DOCKETED	
Docket Number:	19-IEPR-04
Project Title:	Transportation
TN #:	228787-26
Document Title:	IEA.org - Global EV Outlook 2019 - Scaling up the transition to electric mobility - May 27, 2019
Description:	N/A
Filer:	Wendell Krell
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	6/19/2019 9:22:42 AM
Docketed Date:	6/19/2019

https://www.iea.org/publications/reports/globalevoutlook2019/

Global EV Outlook 2019

Scaling up the transition to electric mobility

Released **27 May 2019**.

Abstract

The Global EV Outlook is an annual publication that identifies and discusses recent developments in electric mobility across the globe. It is developed with the support of the members of the Electric Vehicles Initiative (EVI).
Combining historical analysis with projections to 2030, the report examines key areas of interest such as electric vehicle and charging infrastructure deployment, ownership cost, energy use, carbon dioxide emissions and battery material demand. The report includes policy recommendations that incorporate learning from frontrunner markets to inform policy makers and stakeholders that consider policy frameworks and market systems for electric vehicle adoption.

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

Highlights

- Electric mobility is expanding at a rapid pace. In 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car sales. The People's Republic of China remains the world's largest electric car market, followed by Europe and the United States. Norway is the global leader in terms of electric car market share.
- Policies play a critical role. Leading countries in electric mobility use a variety of measures such as fuel economy standards coupled with incentives for zero- and low-emissions vehicles, economic instruments that help bridge the cost gap between electric and conventional vehicles and support for the deployment of charging infrastructure.

Increasingly, policy support is being extended to address the strategic importance of the battery technology value chain.

- Technology advances are delivering substantial cost cuts. Key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants. Other solutions include the redesign of vehicle manufacturing platforms using simpler and innovative design architecture, and the application of big data to right size batteries.
- Private sector response to public policy signals confirms the escalating momentum for electrification of transport. In particular, recent announcements by vehicle manufacturers are ambitious regarding intentions to electrify the car and bus markets. Battery manufacturing is also undergoing important transitions, including major investments to expand production. Utilities, charging point operators, charging hardware manufacturers and other power sector stakeholders are also boosting investment in charging infrastructure.
- These dynamic developments underpin a positive outlook for the increased deployment of electric vehicles and charging infrastructure. In 2030, in the New Policies Scenario, which includes the impact of announced policy ambitions, global electric car sales reach 23 million and the stock exceeds 130 million vehicles (excluding two/three-wheelers). In the EV30@30 Scenario, which accounts for the pledges of the EVI EV30@30 Campaign to reach 30% market share for electric vehicles (EVs) by 2030 (excluding two/three-wheelers), EV sales reach 43 million and the stock is more than 250 million. Projected EV stock in the New Policies Scenario would cut demand for oil products by 127 million tonnes of oil equivalent (Mtoe) (about 2.5 million barrels per day [mb/d]) in 2030, while with more EVs in the EV30@30 Scenario the reduced oil demand is estimated at 4.3 mb/d. Electricity demand to serve EVs is projected to reach almost 640 terawatt-hours (TWh) in 2030 in the New Policies Scenario and 1 110 TWh in the EV30@30 Scenario.
- On a well-to-wheel basis, greenhouse gas (GHG) projected emissions from EVs will continue to be lower than for conventional internal combustion engine (ICE) vehicles. In the New Policies Scenario, GHG emissions of the EV fleet reach almost 230 million tonnes of carbon-dioxide equivalent (Mt CO2-eq) in 2030, offsetting about 220 Mt CO2-eq emissions. In the EV30@30 Scenario, the assumed trajectory for power grid decarbonisation is consistent with the IEA Sustainable Development Scenario and further strengthens GHG emission reductions from EVs.
- An average battery electric and plug-in hybrid electric cars using electricity characterised by the current global average carbon intensity (518 grammes of carbon-dioxide equivalent per kilowatt-hour [g CO2-eq/kWh]) emit less GHGs than a global average ICE vehicle using gasoline over their life cycle. But the extent ultimately depends on the power mix: CO2 emissions savings are significantly higher for electric cars used in countries where the power generation mix is dominated by low-carbon sources. In countries where the power generation mix is dominated by coal, hybrid vehicles exhibit lower emissions than EVs.
- The EV uptake and related battery production requirements imply bigger demand for new materials in the automotive sector, requiring increased attention to raw materials supply. Traceability and transparency of raw material supply chains are key instruments to help address the criticalities associated with raw material supply by fostering sustainable sourcing of minerals. The development of binding regulatory frameworks is important to ensure that international multi-stakeholder co-operation can effectively address these

challenges. The battery end-of-life management – including second-life applications of automotive batteries, standards for battery waste management and environmental requirements on battery design – is also crucial to reduce the volumes of critical raw materials needed for batteries and to limit risks of shortages.

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

Executive summary

Electric mobility continues to grow rapidly. In 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car registrations. The People's Republic of China (hereafter "China") remained the world's largest electric car market, followed by Europe and the United States. Norway was the global leader in terms of electric car market share (46%). The global stock of electric two-wheelers was 260 million by the end of 2018 and there were 460 000 electric buses. In freight transport, electric vehicles (EVs) were mostly deployed as light-commercial vehicles (LCVs), which reached 250 000 units in 2018, while medium electric truck sales were in the range of 1 000-2 000 in 2018. The global EV stock in 2018 was served by 5.2 million light-duty vehicle (LDV) chargers, (540 000 of which are publicly accessible), complemented by 157 000 fast chargers for buses. EVs on the road in 2018 consumed about 58 terawatt-hours (TWh) of electricity (largely attributable to two/wheelers in China) and emitted 41 million tonnes of carbon-dioxide equivalent (Mt CO2-eq), while saving 36 Mt CO2-eq compared to an equivalent internal combustion engine (ICE) fleet.

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

Technology developments are delivering substantial cost reductions. Advances in technology and cost cutting are expected to continue. Key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants. The dynamic development of battery technologies as well as recognition of the importance of EVs to achieve further cost

reductions in the broad realm of battery storage has put the strategic relevance of large-scale battery manufacturing in the limelight of policy attention.

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

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

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

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

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

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

On a well-to-wheel basis, projected greenhouse gas (GHG) emissions from EVs by 2030 are lower at a global average than for conventional internal combustion engine (ICE) vehicles. In the New Policies Scenario, GHG emissions by the EV fleet reach roughly 230 million tonnes of carbon-dioxide equivalent (Mt CO2-eq) in 2030, offsetting emissions of about 220 Mt CO2-eq that would have resulted from a fleet of ICE vehicles of equivalent size. In the EV30@30 Scenario, the assumed trajectory for power generation decarbonisation is consistent with the IEA Sustainable Development Scenario and further strengthens GHG emissions reductions from EVs compared with ICE vehicles.

At global level, battery electric cars (BEVs) and plug-in hybrid electric cars (PHEVs) using electricity characterised by the current global average carbon intensity of electricity generation (518 grammes of carbon-dioxide equivalent per kilowatt-hour [g CO2-eq/kWh]) emit a similar amount of GHG as hybrid vehicles and less GHGs than a global average ICE vehicle using gasoline over their life cycle. The impact however differs strongly by country. CO2 emissions savings are significantly higher for electric cars used in countries where the power generation mix is dominated by low-carbon sources and the average fuel consumption of ICE vehicles is high. In countries where the power generation mix is dominated by coal, very efficient ICEs, such as hybrid vehicles, exhibit lower emissions than EVs. In the future, the emissions reduction potential over the life cycle of EVs can rise further the faster electricity generation is decarbonised.

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

Electric mobility is developing at a rapid pace

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

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

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

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

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

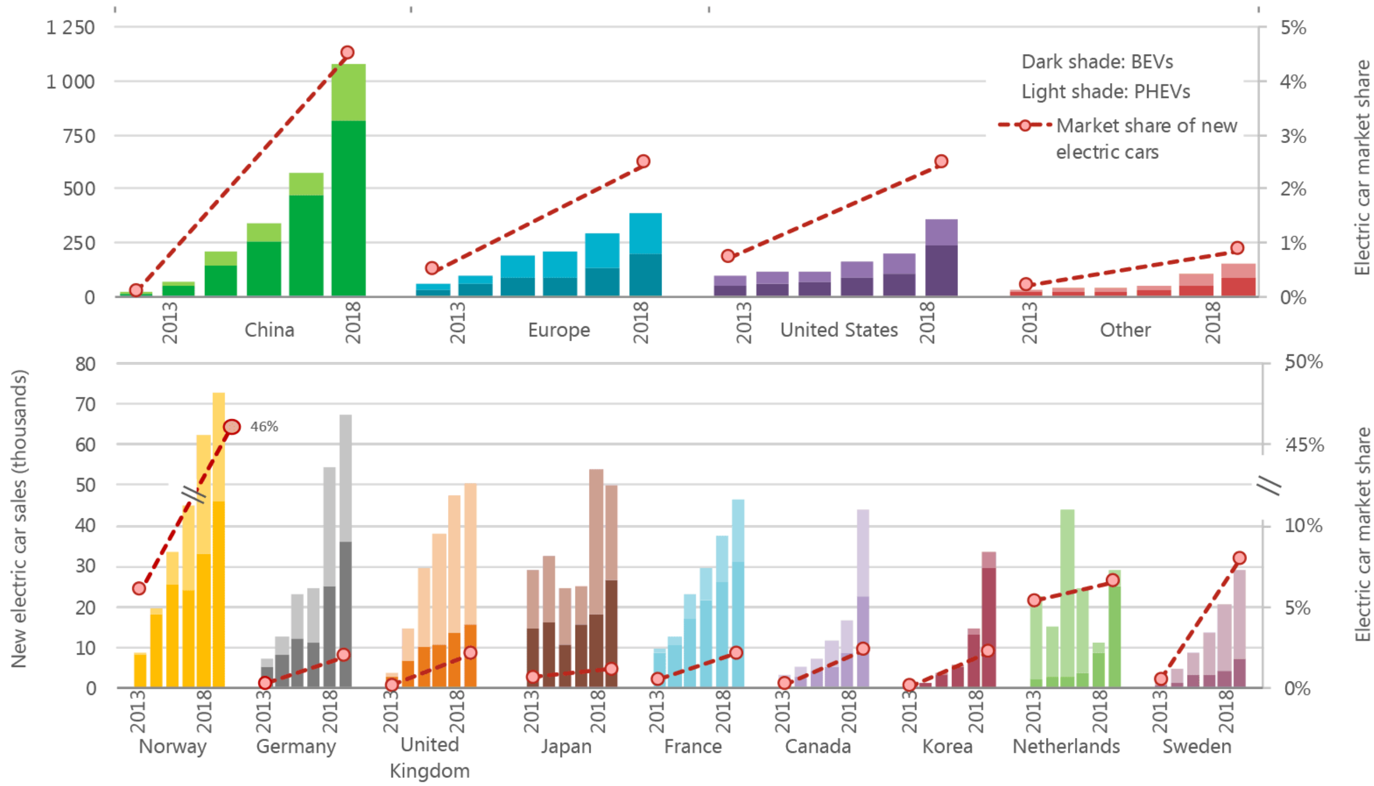
The number of EV chargers continued to rise in 2018 to an estimated 5.2 million worldwide for light-duty vehicles (LDVs). Most are slow chargers (levels 1 and 2 at homes and workplaces), complemented by almost 540 000 publicly accessible chargers (including 150 000 fast chargers, 78% of which are in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

The global EV fleet consumed an estimated 58 terawatt-hours (TWh) of electricity in 2018, similar to the total electricity demand of Switzerland in 2017. Two-wheelers continued to account for the largest share (55%) of EV energy demand, while LDVs witnessed the strongest growth of all transport modes in 2017-18. China accounted for 80% of world electricity demand for EVs in 2018. The global EV stock in 2018 emitted about 38 million tonnes of carbon-dioxide equivalent (Mt CO2-eq) on a well-to-wheel basis. This compares to 78 Mt CO2-eq emissions that an equivalent internal combustion engine fleet would have emitted, leading to net savings from EV deployment of 40 Mt CO2-eq in 2018.

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

Figure 1

Global electric car sales and market share, 2013-18



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

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

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

---

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

Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of

Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Policies have major influences on the development of electric mobility

---

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

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

Table 1

EV-related policies in selected regions

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

Notes: * Indicates that the policy is only implemented at a state/province/local level. ** Standards for chargers are a fundamental prerequisite for the development of EV supply equipment. All regions listed here have developed standards for chargers. Some (China, European Union, India) are mandating specific standards as a minimum requirement; others (Canada, Japan, United States) are not. ZEV = zero-emissions vehicle. Check mark indicates that the policy is set at national level. Building regulations refer to an obligation to install chargers (or conduits to facilitate their future installation) in new and renovated buildings. Incentives for chargers include direct investment and purchase incentives for both public and private charging.

Key policy developments in 2018/19 include:

- In the European Union, several significant policy instruments were approved. They include fuel economy standards for cars and trucks and the Clean Vehicles Directive which provides for public procurement of electric buses. The Energy Performance Buildings Directive sets minimum requirements for charging infrastructure in new and renovated buildings. Incentives supporting the roll-out of EVs and chargers are common in many European countries.

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

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

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

Technology advances are delivering substantial cost reductions for batteries

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

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

Importance of the battery technology value chain increasingly recognised

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

Examples of policy measures related to battery manufacturing include:

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

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

Other technology developments are contributing to cost cuts

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

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

Private sector response confirms escalating momentum for electric mobility

---

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

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

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

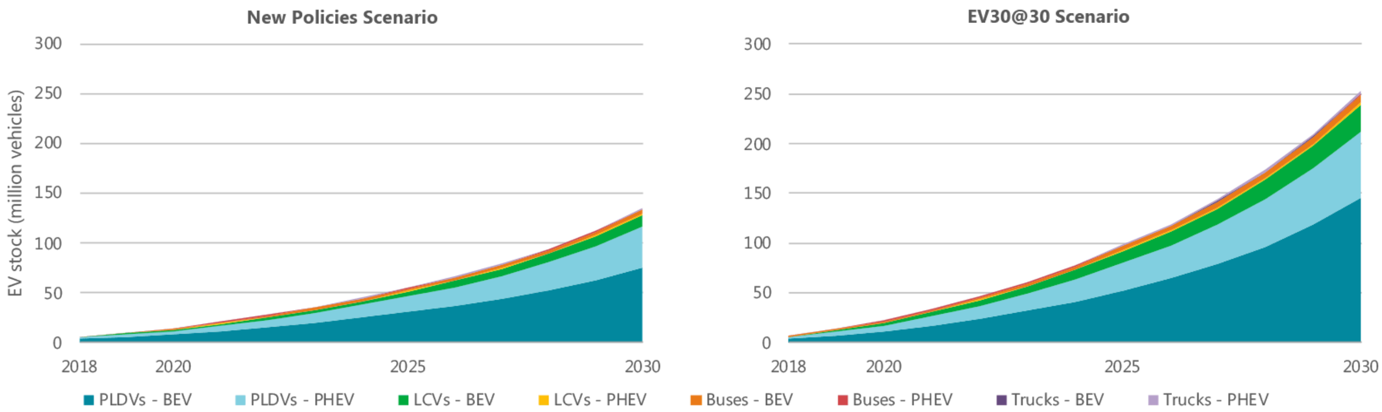
Businesses are not only committing to increased EV uptake from a supply standpoint (vehicle availability or charger deployment), but also from a demand angle by committing to add EVs to their vehicle fleets. One of the most ambitious examples may be a pledge made by DHL to reach 70% clean operations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

Outlooks indicate a rising tide of electric vehicles

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

Figure 2

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



Source: IEA analysis developed with the IEA Mobility Model.

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

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

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

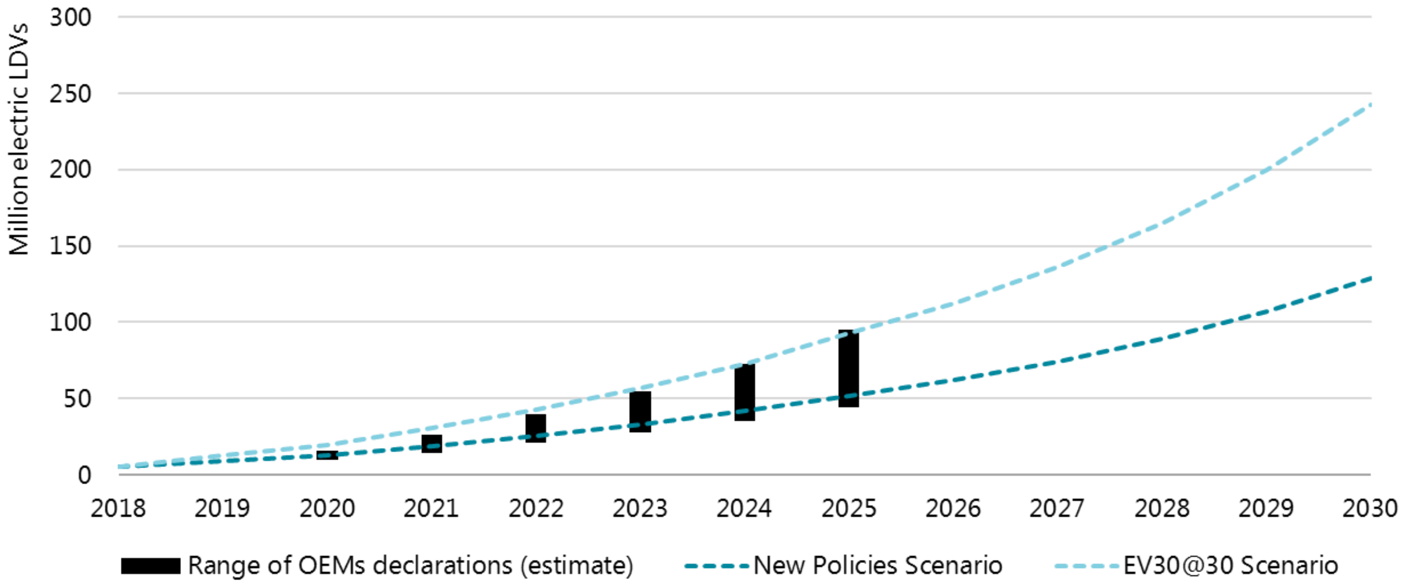
In the EV30@30 Scenario, EVs make up 70% of all vehicle sales in China in 2030 (42% excluding two/three-wheelers). Almost half of all vehicles sold in 2030 in Europe are EVs, 37% in Japan, more than 30% in Canada and United States, 29% in India and 22% in other countries, taken together.

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

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

Figure 3

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



Source: IEA (2019).

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

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

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

Electric cars save more energy than they use

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

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

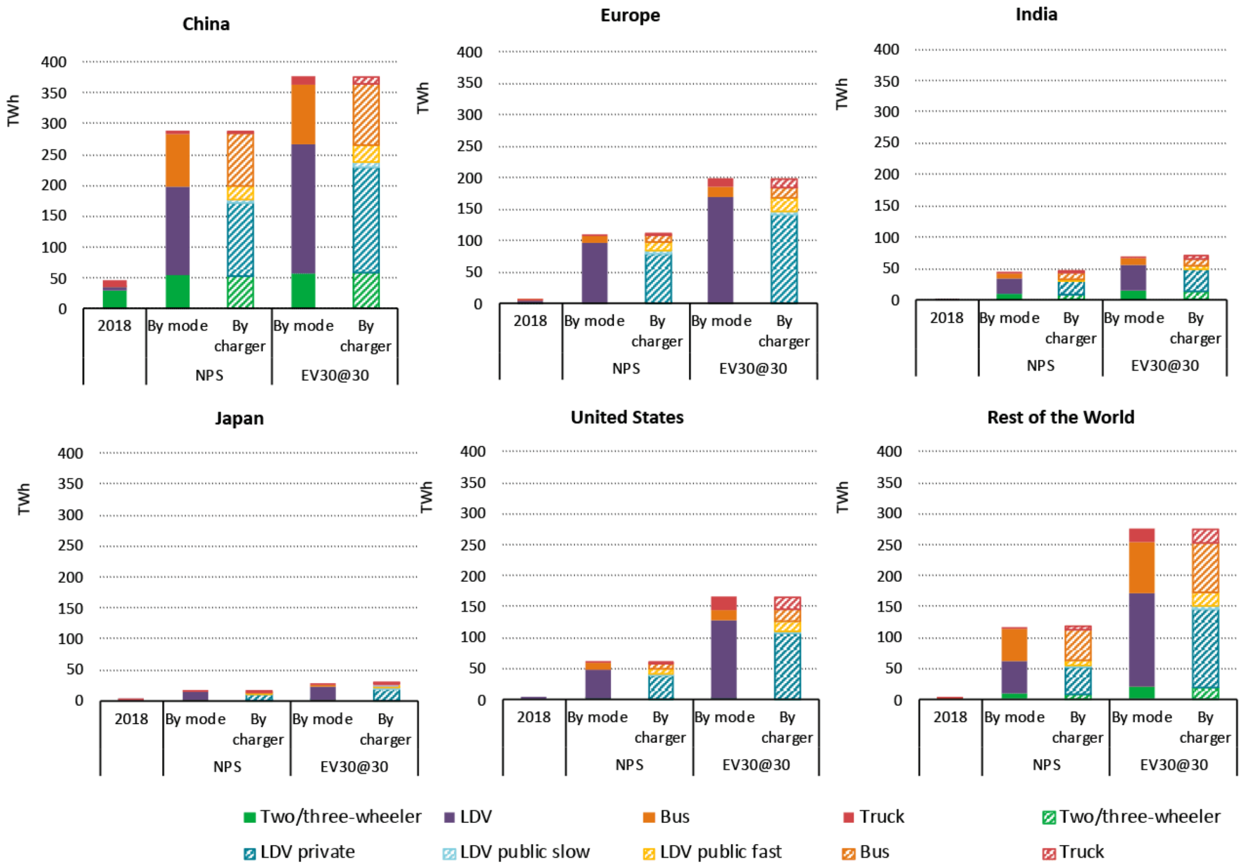
In the New Policies Scenario, light-duty vehicles become the largest electricity consumers among all road modes, surpassing two/three-wheelers in 2020. In 2030, LDVs account for about 60% of the total, followed by buses (26%), two/three-wheelers (12%) and trucks (2%). In the EV30@30 Scenario, LDVs represent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

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

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

Figure 4

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



Source: IEA analysis developed with the IEA Mobility Model.

Notes: NPS = New Policies Scenario; EV30@30 = EV30@30 Scenario; LDV = light-duty vehicle. In the columns with results by type of charger, green and blue correspond to slow chargers; red, yellow and orange correspond to fast chargers. Main assumptions: 20% higher annual mileage for EVs than for conventional ICE vehicles. Fuel consumption (in kilowatt-hours per kilometre): PLDVs 0.20-0.26; LCVs 0.31-0.42; buses 1.2-1.74; minibuses 0.35-1.49; medium trucks 0.87-1.11; heavy trucks 1.46-2.08, two-wheelers 0.03-o.04. Annual mileage (in km): PLDVs 8 000-18 000 km; LCVs 11 000- 31 000; buses and minibuses 15 000-45 000; medium and heavy trucks 22 000-91 000; two-wheelers 4 000-7 600. Ranges indicate the variation across countries. Charging losses are 5% and the share of electric driving for PHEVs is 70% of the annual mileage in 2030.

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

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

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

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

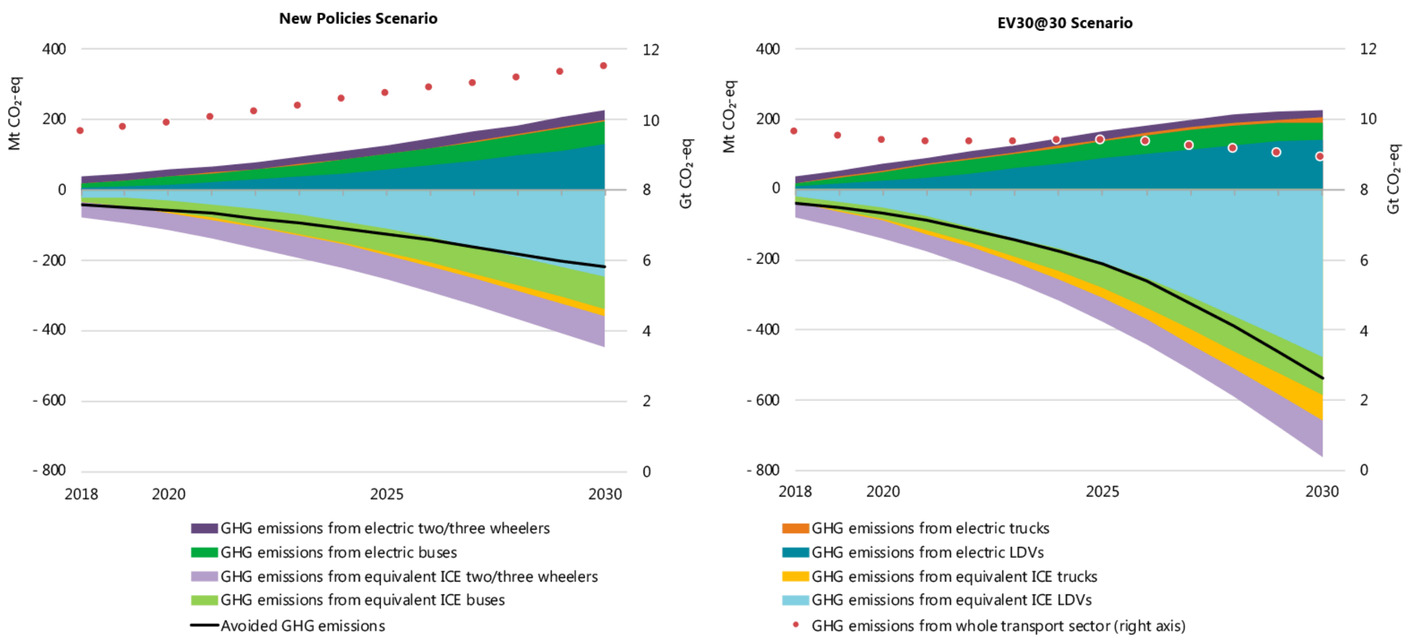
EVs avoid GHG emissions if the electricity mix is not carbon-intensive

---

The well-to-wheel (WTW) GHG emissions from the EV fleet are determined by the combined evolution of the energy used by EVs and the carbon intensity of electricity generation. Today, based on the global average carbon intensity of power generation, WTW emissions from a global average EV are lower than from a global average ICE vehicle powered by liquid and gaseous fuel blends. In the New Policies Scenario, GHG emissions by the EV fleet are projected at roughly 230 Mt CO2-eq in 2030, but would be almost double (450 Mt CO2-eq) if the equivalent vehicle fleet was powered by ICE powertrains. In the EV30@30 Scenario, in which the accelerated deployment of EVs is coupled with a trajectory for power generation decarbonisation consistent with the IEA’s Sustainable Development Scenario, the projected EV fleet emits around 230 Mt CO2-eq in 2030, while an equivalent ICE vehicle fleet would emit about 770 Mt CO2-eq. The rapid decarbonisation of power generation envisioned in the EV30@30 Scenario is important to limit the increase of GHG emissions from the rapid growth in the EV stock in the EV30@30 Scenario. Without these measures, WTW GHG emissions from the EV fleet in the EV30@30 Scenario would be around 340 Mt CO2-eq by 2030.

Figure 5

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



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

Notes: Mt CO2-eq = million tonnes of carbon-dioxide equivalent; Gt CO2-eq = gigatonnes of carbon-dioxide equivalent. Positive values are net emissions from the global EV fleet. Negative values are avoided emissions due to the global EV fleet, calculated as the difference between the emissions from an equivalent ICE fleet and the EV fleet. The WTW GHG emissions from the EV stock are determined in each country/region modelled as electricity consumption from the EVs times the carbon intensity of the power system from the IEA World Energy Outlook for the New Policies Scenario and its Sustainable Development Scenario for the EV30@30 Scenario. The WTW GHG emissions for the equivalent ICE fleet are those that would have been emitted if the EV fleet was instead powered by ICE vehicles with diesel and gasoline shares and fuel economies representative of each country/region in each year.

Electric vehicles reduce WTW GHG emissions by half from an equivalent ICE fleet in 2030, offsetting 220 Mt CO2-eq in the New Policies Scenario and 540 Mt CO2-eq in the EV30@30 Scenario.

Whether or not EVs deliver net benefits in terms of GHG emissions savings ultimately depends on the emissions that occur throughout the entire value chain, i.e. over the life cycle of EVs compared with other options. Overall, when accounting for the scale-up of battery manufacturing facilities (compatible with state-of-the-art plants, and in line with those that are assumed to be scaled up in the New Policies and EV30@30 scenarios) and assuming the current global average carbon intensity of power generation (518 g CO2/kWh, including losses), a mid-sized global average BEV and a plug-in hybrid electric car emit less than an average global ICE vehicle using gasoline on a life-cycle basis (Figure 6)*. The extent of the impact differs depending on the size of the ICE vehicle.

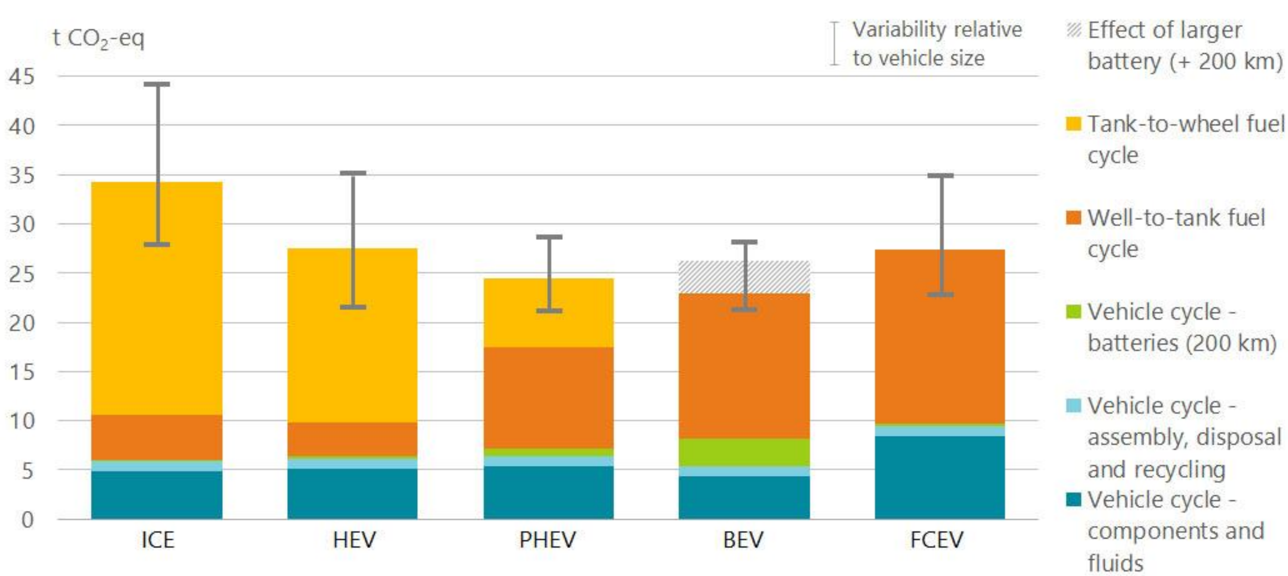
Net savings are larger for BEV cars with smaller batteries and therefore lower driving ranges. GHG emissions of BEVs using electricity characterised by the current global average carbon intensity are similar to those of fuel cell electric vehicles (FCEVs) using hydrogen produced from steam methane reforming and to those of hybrid electric vehicles (HEVs) using gasoline. On average, the capacity of BEV cars to deliver net GHG emission savings in comparison with plug-in hybrid cars depends on the size of the battery pack.

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

*This assessment considers 150 000 km over ten years of vehicle life.

Figure 6

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



Source: IEA (2019).

Notes: This figure portrays mid-size vehicles having similar performance with the exception of driving range. The BEV refers to a vehicle with 200 km range, the addition of the shaded area refers to a vehicle with 400 km range. The ranges suggested by the sensitivity bars represent the case of small cars (lower bound) and of large cars (upper bound) – for BEVs, the lower bound of the sensitivity bar represents a small car with a 200 km range, and the upper bound represents a large car with a 400 km range.The carbon intensity of the electricity mix is assumed equal to the global average (518 g CO2/kWh). FCEVs are assumed to rely entirely on hydrogen produced from steam methane reforming. Other assumptions used to develop this figure are outlined in the Chapter 4 of the Global EV Outlook 2019, focused on life-cycle GHG emissions.

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

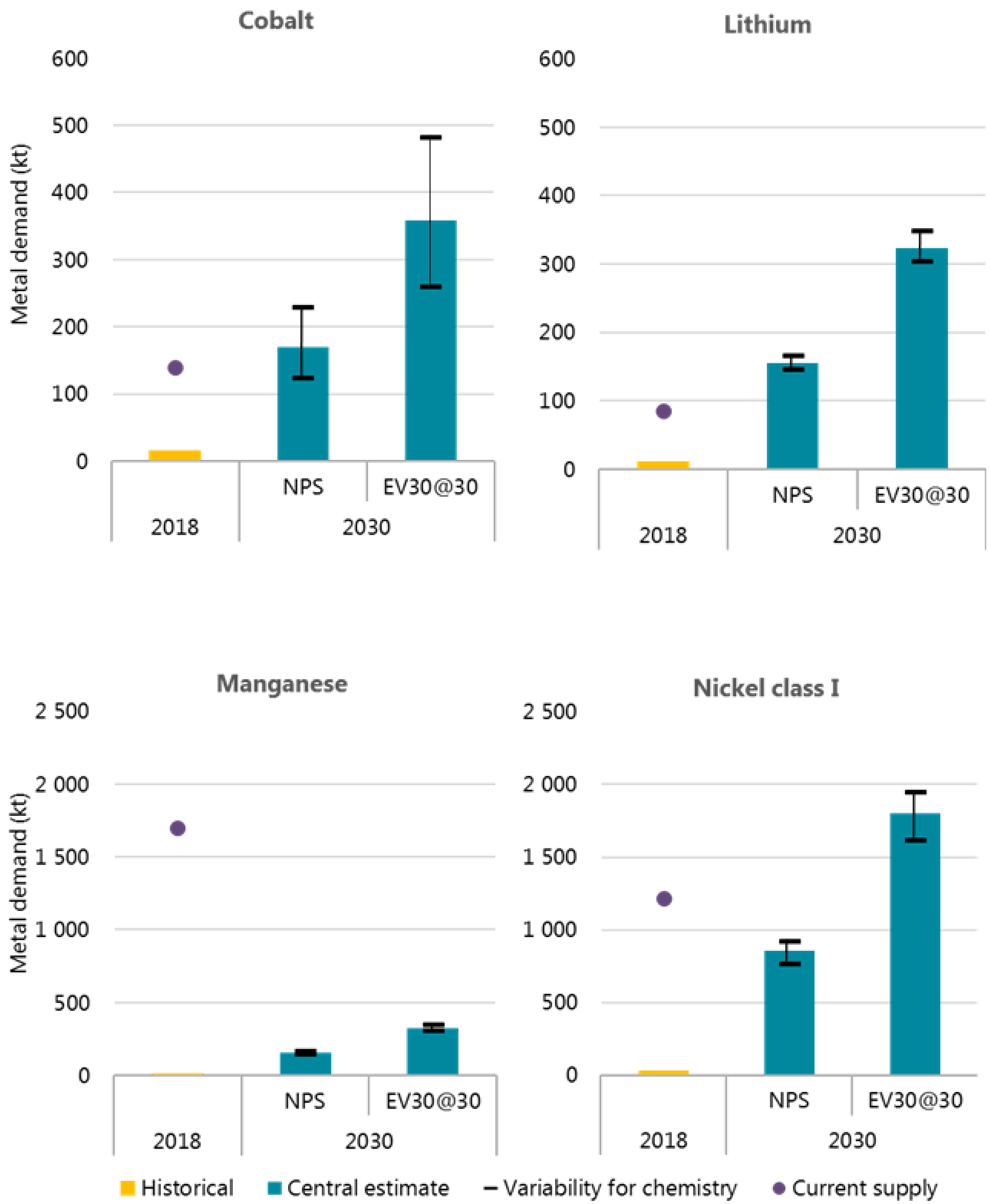
The biggest emissions reduction potential over the vehicle life cycle of EVs is in the decarbonisation of power generation systems. Today, net savings are higher in countries where the carbon intensity of the generation mix is low. Moving forward, this can be a significant advantage for BEVs and PHEVs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

Electric mobility increases demand for raw materials

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

Figure 7

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



Source: IEA (2019).

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

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

Managing change in the material supply chain

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

- Ramp-up of production, linked with the availability of raw materials, potential price spikes such as demand/supply unbalance and geographic concentration of extraction and/or refining.
- Environmental impacts, e.g. local pollution, supply chain related CO2 emissions, landscape destruction, and impacts on local ecosystems and water resources.
- Social issues, including child labour and elements that influence the well-being of communities affected by mining operations.

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

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

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

Safeguarding government revenue from transport taxation

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

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

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

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

New mobility modes have challenges and offer opportunities

Emerging changes related to connected, shared and autonomous mobility could significantly reshape road transport over the coming decades, with important implications for vehicle electrification. Close co-operation between EV manufacturers and fleet operators will be important to ensure that EVs can effectively meet the operational and technical requirements of shared mobility services and take advantage of their high vehicle utilisation rates. Ensuring that shared vehicles will be electric requires reducing financing barriers for the more expensive vehicle purchases (especially for vehicles owned by individuals, given that they are often capital constrained) and providing access to chargers. Combinations of policy measures and company efforts could accelerate the electrification of fleets. For example, Uber's Clean Air Program in London works in concert with the city's Ultra Low-Emissions Zone to provide financial incentives to drivers to switch to EVs.

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

Policy considerations

Ensure a policy environment conducive to increasing EV uptake

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

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

Anticipate long-term impacts of the transition to electric mobility

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

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

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

Maximise the GHG emissions reduction benefits of EVs

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

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

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

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

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

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

Increase the attention on raw material supply

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

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

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

References

ACEA (European Automobile Manufacturers Association) (2019), *Truck makers react to final CO2 deal setting first-ever EU standards for heavy-duty vehicles*, , www.acea.be/press-releases/article/truck-makers-react-to-final-co2-deal-setting-first-ever-eu-standards-for-he..

EAFO (European Alternative Fuels Observatory) (2019), , www.eafo.eu/ (accessed on 1 March 2019).

EV Volumes (2019), *EV Data Center*, , www.ev-volumes.com/datacenter/ (accessed on 15 March 2019).

Marklines (2019), , www.marklines.com/portal_top_en.html (accessed on 1 March 2019).

OICA (International Organization of Motor Vehicle Manufacturers) (2019), , www.oica.net/ (accessed on 1 February 2019).