electric vehicles, but the characteristics of the charging infrastructure vary across various transport modes.

Private chargers

Private charging (home and workplace) is the most common means of powering electric cars owned by individuals. Charging at home is much less expensive than fast charging, and can be coupled with smart metering since private vehicles typically need to be charged only a fraction of the time that they are parked.

Private fleets, for instance a delivery business, also rely extensively on private charging facilities. Fleets managed by large operators rely on chargers installed in dedicated parking areas. The features of the EVSE used for private fleets is likely to be optimised to take account of the needs dictated by the vehicle use profile, i.e. calibrated primarily on daily usage cycles. Chargers in use for home, workplace and LCV fleet charging generally rely on Level 1 and 2 outlets and have a power rating lower than 7 kW. Bus chargers are primarily installed in dedicated parking facilities and have power ratings that today tend to be around 50 kW. Two-wheelers do not need dedicated charging infrastructure and can use conventional electrical outlets, although some business models and demonstrations underway in Chinese Taipei provide battery swapping solutions.

Private charging installations for electric cars can be supported by fiscal incentives and regulatory measures. Requirements that prioritise these installations over public charging are justified by the fact that they typically cost less to install and generally have less impact on the power grid, as they enable night time charging and tend to use lower wattage than public fast chargers. Regulations can require that parking spaces in new or refurbished buildings are "EV-ready", i.e. including the necessary elements such as conduits to facilitate a grid connection. Property laws should be adapted to simplify and accelerate approval procedures for electric car owners to install and use charging infrastructure.

Fiscal incentives can also facilitate the installation of private chargers for fleet vehicles. As in the case of vehicle purchase incentives, these instruments need to be carefully considered, ensuring

that they can be adapted as the market emerges. Fleet vehicles tend to have higher utilisation rates than private cars, and therefore are more likely to achieve cost parity with ICE vehicle options at an earlier stage.

Publicly accessible chargers

Publicly accessible chargers need to complement the availability of private chargers. Even though the frequency of use of publicly accessible charging infrastructure is fairly low in comparison with private installations today,³ public chargers are an important component of the EV charging infrastructure. Publicly accessible chargers are subject to greater attention in terms of regulations and market structure, since they need to cater to the emergence of new players and new business models.

Policies that promote the deployment of publicly accessible chargers include a range of instruments. Primary examples include:

- Definition of clear deployment targets (to be defined in conjunction with vehicle deployment targets and taking into account deployment by mode).
- Mobilisation of funding for direct investment (e.g. for the deployment of a critical mass of EVSE, as well as for chargers to provide a minimum service level).
- Provision of financial support. This can take the form of financing from public entities at low interest rates,⁴ loan guarantees,⁵ debt service reserves,⁶ sub-ordinated debt,⁷ credit insurance products for bond financing⁸ and public-private partnerships, where the commercial risk is shared among private partners and the public sector.⁹
- Use of regulations (e.g. in the case of publicly accessible chargers for individuals who do not have access to private parking).
- Use of open standards for vehicle-charge point communication and payment as a means to enable inter-operability between charging networks, increase innovation and competition, and reduce costs to drivers.

Collaborative approaches and programmes that engage multiple stakeholders have been most successful in promoting the development of early charging infrastructure (ICCT, 2017c). Examples include the integration of driver feedback on charger deployment, implementation of smart charging systems, distribution of funding to local governments, creation of PPPs and consultation

³ The EVSE per electric car ratios for public chargers typically range between 1-to-6 and 1-to-20, based on data collected in European countries and other EVI member countries.

⁴ Low interest rate loans can also be facilitated by public grants to investors that reduce the market interest rate of a loan.

⁵ This is a guarantee by a public authority to back a loan in case of default.

⁶ Debit service reserves are cash deposits to pay interest and principal payments in case a borrower fails to make scheduled payments.

⁷ Sub-ordinated debt is where a public agency agrees to allow a lower priority position than senior debt holders (in case of default, senior debt holders are paid in full before other debt holders are repaid).

⁸ Credit insurance for bond financing is the case of an insurance agreeing to pay a bond in the event that a payment default occurs by the issuer.

⁹ Public-private partnerships include project financing schemes where private partners are entrusted with the infrastructure financing, construction, operation and maintenance in exchange for revenues for a number of years (and thereby bear most of the risk). They also include mechanisms that modulate the fraction of the risk component falling on both parties, giving more importance to the infrastructure availability and provision of a public service than to the frequency of its use. They may include the participation of the public sector at the financing stage, renegotiation of contract terms to address risks and can accommodate the payment of fees by public authorities to private investors/operators in exchange for contractual guarantees on service quality and efficiency. Risk-sharing solutions may also include projects where the public sector confers existing assets to the private party in exchange for the development of new infrastructure.

with utilities to minimise grid impacts and limit costs. ICCT further points out that difficult market segments, such as roadside charging stations and fast charging stations on highways, need public support in the early phases of EV deployment. Major EV markets such as China, the European Union and the United States are taking steps in this regard (as discussed in Chapter 2).

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Standardisation and inter-operability

As highlighted in previous editions of the *Global Electric Vehicle Outlook*, standardisation and inter-operability for hardware and software – both in standards and protocols – are essential to ensure that the transition to electric vehicles proceeds as quickly and smoothly as possible. While there are reasons (above all historic lock-in) for charging infrastructures to differ across major world regions, it is important to ensure that charging points are inter-operable not only across cities, provinces and single counties, but also across major regions (such as the European Union).

National policies to regulate emissions

In the context of commitments to climate change targets and other environmental objectives, the importance of national targets to phase out ICE vehicles and transition to electric vehicles is not merely symbolic or aspirational – it sends a clear message to financial markets. In order to deliver a credible message to incentivise investment, such targets must be ambitious while also being attainable.

Fuel-economy and tailpipe CO₂ emissions standards have demonstrated their efficacy to lead to improved ICE vehicle efficiency.¹⁰ Recognition that regulatory efforts must ensure that standards reflect fuel consumption in real on-road conditions is informing an overhaul of regulations and verification regimes. As vehicle emissions standards in major markets such as China, the European Union and the United States become more stringent, automakers will need to diversify the powertrains they offer beyond conventional hybrids to include more plug-in and battery electric models.

It is important that fuel-economy and emissions standards are set on a timeline that allows automakers, component suppliers and their upstream providers to adapt new models and production lines (i.e. upwards of five years for cars). At the same time, standards must be sufficiently stringent to secure timely investment and help ramp-up production and supporting infrastructure. It is imperative that once legislated, such standards are not compromised, as this undermines the credibility of future legislation and investor confidence thereby increasing risk. Automakers that focus on national markets where the continuing commitment to such standards is cast into doubt may find their competitiveness comprised as OEMs in other regions continue to improve.

Measures in the energy sector such as mandates and incentives for power generation to decarbonise complement approaches in transport such as tailpipe emissions restrictions that together can foster the transition to low and zero emissions mobility. Such policy direction and its effective communication can provide the signals needed for automakers to invest at levels that lead to economies of scale and to provide stimulus for the entire supply chain, from metals mining and processing to battery cell and pack production. It also helps to delineate a timeline for developing EVSE infrastructure. ZEV mandates provide a higher degree of certainty on volumes than other

¹⁰ Fuel-economy standards and differentiated taxation can also be applied in countries where used imports constitute a significant share of the market, helping to limit cross-border trade in fuel guzzling and highly polluting motor vehicles. The public health benefits of such regulations are clear and can be strengthened further by ensuring that imported vehicle also respect minimum requirements in terms of emissions of local pollutants. Potential for adverse equity impacts can be reduced if these measures are complemented by sufficient investment in public transport infrastructure and other mobility options.

policy options. Incentives leave more room for flexibility to manage technology uncertainties. Once key stakeholders have committed to achievable but ambitious ZEV mandates or incentives, they can lay the foundation for a smooth and rapid transition to electric mobility.¹¹

The success of ZEV mandates and incentives, first conceived of and implemented for light-duty vehicles (LDVs), can be replicated for other modes. Building on past successes (and failures) with its previous ZEV policies, in 2016, California extended its ZEV policies to medium- and heavy-duty vehicles (including trucks and buses).

A growing group of stakeholders is advocating a shift to a regulatory regime based on a broader and more systemic consideration of impacts, whether well-to-wheel (WTW) emissions or using life cycle analysis (LCA) to incorporate cradle to grave externalities. If issues associated with overlaps with other regulatory frameworks (such as those regulating emissions for the fuel supply chain) could be overcome, and provided that technology policies such as ZEV mandates or incentives can be integrated in the policy structure, a transition to a regulatory scope based on WTW and/or LCA analyses would be a desirable development.

Local initiatives to regulate access

Commitments of cities to establish low, ultra-low or zero-emission zones, following the example of the 12 major cities that signed the C40 fossil-fuel-free streets declaration (C40, 2017), can have significant impact on consumer preference. These commitments go hand-in-hand with regional and municipal ICE (and diesel) bans and EV sales targets, articulating the same hopes for a cleaner living environment as national targets. However, given the more direct relationship between constituents and local representatives, as well as the stronger alignment of interests at the local level, such targets have the potential to be more aggressive and more readily implemented.

The signals sent by such local pronouncements are likely to be less welcome by OEMs than at a national level because of their potential to fragment market demand into multiple clusters. This is a fair point. The use of a nationwide or even multi-national labelling schemes, based on the emissions performance of vehicles, to define categories of vehicles that could be allowed or denied access to low- and zero-emission zones is an interesting option. This would not only enable drivers (especially on trips to destinations beyond their usual route) to face fewer hurdles when trying to comply with regulations, but also provide more transparent, clear and consistent guidelines and rules for industrial stakeholders.

Already in place are hybrid approaches that combine access restrictions in particular zones and fiscal measures. For example, in London and Milan, electric vehicles are exempt from congestion and urban access charges. Other examples include licence tag lotteries and quotas on new registrations in many cities in China. Access restrictions for motorcycles were among the measures that led to the mass market adoption of electric two-wheelers in China over a decade ago (see Box 2.4).

¹¹ Both ZEV mandates and incentives can be tailored to be more or less favourable to zero- (BEVs and FCEVs) or low-emission vehicles (PHEVs). Ambitious targets are essential to mobilise sufficient capital to enable cost reductions in battery manufacturing. Current and proposed schemes tend to favour ZEVs over low-emission vehicles by using weighting factors that give more credit to vehicles with a higher zero-emission range. This is based on the intention to calibrate these ZEV policies to vehicles that require more advanced technologies (and which are therefore subject to increased deployment challenges). The more competitive total cost of ownership of PHEVs *vis-à-vis* ICEs at low mileage usage suggests that cost parity can be achieved earlier, and that there is a less compelling case for a mandate or incentives for technologies that could benefit from spill overs from the increasing deployment of battery storage capacity. Another factor that reinforces these dynamics is the limited reliance on all-electric driving of PHEVs, given that part of their activity is not intended for commuting trips.

Seizing opportunities from Mobility as a Service (MaaS)

Today, the total cost of ownership per kilometre for a BEV is competitive with conventional cars if operated in fleets with intensive use, such as buses, taxis, ride-hailing services and shared cars. Public policies that support and manage the transition of urban mobility toward a greater reliance on a range of integrated services, including public transport and ride-hailing (as opposed to private vehicle ownership), are also likely to encourage the adoption of electric mobility. Adequate progress on vehicle automation (self-driving) could accelerate the transition by reducing the cost of mobility services that offer convenient, reliable, affordable and safe alternatives to the conventional norm (of the past half century) of private passenger cars.

Complementing fuel taxes with road pricing

Our scenario analyses indicate that the growing share of electric vehicles gradually will reduce sales of diesel and gasoline. Eventually this will translate into less government revenue from fuel taxation. In 2017, nearly USD 2.6 billion of fuel tax revenue was foregone as a result of the high share of electric two- and three-wheelers in the vehicle stock in China.¹² In the New Policies Scenario, the estimated foregone revenue from tax on petroleum road fuels is expected to reach USD 47 billion in 2030, while in the EV30@30 Scenario this figure is USD 92 billion. The major increase in the estimate of foregone revenues for the 2030 timeframe suggest that, for governments to retain sufficient income to invest in and maintain infrastructure, as well as to cover externalities from road transport, alternative taxation systems will be needed.

Taxation based on vehicle activity, such as distance- or congestion-based pricing, would ensure a technology-neutral approach and a more direct link between infrastructure impacts and vehicle use. Road pricing mechanisms are also well suited to account for the local nature of the impacts of pollutant emissions. For governments to retain the same level of aggregated income in the EV30@30 Scenario, per-km taxes would need to be in the range of USD 0.01/km in the United States and China, to USD 0.08/km in the European Union and Japan (IEA, 2017d).

Achieving demand- and business-driven EVSE development

Local, national and regional stakeholders must work together to achieve adequate development of the charging infrastructure. As more and more companies, automakers, and energy and grid service providers form alliances to build EVSE, the need for public funding will wane. Moving past the initial deployment phase, EVSE should be mainly relying on end-user charges and its development should be primarily demand-driven and business-led.

Ensuring high frequency of use for publicly accessible chargers is crucial to enable this transition. Full cost recovery can also be facilitated by making available additional revenue streams that can be effectively recovered, such as parking fees or the income derived from attracting customers to commercial facilities that offer EV charging.

Given the need to maintain the publicly accessible charging infrastructure across a whole road network, it is possible that targeted support for some EVSE installations will be needed for cases where full cost recovery conflicts with the need to ensure the provision of adequate charging options. Useful instruments could include regulatory requirements for compulsory

¹² This value is calculated as a product of the number of vehicles by mode multiplied by their mileage and fuel economy, assuming that they would have been substituted by ICE vehicles with comparable characteristics.

purchase orders; allowing cross-subsidisation from charging points with high rates of utilisation; and/or using public service contracts driven by public service obligations (which are employed in Norway).

Public-private partnerships (PPPs), provide flexible models that can facilitate the transition. PPPs are also viable in the longer term as a means of ensuring that the availability of publicly accessible chargers is sustained not only on the basis of business-driven considerations, but also as a public service. Only genuine "grey zones" where business cases do not exist, but where infrastructure nevertheless is critical to promote a transition to electric mobility, would benefit from public support. Ensuring that public funds do go to building charging infrastructure in such grey zones is important because, although they are not a major contributor to the EV value chain, absence of an adequately developed charging network could jeopardise EV deployment. California has addressed this issue by mandating that electricity distributors (or other agents) guarantee a minimum deployment of EVSE.

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Ensuring that EVs are effectively integrated in the electricity grid

The effects of increased electrification of road transport on electricity demand and consequently on power grids could be sizeable. Ensuring that this demand is met with low-carbon electricity is a major imperative. The trend is encouraging. In 2016, growth in solar photovoltaic (PV) capacity was larger than any other form of generation, and since 2010, costs of new solar PV have declined by 70%, wind by 25% and battery costs by 40% (IEA, 2017b). Together wind and solar are expected to account for more than 80% of global renewable capacity additions in the next five years (IEA, 2017b). The regional and temporal variability of power supply from variable energy sources suggests that power systems will need enhanced flexibility. While supply-side solutions such as peaking power plants can facilitate the variability of renewables-based generation, there is growing support for approaches that maximise options to modulate demand.

Regulatory frameworks could be passed to mandate that EV manufacturers install software that by default distributes the majority of charging to occur during power demand troughs (such as in the early hours of the morning). Depending on their needs, EV buyers could then opt out of such default charging algorithms. Time-of-use (TOU) pricing is another promising option that provides opportunities to delay or anticipate significant electricity loads from EVs charging at home during the night, thereby offering positive synergies with the integration of variable renewables in the power system at these times. Similar opportunities arise from workplace charging and power supply peaks from solar electricity during the day. The same demand-side management (DSM) solutions that encourage shifts in EV load from peak hours to troughs of power demand can also significantly reduce (and potentially even fully offset) requirements for grid upgrades and additional generation capacity. Taking these strong synergies into account, IRENA/IEA/REN21 (2018) suggests that the integration of EVs and renewable electricity uptake could be promoted with measures binding EV penetration to renewable energy targets and mandates.

DSM measures that promote the mutual benefits of EVs and variable renewables also enable EVs to provide valuable ancillary services to the power grid, including frequency regulation, voltage support and power factor correction, as well as load balancing in distribution networks. EVs represent storage capacity that is clearly an additional asset and can enable enhanced demand response services through V2G technologies.

Regulators should accelerate the roll-out of smart meters, which enable DSM solutions. Given that the response to price signals is stronger in the presence of aggregators, regulators should also

ensure that aggregators can participate in the short-term and system services power markets.¹³ In the case of V2G, double taxation for both power taken from and provided to the network should be removed.

The advantages of effective and efficient EV grid integration also suggest that transport policy makers and power systems regulators have much to gain from closer collaboration. Considering the major economic investments and long lead times required to install new power generation and to upgrade electricity networks, capacity planning and reliability studies that take adequate account of the electrification of mobility are crucial prerequisites for proper sizing of the future grid infrastructure and power equipment. Governments should facilitate collaboration and the exchange of information between transport and energy policy makers, regulators, utilities and grid operators.

Managing changes in material demand from EV batteries

Investment challenges to the extraction of raw materials needed for battery production are emerging as a critical issue, especially for cobalt.¹⁴ This is attributable to several factors, including:

- The small size of the cobalt market in the face of rapid demand growth. Cobalt prices have nearly tripled in the past two years. This is further exacerbated by stockpiling activities at different levels along the supply chain and traders taking speculative positions.
- Cobalt is extracted as a by-product of nickel and copper (metals with a much larger market demand in volume terms). This poses challenges for mining companies to commit to greenfield projects.
- Known cobalt production is concentrated in the Democratic Republic of Congo, which limits the scope for supply diversification.

Investment certainty is further challenged by the lack of customer commitments to long-term agreements, partly due to the risk associated with evolving technology for battery cathode materials (with clear attempts to minimise the reliance on cobalt), and partly to uncertainties on prospects for BEV uptake. Long-term contracts between OEMs/battery producers and mining companies may provide a possible solution to overcome investment hurdles. Policy makers can facilitate this development by reducing uncertainty in the only area that falls within the direct scope of their actions, i.e. the EV (primarily BEV) uptake, by providing clear signals on the commitment to meet policy objectives and their timeline (e.g. through ZEV mandates and EV sales targets).

Minimum standards of labour and environmental conditions

Regulators can play an important role in setting minimum standards related to labour and environmental conditions, and in developing effective instruments to ensure that they are properly enforced. At present, this is especially important for activities related to raw material extraction. This is of grave concern in the pervasive occurrence of child labour in artisanal mining in the

¹³ Today, only a few countries allow aggregators to participate in such markets (IEA, 2017a). In the United States, the Federal Energy Regulatory Commission recently voted to remove the barriers that prevented EVs from participating in such markets (Federal Energy Regulatory Commission, 2018; John, 2018).

¹⁴ Lithium prices also have experienced a significant surge since 2015, but a sizeable lithium supply response is expected to become available and uncertainties from changes in battery cathode chemistry are minor compared with how these changes affect cobalt demand.

Democratic Republic of Congo, highlighted by several organisations.¹⁵ Instruments providing leverage on corporate social and environmental responsibility, including solutions that improve the supply chain traceability of materials used in batteries, are needed.

There are clear gaps today in the supply chain traceability of EV manufacturers (partly due to the complex and international nature of the material supply chain for batteries) (Amnesty International, 2017a; Amnesty International, 2017b). Multilateral engagement from public policy makers, international institutions, non-governmental organisations and the private sector is important to guarantee the transparency of battery-related operations along the supply chain and throughout their lifetime. The sooner these standards are developed and respected, the earlier the battery industry will have certainty on resulting costs and the availability of secure, sustainable, and increasingly diversified supply of raw materials for automotive batteries.

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Maximising the economic value of batteries while ensuring their environmental sustainability

Maximising the economic value of batteries is likely to result in net advantages for the environmental sustainability of battery production, use and end-of-life management. Key instruments include the extension of the scope for battery applications and the maximisation of their residual value once they reach the end of their useful life.¹⁶

Retaining responsibility for battery end-of-life treatment

Uncertainty as to whether the battery manufacturer, the OEM, the consumer or a third-party stakeholder owns and is responsible for a battery at the end of its lifetime bears the risk of encouraging the disengagement of all potentially responsible stakeholders towards end-of-life treatment. Designating stakeholders that retain responsibility for batteries along their lifetime or at the various stages of their life cycle, particularly for disposal, can provide effective incentives to ensure that the residual value of batteries is maximised. In China, recently adopted rules target the areas of technical requirements for recycling and legal responsibility. These rules constitute a first step in regulation of an emerging industry for automotive battery recycling (Reuters, 2018b). Useful lessons can be drawn from flaws in international regulations on used consumer electronics trade and recycling, which, in some cases, have resulted in large-scale transportation of disposed goods from developed regions to emerging countries where they found their way into informal material extraction and recycling, and illegal landfills (harmful for the environment and local populations) (The Guardian, 2013).

Holding specific stakeholders responsible for batteries across their lifetime can also help to ensure the effective establishment of robust and transparent global certification schemes for the mining of raw materials used in making batteries, as well as adequate traceability mechanisms for second-life to end-of-life operations. Credible labelling schemes or product guarantees that cover both product manufacturing (including material sourcing), second-life and end-of-life treatments could influence consumer choice and effectively drive stakeholders to responsibly handle batteries over their lifetime to track and improve their supply and disposal chains.

¹⁵ For example, Amnesty International points out that "the energy solutions of the future must not be built on human rights abuses" (Amnesty International, 2017b).

¹⁶ Using batteries in second-life stationary applications could extend their economic and useful life, thereby boosting residual values. In addition, it could reduce cost to provide stationary energy storage and facilitate the integration of variable renewable into power grids.

Developing a regulatory framework to reduce battery end-of-life treatment costs

Current approaches for battery end-of-life treatment include pyrometallurgical, hydrometallurgical and physical processes. Both the pyrometallurgical and hydrometallurgical solutions can handle a variety of battery types, but the processes alter the original chemistries which lowers the value of the products that can be recouped and recycled. In the pyrometallurgical processes, this is due to the high temperatures required. For hydrometallurgical solutions, this is due to the use of strong chemical agents. Physical separation has the advantage to recover active materials and to minimise their alteration. The main drawbacks of physical separation are the high costs induced by the need for tailored approaches, changing from battery pack to battery pack, due to a lack of standards in their manufacture.

The development of a regulatory framework to facilitate the adoption of physical separation for the end-of-life treatment of batteries could be a good way forward to maximise their residual value. Physical separation enables more effective recovery of high value materials and the cost-related barrier could be overcome by standards that would enable automation. On the other hand, taking into account the potential changes in battery chemistries may also have significant impacts on the manner that batteries and their components will be designed and manufactured.

Given the complexity of the subject, reaching the goal of affordable battery recycling for high value materials calls for effective dialogue among the relevant stakeholders on the best way forward. This could be supported via a platform to host dialogues with the stated aim to minimise battery recycling costs while ensuring that environmental and social standards are respected.

Building this co-ordination among stakeholders from the current stage of EV market deployment is important to ensure that significant volumes of spent batteries can be properly handled from environmental and sustainability perspectives, and to ensure that this is structurally possible because it makes sense from a market point of view. By the early 2030s, regions that have made early investments in recycling regulations could begin to reap dividends, as they will have developed an alternative to primary metals.

Statistical annex

This annex presents the electric car and electric vehicle supply equipment (EVSE) time series data for the 44 countries covered in this report. These include the Electric Vehicles Initiative (EVI) members, countries falling under the scope of activity of the European Alternative Fuel Observatory and countries that have reported data to the EVI.

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The main data sources are submissions from EVI members, statistics and indicators available from the European Alternative Fuels Observatory (EAFO, 2018a; EAFO, 2018b) for European countries that are not members of the EVI, data extracted from commercial databases (Marklines, 2018), and information released by relevant stakeholders (ACEA, 2018; ACEM, 2018; CAAM, 2018).

In the following tables, the category “others” includes Austria, Belgium, Bulgaria, Croatia, Cyprus¹, Czech Republic, Denmark, Estonia, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malaysia, Malta, Poland, Romania, Slovakia, Slovenia, Spain.

Electric car stock

Table A.1: Electric car stock (BEV and PHEV) by country, 2005-17 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.05	0.30	0.60	1.92	3.69	5.06	7.34
Brazil									0.06	0.15	0.32	0.68	
Canada							0.52	2.54	5.66	10.73	17.69	29.27	45.95
Chile							0.01	0.01	0.02	0.03	0.07	0.10	0.25
China					0.48	1.91	6.98	16.88	32.22	105.39	312.77	648.77	1 227.77
Finland							0.06	0.24	0.47	0.93	1.59	3.29	6.34
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
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
India				0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80	6.80
Japan					1.08	3.52	16.14	40.58	69.46	101.74	126.40	151.25	205.35
Korea						0.06	0.34	0.85	1.45	2.76	5.95	11.21	25.92
Mexico							0.09	0.10	0.15	0.25	0.66	0.92	
Netherlands				0.01	0.15	0.27	1.14	6.26	28.67	43.76	87.53	112.01	119.33
New Zealand						0.01	0.03	0.06	0.09	0.41	0.91	2.41	5.88
Norway				0.01	0.26	0.40	0.79	2.63	7.15	15.67	35.44	69.17	114.05
Portugal													1.78
South Africa									0.03	0.05	0.29	0.67	0.86
Sweden							0.18	1.11	2.66	7.32	15.91	29.33	49.67
Thailand	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.10	0.37	0.38	0.40
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
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
Others	0.53	0.53	0.53	0.61	0.64	0.81	2.60	5.31	9.35	18.73	37.17	61.63	103.44
Total	1.89	2.23	2.69	5.15	7.48	14.26	61.33	179.03	381.30	703.65	1 239.45	1 982.04	3 109.05

¹ 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.

Table A.2: Battery electric car (BEV) stock by country, 2005-17 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.05	0.22	0.41	0.78	1.54	2.21	3.42
Brazil									0.06	0.12	0.25	0.32	
Canada							0.22	0.84	2.48	5.31	9.69	14.91	23.62
Chile							0.01	0.01	0.02	0.02	0.03	0.05	0.16
China					0.48	1.57	6.32	15.96	30.57	79.48	226.19	483.19	951.19
Finland							0.06	0.11	0.17	0.36	0.61	0.84	1.35
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
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
India					0.37	0.53	0.88	1.33	2.76	2.95	3.35	4.35	4.80
Japan						1.08	3.52	16.13	29.60	44.35	60.46	70.93	86.39
Korea							0.06	0.34	0.85	1.45	2.76	5.67	10.77
Mexico									0.09	0.10	0.15	0.24	0.57
Netherlands							0.01	0.15	0.27	1.12	1.91	4.16	6.83
New Zealand							0.00	0.00	0.01	0.03	0.05	0.08	0.19
Norway							0.01	0.26	0.40	0.79	2.63	6.81	15.01
Portugal													1.78
South Africa										0.03	0.05	0.17	0.27
Sweden							0.18	0.45	0.88	2.12	5.08	8.03	12.39
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
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
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
Others	0.53	0.53	0.53	0.61	0.64	0.79	2.56	4.85	8.23	15.23	27.40	38.98	57.14
Total	1.89	2.23	2.69	5.16	7.48	13.87	51.95	109.72	220.58	409.09	726.91	1 185.60	1 928.36

Table A.3: Plug-in hybrid electric car (PHEV) stock by country, 2005-17 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Australia							0.08	0.18	1.13	2.15	2.85	3.92		
Brazil										0.03	0.08	0.36		
Canada						0.30	1.70	3.18	5.42	8.00	14.36	22.33		
Chile									0.01	0.04	0.05	0.09		
China					0.34	0.66	0.92	1.65	25.92	86.58	165.58	276.58		
Finland							0.13	0.30	0.57	0.97	2.44	4.99		
France						0.10	0.70	1.53	3.60	9.28	17.03	25.82		
Germany						0.24	1.40	3.02	7.41	18.52	31.81	50.47		
India														
Japan						0.02	10.98	25.11	41.28	55.47	64.86	100.86		
Korea										0.27	0.44	1.84		
Mexico										0.01	0.09	0.13		
Netherlands						0.02	4.35	24.51	36.94	78.16	98.90	98.22		
New Zealand							0.01	0.01	0.22	0.42	0.76	1.30		
Norway							0.34	0.66	2.34	10.28	30.95	60.18		
Portugal										0.13	0.40	0.53		
South Africa										0.66	1.78	5.21	10.83	
Sweden										10.83	21.29	37.28		
Thailand										0.06	0.32	0.32	0.32	
United Kingdom					0.02	0.03	1.02	2.09	10.02	27.55	54.96	88.66		
United States							7.98	46.57	95.58	150.94	193.77	266.65	360.51	
Others						0.02	0.04	0.46	1.13	3.50	9.77	22.65	46.29	
Total						0.39	9.38	69.31	160.72	294.56	512.54	796.44	1 180.69	

New electric car sales

Table A.4: New electric car sales (BEV and PHEV) by country, 2005-17 (thousands)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.05	0.25	0.29	1.32	1.77	1.37	2.28
Brazil							0.09	0.17	0.06	0.09	0.17	0.36	
Canada							0.52	2.02	3.12	5.07	6.96	11.58	16.68
Chile							0.01	0.01	0.01	0.01	0.04	0.03	0.15
China					0.48	1.43	5.07	9.90	15.34	73.17	207.38	336.00	579.00
Finland							0.03	0.18	0.22	0.44	0.69	1.43	3.06
France	0.01	0.01	0.01		0.01	0.19	2.73	6.26	9.62	12.64	22.95	29.51	34.78
Germany	0.02			0.07	0.02	0.14	1.65	3.37	6.93	12.74	23.19	24.61	54.56
India				0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00
Japan					1.08	2.44	12.62	24.44	28.88	32.29	24.65	24.85	54.10
Korea						0.06	0.27	0.51	0.60	1.31	3.19	5.26	14.71
Mexico							0.09	0.01	0.05	0.10	0.27	0.26	
Netherlands				0.01	0.03	0.12	0.88	5.12	22.42	15.09	43.77	24.48	11.07
New Zealand						0.01	0.01	0.03	0.04	0.32	0.49	1.50	3.47
Norway			0.01	0.24	0.15	0.39	1.84	4.51	8.52	19.77	33.73	44.89	62.26
Portugal						0.72	0.19	0.05	0.18	0.20	0.64	1.47	1.78
South Africa									0.03	0.01	0.24	0.38	0.20
Sweden							0.18	0.93	1.55	4.67	8.59	13.42	20.35
Thailand							0.01	0.01	0.01	0.07	0.27	0.03	
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
United States	1.12			1.47		1.19	17.73	53.24	96.70	118.78	113.87	159.62	198.35
Others	0.53			0.09	0.03	0.17	1.80	2.71	4.23	9.55	17.79	25.02	42.02
Total	1.89	0.34	0.47	2.46	2.13	7.49	47.24	117.84	202.80	322.70	540.72	744.22	1 148.70

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Table A.5: New battery electric car (BEV) sales by country, 2005-17

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.05	0.17	0.19	0.37	0.76	0.67	1.21
Brazil							0.07	0.13	0.06	0.06	0.13	0.07	
Canada							0.22	0.62	1.64	2.83	4.38	5.22	8.71
Chile							0.01	0.01	0.01	0.01	0.01	0.02	0.10
China				0.48	1.09	4.75	9.64	14.61	48.91	146.72	257.00	468.00	
Finland							0.03	0.05	0.05	0.18	0.24	0.22	0.50
France	0.01	0.01	0.01		0.01	0.19	2.63	5.66	8.78	10.57	17.27	21.76	25.98
Germany	0.02			0.07	0.02	0.14	1.40	2.21	5.31	8.35	12.08	11.32	25.07
India			0.37	0.16	0.35	0.45	1.43	0.19	0.41	1.00	0.45	2.00	
Japan				1.08	2.44	12.61	13.47	14.76	16.11	10.47	15.46	18.10	
Korea					0.06	0.27	0.51	0.60	1.31	2.92	5.10	13.30	
Mexico							0.09	0.01	0.05	0.09	0.21	0.21	
Netherlands			0.01	0.03	0.12	0.86	0.79	2.25	2.66	2.54	3.74	8.63	
New Zealand					0.01	0.01	0.02	0.03	0.11	0.30	1.16	2.94	
Norway			0.01	0.24	0.15	0.39	1.84	4.18	8.20	18.09	25.78	24.22	33.03
Portugal						0.72	0.19	0.05	0.14	0.19	0.64	0.79	1.78
South Africa									0.03	0.01	0.12	0.10	0.07
Sweden							0.18	0.27	0.43	1.24	2.96	2.95	4.36
Thailand							0.01	0.01	0.01	0.01	0.01	0.03	
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
United States	1.12			1.47		1.19	9.75	14.65	47.69	63.42	71.04	86.73	104.49
Others	0.53			0.09	0.03	0.15	1.78	2.28	3.57	7.18	11.51	12.15	18.37
Total	1.89	0.34	0.47	2.46	2.13	7.11	38.25	57.89	111.32	188.86	321.00	459.91	750.49

Table A.6: New plug-in hybrid electric (PHEV) car sales by country, 2005-17

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Australia								0.08	0.10	0.95	1.01	0.70	1.08	
Brazil								0.02	0.03		0.03	0.05	0.29	
Canada							0.30	1.40	1.48	2.24	2.58	6.36	7.97	
Chile										0.01	0.02	0.01	0.04	
China						0.34	0.32	0.26	0.73	24.27	60.66	79.00	111.00	
Finland								0.13	0.17	0.26	0.44	1.21	2.55	
France								0.10	0.60	0.83	2.07	5.68	7.75	8.79
Germany								0.24	1.16	1.62	4.39	11.11	13.29	29.50
India														
Japan							0.02	10.97	14.12	16.18	14.19	9.39	36.00	
Korea											0.27	0.16	1.41	
Mexico											0.01	0.06	0.05	
Netherlands							0.02	4.33	20.16	12.43	41.23	20.74	2.45	
New Zealand								0.01	0.01	0.21	0.20	0.34	0.54	
Norway								0.33	0.32	1.68	7.95	20.67	29.23	
Portugal									0.04	0.01		0.69		
South Africa											0.12	0.28	0.13	
Sweden								0.66	1.12	3.43	5.63	10.46	15.99	
Thailand											0.06	0.26		
United Kingdom						0.02	0.01	0.99	1.07	7.93	19.24	27.40	33.70	
United States								7.98	38.59	49.01	55.36	42.83	72.89	93.86
Others								0.02	0.02	0.43	0.66	2.37	6.28	12.87
Total								0.38	9.00	59.95	91.48	133.83	219.73	284.31
													398.21	

Market share of electric cars

Table A.7: Market share of electric cars (BEV and PHEV) by country, 2005-17 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.01%	0.02%	0.02%	0.1%	0.1%	0.1%	0.1%
Brazil												0.01%	0.02%
Canada							0.04%	0.1%	0.2%	0.3%	0.5%	0.8%	1.1%
Chile										0.01%	0.02%	0.01%	0.1%
China					0.01%	0.01%	0.04%	0.1%	0.1%	0.4%	1.0%	1.4%	2.2%
Finland							0.02%	0.2%	0.2%	0.4%	0.6%	1.2%	2.6%
France						0.01%	0.1%	0.3%	0.5%	0.7%	1.2%	1.4%	1.7%
Germany							0.1%	0.1%	0.2%	0.4%	0.7%	0.7%	1.6%
India		0.02%	0.01%	0.02%	0.02%		0.05%	0.01%	0.02%	0.04%	0.02%	0.06%	
Japan			0.03%	0.1%	0.3%		0.5%	0.6%	0.7%	0.6%	0.5%	1.0%	
Korea					0.01%	0.02%	0.04%	0.1%	0.1%	0.3%	0.3%	0.5%	1.3%
Mexico							0.01%			0.01%	0.02%	0.02%	
Netherlands					0.01%	0.02%	0.15%	1.02%	5.4%	3.9%	9.7%	6.4%	2.7%
New Zealand						0.01%	0.01%	0.01%	0.02%	0.1%	0.1%	0.5%	1.1%
Norway		0.01%	0.2%	0.1%	0.3%	1.3%	3.3%	6.0%	13.7%	22.4%	29.0%	39.2%	
Portugal						0.3%	0.1%	0.1%	0.2%	0.1%	0.4%	0.7%	0.8%
South Africa									0.01%		0.1%	0.1%	0.1%
Sweden							0.1%	0.3%	0.5%	1.4%	2.4%	3.4%	6.3%
Thailand										0.01%	0.03%		
United Kingdom	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.1%	0.1%	0.2%	0.6%	1.1%	1.4%	1.7%
United States	0.01%			0.01%		0.01%	0.2%	0.4%	0.7%	0.8%	0.7%	1.0%	1.2%
Others							0.03%	0.05%	0.1%	0.2%	0.3%	0.4%	0.7%

Table A.8: Market share of battery electric (BEV) cars by country, 2005-17 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia							0.01%	0.02%	0.02%	0.04%	0.1%	0.1%	0.1%
Brazil												0.01%	
Canada							0.02%	0.05%	0.1%	0.2%	0.3%	0.4%	0.6%
Chile											0.01%	0.01%	0.05%
China					0.01%	0.01%	0.04%	0.1%	0.1%	0.2%	0.7%	1.0%	1.8%
Finland							0.02%	0.05%	0.05%	0.2%	0.2%	0.2%	0.4%
France						0.01%	0.1%	0.3%	0.5%	0.6%	0.9%	1.1%	1.3%
Germany							0.04%	0.1%	0.2%	0.3%	0.4%	0.3%	0.7%
India		0.02%	0.01%	0.02%	0.02%	0.05%	0.01%	0.02%	0.04%	0.04%	0.04%	0.02%	0.06%
Japan			0.03%	0.1%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Korea				0.0%	0.02%	0.04%	0.1%	0.1%	0.1%	0.3%	0.4%	1.1%	
Mexico							0.01%				0.01%	0.02%	0.02%
Netherlands				0.01%	0.02%	0.2%	0.2%	0.5%	0.7%	0.6%	1.0%	2.1%	
New Zealand					0.01%	0.01%	0.01%	0.02%	0.05%	0.1%	0.5%	1.1%	
Norway		0.01%	0.2%	0.1%	0.3%	1.3%	3.0%	5.8%	12.5%	17.1%	15.7%	20.8%	
Portugal						0.3%	0.1%	0.1%	0.1%	0.1%	0.4%	0.4%	0.8%
South Africa									0.01%		0.03%	0.03%	0.02%
Sweden						0.05%	0.09%	0.15%	0.38%	0.82%	0.75%	1.34%	
Thailand													
United Kingdom	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.1%	0.1%	0.1%	0.3%	0.4%	0.4%	0.5%
United States	0.01%			0.01%		0.01%	0.1%	0.1%	0.3%	0.4%	0.4%	0.5%	0.6%
Others						0.03%	0.05%	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%

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Table A.9: Market share of plug-in hybrid electric (PHEV) cars by country, 2005-17 (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia									0.01%	0.01%	0.01%	0.01%	0.01%
Brazil												0.02%	
Canada						0.02%	0.1%	0.1%	0.2%	0.2%	0.4%	0.5%	
Chile									0.0%	0.0%		0.02%	
China									0.1%	0.3%	0.3%	0.4%	
Finland							0.1%	0.2%	0.2%	0.4%	1.0%	2.2%	
France							0.03%	0.05%	0.1%	0.3%	0.4%	0.4%	0.4%
Germany						0.01%	0.04%	0.1%	0.1%	0.3%	0.4%	0.9%	
India													
Japan							0.2%	0.3%	0.3%	0.3%	0.2%	0.7%	
Korea										0.02%	0.01%	0.1%	
Mexico													
Netherlands							0.9%	4.8%	3.2%	9.2%	5.4%	0.6%	
New Zealand									0.01%	0.01%	0.02%	0.02%	
Norway							0.2%	0.2%	1.2%	5.3%	13.4%	18.4%	
Portugal									0.03%	0.01%		0.33%	
South Africa										0.03%	0.08%	0.04%	
Sweden							0.2%	0.4%	1.1%	1.6%	2.7%	4.9%	
Thailand									0.01%	0.03%			
United Kingdom							0.05%	0.05%	0.3%	0.7%	1.0%	1.2%	
United States						0.1%	0.3%	0.4%	0.4%	0.3%	0.4%	0.6%	
Others							0.01%	0.05%	0.1%	0.2%	0.2%	0.4%	

Electric vehicle supply equipment stock

Table A.10: Publicly accessible chargers (slow and fast) by country, 2005-17

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia													476
Brazil													
Canada							724	1179	2321	3508	4215	5841	
Chile						3	15	17	26	30	32	51	
China									30000	58758	141254	213903	
Finland								267	383	848	858	885	
France							809	1802	1827	10568	15567	15978	
Germany							1518	2447	2846	5328	17509	24289	
India										25	25	222	
Japan					312	801	1381	1794	11517	22110	24372	28834	
Korea						62	177	292	388	790	1566	5612	
Mexico												1528	
Netherlands					400	400	2803	5791	11981	18044	26448	33431	
New Zealand												104	
Norway					2800	3123	3746	4651	5385	5703	7758	9530	
Portugal						1086	1135	1171	1189	1214	1233	1476	
South Africa												124	
Sweden							505	1020	1165	1520	2162	4071	
Thailand												96	
United Kingdom						1503	2840	5691	7742	9377	11208	13534	
United States	374	381	419	542	4392	13160	16867	22633	31674	40473	45868		
Others						1306	4145	5980	8237	14301	18887	24298	
Total	374	381	419	4 054	12 676	32 958	48 969	107 640	183 798	313 567	430 151		

Table A.11: Publicly accessible slow chargers by country, 2005-17

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia													436
Brazil													
Canada						722	1172	2266	3361	3900	5168		
Chile						1	7	9	16	20	20	37	
China								21000	46657	86365	130508		
Finland							250	357	706	706	706		
France							800	1700	1700	9865	14250	14407	
Germany							1500	2400	2606	4587	16266	22213	
India												222	
Japan									8640	16120	17260	21507	
Korea						29	59	115	151	449	1075	3081	
Mexico												1486	
Netherlands					400	400	2782	5770	11860	17786	26088	32976	
New Zealand													
Norway					2800	3105	3688	4511	5185	5185	7040	8292	
Portugal						1080	1128	1154	1172	1192	1192	1322	
South Africa												87	
Sweden							500	1000	1065	1251	1737	3456	
Thailand												88	
United Kingdom						1503	2804	5435	7182	8174	9594	11497	
United States	333	339	373	482	3903	11695	14990	20115	28150	35089	39601		
Others						1299	3940	5419	7533	12518	16676	21038	
Total	333	339	373	3 682	11 320	29 625	43 925	90 848	156 021	237 258	318 128		

Table A.12: Publicly accessible fast chargers by country, 2005-17

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Australia													40
Brazil													
Canada							2	7	55	147	315	673	
Chile							2	8	8	10	10	12	14
China									9000	12101	54889	83395	
Finland									17	26	142	152	179
France								9	102	127	703	1317	1571
Germany								18	47	240	741	1243	2076
India											25	25	
Japan						312	801	1381	1794	2877	5990	7112	7327
Korea						33	118	177	237	341	491	2531	
Mexico												42	
Netherlands								21	21	121	258	360	455
New Zealand												104	
Norway							18	58	140	200	518	718	1238
Portugal							6	7	17	17	22	41	154
South Africa												37	
Sweden								5	20	100	269	425	615
Thailand												8	
United Kingdom								36	256	560	1203	1614	2037
United States	42	42	47	60	489	1464	1877	2518	3524	5384	5384	6267	
Others						7	205	561	704	1783	2211	3260	
Total	42	42	47	372	1 356	3 332	5 044	16 792	27 777	76 309	112 023		

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

AC	Alternating current
ACEA	European Automobile Manufacturers Association
BEV	Battery electric vehicle
CHAdeMO	Charge de Move
CO ₂	Carbon dioxide
CPO	Charge point operator
DC	Direct current
DSM	Demand-side management
DSO	Distribution system operator
EAFO	European Alternative Fuels Observatory
EC	European Commission
EEA	European Environment Agency
EESL	Energy Efficiency Services Limited
EMSP	E-mobility service provider
EPA	Environmental Protection Agency (US)
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
FERC	Federal Energy Regulatory Commission
FCEV	Fuel-cell electric vehicle
GEVO	Global electric vehicle outlook
GHG	Greenhouse gas
GVW	Gross vehicle weight
HEV	Hybrid vehicle
HVAC	Heating, ventilation and air conditioning
ICE	Internal combustion engine
IEA	International Energy Agency
LCV	Light commercial vehicles
LDV	Light-duty vehicle ¹
Lge	Litres of gasoline equivalent
LSEV	Low speed electric vehicle
NEV	New energy vehicle
NEVO	Nordic electric vehicle outlook
NPS	New Policy Scenario
NVE	Norway's Water Resources and Energy Directorate
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid vehicle
PLDV	Passenger light-duty vehicle

¹ Including passenger cars and light commercial vehicles..

PNNL	Pacific Northwest National laboratory
SDS	Sustainable Development Scenario
TCO	Total cost of ownership
TCP	Technology Collaboration Programme
TOU	Time-of-use
TSO	Transmission system operator
TTW	Tank-to-wheel
UNFCCC	United Nations Framework Convention on Climate Change
USD	US Dollar
V	Volt
V2G	Vehicle-to-grid
V2X	Vehicle-to-[another element], e.g. vehicle-to-vehicle or vehicle-to-infrastructure
VAT	Value-added tax
WTW	Well-to-wheel
ZEV	Zero-emissions vehicle

Units of measure

gCO ₂	grammes of carbon dioxide
gCO 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
MtCO ₂	million tonnes of CO ₂
MW	megawatt
tCO ₂	tonnes of CO ₂
Wh/kg	watt-hour per kilogramme

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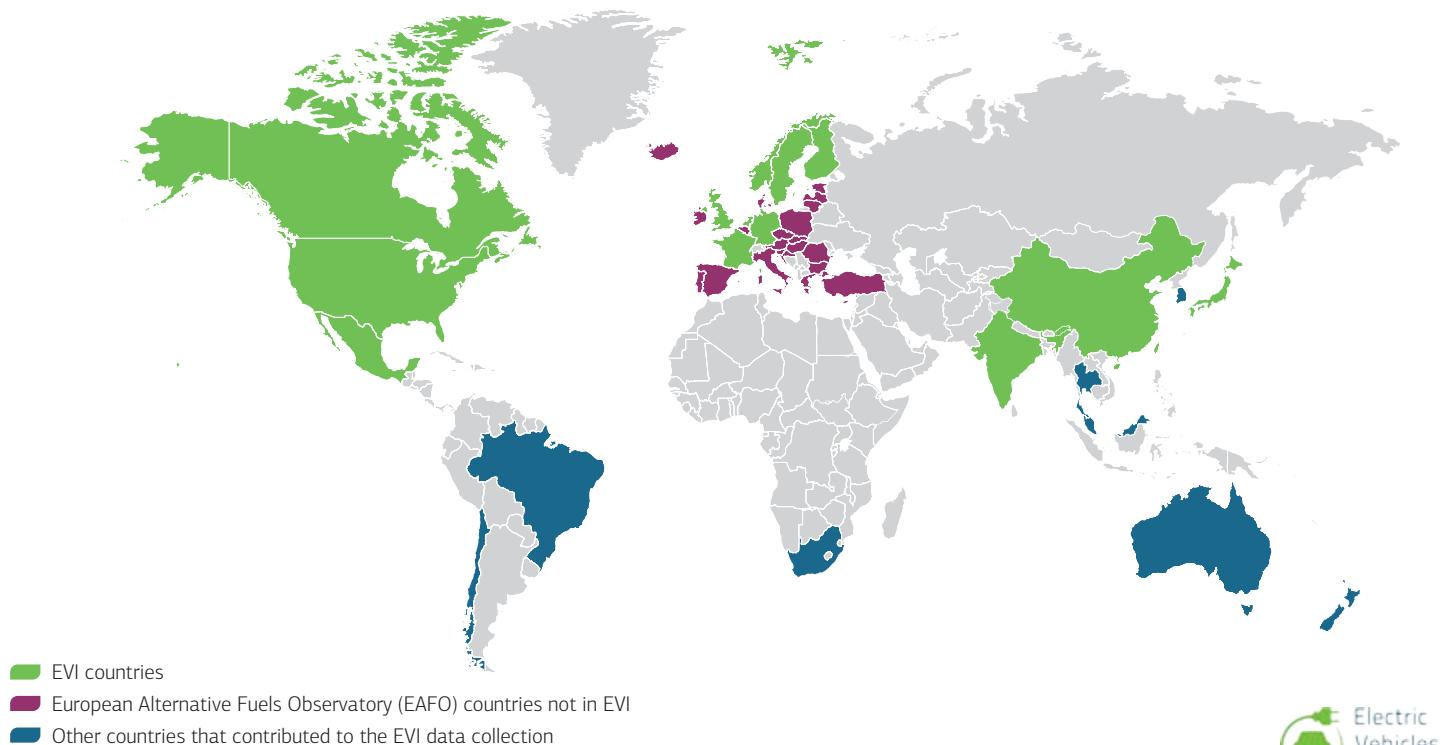
Global EV Outlook 2018

The Global EV Outlook

The Global EV Outlook is an annual publication that identifies and discusses recent developments in electric mobility across the globe. Combining historical analysis with projections to 2030, the report examines key areas of interest such as electric vehicle and charging infrastructure deployment, ownership costs, energy use, CO₂ emissions and battery materials demand. The publication includes policy recommendations, learning from frontrunner markets to inform policymakers and stakeholders who aim to encourage electric vehicle adoption. The Global EV Outlook annual series is developed with the support of the members of the Electric Vehicles Initiative (EVI).

Electric Vehicles Initiative

The EVI is a multi-government policy forum established in 2009 under the Clean Energy Ministerial, dedicated to accelerating the deployment of electric vehicles worldwide. The EVI counts today thirteen member governments (Canada, China, Finland, France, Germany, India, Japan, Mexico, the Netherlands, Norway, Sweden, the United Kingdom and the United States), representing the majority of the global electric vehicle rolling stock and including the largest and most rapidly growing electric vehicle markets worldwide. Canada and China are currently co-leading the EVI, and the IEA serves as the co-ordinator of the initiative.



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