ELECTRIC VEHICLES
TECHNOLOGY BRIEF

ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

ACKNOWLEDGEMENTS

Disclaimer

Contents

Insights for Policy Makers

» There are two main types of electric vehicles (EV): battery electric vehicles (BEV) that use only batteries for energy storage and must be plugged in to be recharged, and plug-in hybrid electric vehicles (PHEV) that have both batteries and liquid-fuel storage and refuelling systems.

» The global stock of electric vehicles (EVs) reached 1 million during 2015 and is expected to pass the 2 million mark in 2016. This rapid rise has been led by China, the US, Japan and several European countries.

» The uptake of EVs is the result of several factors, including strong technological progress, cost reductions (especially batteries), and policy support, including purchase incentives, driving and parking access advantages, and increased public charging infrastructure availability.

» Battery electric vehicles (BEVs) dominated sales over plug-in hybrid electric vehicles in most countries until 2014, but plug-in hybrid electric vehicle (PHEV) sales have grown rapidly in the past two years and as of early 2016 were nearly equal to BEV sales worldwide. PHEVs have a considerable range advantage but sacrifice all-electric driving to achieve this.

» Despite on-going battery performance improvements and cost reductions, EVs still face potentially important obstacles. New models to be introduced in 2017 and 2018 will be able to drive up to 300 kilometres (km) per recharge, but battery packs up to 60 kilowatt-hour (kWh), even if battery costs drop from their current levels of around USD 350/kWh to USD 150 kWh would cost USD 9 000, much more than the drive systems of today's internal combustion engine vehicles. Fuel savings will help pay this back, especially for high-mileage drivers.

» Battery-electric vehicles provide zero-vehicle-emissions driving (for both CO_2 and pollutant emissions), but the "upstream" CO_2 can be substantial, for example in countries with dominant coal power generation. Electric grids must be considerably decarbonised (to 600 grams/kWh or less) for EVs to have a CO_2 advantage relative to similar sized hybrid internal combustion engine (ICE) vehicles. Carbon intensities will need to continuously improve in the future, since hybrids and other ICE vehicles will also become more efficient. EVs also produce no direct air pollution and reduce noise pollution in cities.

» For the most benefit, EV deployment requires four concurrent strategies: (i) electrification of vehicles, (ii) provision of sufficient charging equipment, (iii) decarbonisation of the electricity generation, and (iv) integration of electric vehicles into the grid.

» EV deployment growth would allow a higher share of variable renewable energy (VRE) in the power system, via five areas of interaction: (i) actively using the mobile battery storage system in the vehicle, (ii) use of second-hand batteries in a "second life" role as stationary battery storage systems; (iii) widespread deployment of charging technologies and infrastructure; (iv) evolution in the charging behaviour of EV owners, for example, in which they become comfortable with variable charging rates and times, and (v) provision of other ancillary services from EVs to the grid such as frequency regulation, shaving peak demand, power support to enhance operation, and reserve capacity to secure the grid by stored energy in its batteries.

» Electric vehicles create a paradigm shift for both the transport and power sectors, and could support variable renewable power growth through different charging schemes such as time-variable "smart charging" and vehicle to grid (V2G) electricity supply. Such systems can help support a global doubling of the share of renewable energy by 2030 compared to 2015.

» The eventual deployment of charging schemes such as smart charging and V2G can support the growth of variable renewable energy and can interplay with information communication technology (ICT) systems to maximise the technical features and minimise the operation costs using demand-side management tools;

» REmap – a global roadmap from the International Renewable Energy Agency (IRENA) to double renewables in the energy mix – estimates that a 160 million EVs by 2030 would provide sufficient battery capacity in major markets to support VRE at a large scale. Achieving this stock level, however, will be challenging and will require annual sales growth rates on the order of 30-40% between now and then. To achieve this will probably require that EV markets achieve a "tipping point" between 2020 and 2025, when they start to rapidly increase market share relative to ICE vehicles.

» To achieve a tipping point in sales, EVs will likely need to achieve near-parity on a first cost basis with ICE vehicles, and provide sufficient amenities (such as driving range and recharging convenience) such that consumers do not consider them inferior to or comparable to ICEs. EVs are already perceived to provide an excellent driving experience, and new models being introduced during 2017 and 2018 will have much greater driving range than most of today's models. But strong policies to a) reduce the first cost of EVs, b) provide driving/parking advantages, and c) ensure sufficient recharging infrastructure, will likely all be needed for at least five to 10 more years to have a chance for rapid sales growth and achieving target stock levels by 2030.

» Assuming all these new electric vehicles were to consume 100% renewable electricity, around 450 terawatt-hours (TWh) per year of additional renewable electricity would be required by 2030. This is equivalent to 1.5% of today's total global electricity generation.

» Benefits of EVs include zero tailpipe emissions and therefore less local air pollution and, depending on the power generation, lower CO_2 emissions. EVs can also reduce noise pollution in cities. Governments should also consider promoting electric two-wheelers and electric buses as a way of reducing pollution and noise in populated regions where point-to-point charging is possible.

Highlights
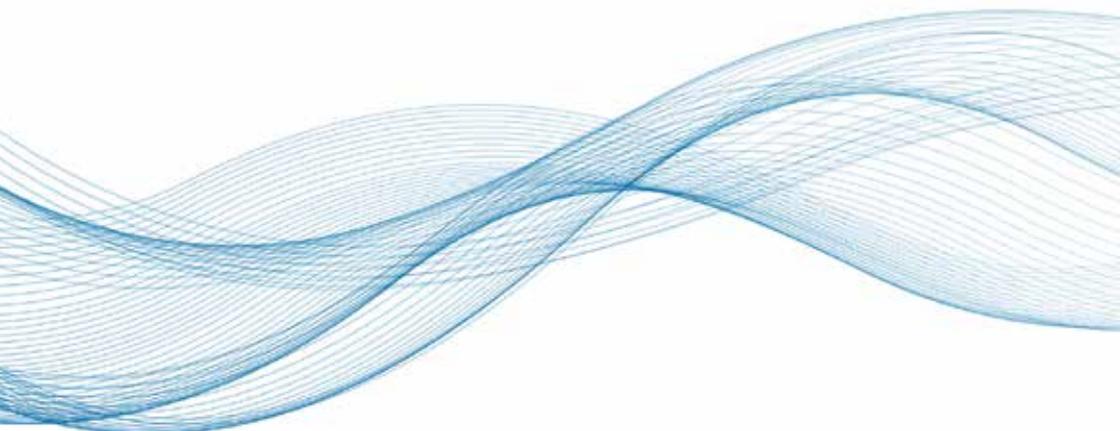
Technology status and performance

Two main types of electric vehicle (EV) have both achieved significant sales in the world's major vehicle markets in the past year. These are:

(1) battery electric vehicles (BEVs), which use only batteries for energy storage and must be plugged in to be recharged, and

(2) plug-in hybrid electric vehicles (PHEVs), which have both batteries and liquid-fuel storage/refuelling systems.

In both cases, the electric motor is very efficient, using 90-95% of the input energy to power the movement of the vehicle, and offer zero vehicle emissions driving. But the use of batteries poses the two main challenges for battery electric vehicles: their cost and driving range. Most current models of BEV do not store enough energy to provide "normal" driving range, and are limited to below 250 km (160 miles) per recharge. However, some new and forthcoming models offer substantially more range, up to 400 km. PHEVs already offer 500 km or more due to the availability of their liquid-fuelled internal combustion engine. Both technologies are expensive, with battery costs estimated around USD 350/kWh in 2015 and the cost of a hybrid system of several thousand dollars in PHEVs.

For BEVs, a vehicle with 40 kWh of battery capacity may have a battery cost of USD 14 000, leading to a vehicle incremental cost of at least USD 12 000 compared to similar ICE vehicles, depending on retail mark-ups, incentives and other factors.

Fortunately, strong policies and on-going cost reductions of batteries have helped enable the growth of EVs. EV sales have grown rapidly over the past five years, reaching nearly 500 000 worldwide in 2015, and likely to approach sales of 1 million in 2016, with nearly half of 2016 sales likely to be in China. EV sales and market share are quite variable across different countries and markets. In 2015, EV market share was over 20% in Norway, nearly 10% in the Netherlands, and 3% in California, while under 2% in all other major markets. Electric trucks and buses are also emerging, with over 150 000 electric buses in service around the world, mostly in China. Electric two-wheelers are the runaway leaders with over 200 million sold through 2015, the vast majority in China. As battery costs continue to drop, and higher range EVs become available at a reasonable cost, sales are expected to continue to rise rapidly at least through 2020.

All modern EVs rely on some type of lithium-ion based battery. Lithium-ion batteries offer relatively high energy

density, high specific energy and good cycle life. Much progress has been made in the last few years, making lithium-ion batteries more compact, lighter, more durable (to last the life of the vehicle) as well as charge fully in a few minutes.

A common target is USD 150/kWh for full battery packs, a point at which the overall costs of an EV may become competitive with gasoline or diesel vehicles (although purchase costs may remain higher for higher battery-range EVs).

Electric vehicles and renewable energy deployment: Towards a new paradigm

Electric vehicles need to be recharged on a regular basis, and this can occur either at home or at work. It can also be done while shopping or during other types of stops when travelling. A general issue for EVs has been the long duration needed for charging – typically up to eight hours for a full charge when using slow chargers. Faster charging is desirable though not needed in most situations. Home slow-charging mostly, but not always, happens at night. This is relevant since EVs interact with the grid via charging and discharging. There are different modes of interaction with the grid, the first mode is grid-to-vehicle (G2V) where the vehicle is charged from the grid, while V2G refers to when vehicles discharge power to the grid. The V2G mode could also be considered as a bidirectional charging where EV can charge from and discharge to the grid at regular intervals. Other charging modes such as vehicle to building (V2B) and controlled charging are also available.

EVs can be used to enable a higher share of variable renewable energy in the power system by: (i) actively using the mobile battery storage system in the vehicle in V2G applications, (ii) use of second-hand batteries in a "second life" role as stationary battery storage systems, (iii) widespread deployment of charging technologies and infrastructure, (iv) evolution in consumer behaviour of EV owners, and (v) provision of other ancillary services from EVs to the grid. This occurs by making use of EV batteries to store excess electricity and to provide ancillary services to the grid, such as frequency regulation, shaving peak demand, power support to enhance the operation, and reserve capacity to secure the grid. One of the main advantages of EVs are their high level of flexibility in charging times which can efficiently support operation of the grid. According to IRENA's REmap analysis, if a target of 160 million EVs worldwide can be reached by 2030, this will provide around 8 000 gigawatt-hours (GWh)/

year in battery storage that could benefit the installed power generation capacity. This is equivalent to approximately 1 200 GW of battery storage capacity. Along with the pumped hydro storage and second-hand batteries estimated under REmap by 2030, this adds up to a total of 1 650 GW. This compares with approximately 3 700 GW of variable renewable power capacity. The stored battery capacity can provide additional support to renewable power integration to the grid among other flexibility measures.

The evolution of the combination of EVs with smart grids is very important as this allows customers to control and make well informed decisions on their consumption of electricity, as well as minimise their bills. This kind of consumption control is called demand-side management (DSM). DSM can help customers in optimising their consumptions through an intelligent system, and can greatly support customers in shifting their loads during peak periods.

Considering the future: Electric vehicle market projections

To achieve the conditions needed for EVs to provide significant benefits to electric power systems and variable renewable electricity by 2030, IRENA estimates that 160 million will be needed worldwide in that year. In this brief we articulate this vision by region, showing one plausible scenario for how the sales and use of EVs and PHEVs could increase in various markets to achieve such a target. With an average of 50 kWh battery pack per vehicle, 160 million vehicles could provide about 8 000 GWh of battery storage by 2030.

Assuming average driving levels per vehicle, the combined electricity demand from these vehicles could reach close to 500 TWh per year by 2030. Since this battery capacity could assist in the development of VRE capacity, we estimate that most or all of this new demand could be served by renewable power. However, the scenario will be challenging to achieve: annual EV sales would need to reach 40 million to 50 million by 2030, out of an expected overall market of 120 million to 130 million vehicles, in order for stocks to reach 160 million.

Achieving a 25% or greater market share will not be easy and will require rapid sales increases in all major car markets in the next decade, with a "tipping point" in sales probably in the 2020-2025 time frame. Strong policies will be necessary to reach such a point, where EVs are cost competitive and otherwise attractive to a wide range of consumers in many countries.

Technology status and performance

The term "electric vehicle" (EV) typically means a vehicle with an electric drive (motor) propulsion system that can be plugged in to recharge the batteries that provide at least some of the energy storage on the vehicle. There are two main types of EV: battery electric vehicles (BEV) that use only batteries for energy storage and must be plugged in to be recharged, and plug-in hybrid electric vehicles (PHEV) that have both batteries and liquid-fuel storage systems and that can either be plugged in or refuelled with liquid fuel to increase energy stored on the vehicle. Regular (non-plug-in) hybrids also have an electric drive system, but no plug. They rely on liquid fuel to recharge the batteries on board the vehicle, along with features such as regenerative braking.

PHEVs typically are provided with a much smaller battery pack than BEVs, since they also have an internal combustion engine operating on liquid fuel. The vehicles may have a shorter driving range on batteries but usually have a longer overall driving range due to the liquid fuel – typically similar to conventional vehicles, achieving 750 or more kilometres of range overall. Current BEVs typically have less than 250 km (160 miles) of all-electric range today. However, some models, such as the Tesla Model S[1] and BYD E6[2], have more than a 300 km range. Chevrolet will introduce the Bolt in late 2016 with a claimed range almost 400 km and priced around USD 37 000. Other higher-range models have been announced for 2017[3].

Figure 1 shows, for the models of BEV and PHEV sold in different countries during 2015, how much battery capacity these vehicles have and the rated driving range on these batteries (a function of the battery storage but also the efficiency of the vehicle in converting that energy into driving distance). The PHEVs typically have far lower battery capacity and electric driving range, though they also provide considerable range on liquid fuels. The BEVs typically offer more than 100 km of driving range and several offer more than 200 km. As mentioned, in 2015 a few models offered more than 250 km, notably the BYD E6 and, at over 400km, the Tesla Model S.

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1   < www.tesla.com/models>

2   < www.byd.com/la/auto/e6.html>

3   < www.chevrolet.com/bolt-ev-electric-vehicle.html>

Figure 1: Comparison of battery capacity/driving range for BEVs and PHEVs
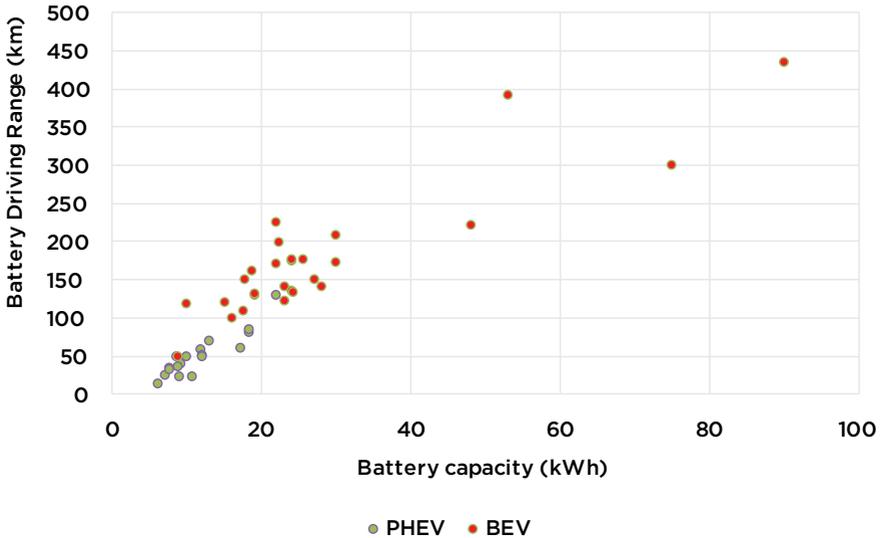
Source: UC Davis market data

Liquid fuels, primarily gasoline and diesel from oil, are considered energy dense, allowing vehicles to be driven long distances before refuelling. Drivers can fill their tanks easily in a few minutes at refuelling stations. One drawback with combustion of fuels in engines is that most of this energy is wasted as heat, with typically 20-30% conversion efficiencies (with hybrids at the high end).

By contrast, electric motors are very efficient, using 90-95% of the input energy to power the movement of the vehicle. But the challenge with electric vehicles is storing enough energy in batteries to provide adequate driving range, as well as recharging that battery without excessive inconvenience to drivers. Fortunately batteries have been improving and becoming less expensive over time.

Every design and commercialised EV now relies on some type of lithium-ion based battery, a technology which has matured over the last 25 years for use in portable electronics, especially cell phones and portable computers, replacing all other batteries. Lithium-ion batteries offer relatively high energy density, high specific energy and good cycle life.

We are at a new phase in that maturation, scaling production, performance and packaging of lithium-ion batteries cells in sophisticated, managed "packs" for vehicles and other uses, such as large storage batteries for use with the electric grid. Much progress has been made in the last few years, making batteries more compact, lighter, more durable (to last the life of the vehicle) as well as charge fully in a few minutes. Circling around this is costs, which are measured per kWh of capacity. A common target is USD 150/kWh for full battery packs, a point at which the overall (purchase plus energy) costs of an EV can become competitive with ICE vehicles. In Figure 2, a multi-source study by two Swedish researchers shows the progress through 2014 and show the USD 50/kWh target by 2030. A 2016 report suggests costs could fall to USD 100/kWh achievable within a decade (Bloomberg New Energy Finance and McKinsey & Co., 2016).

Figure 2: Estimates of costs of lithium-ion batteries for use in electric vehicles
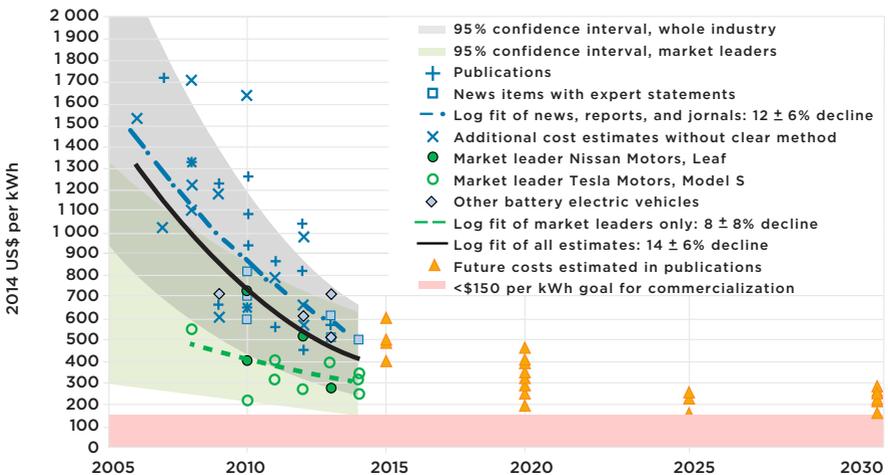
Source: Björn Nykvist and Måns Nilsson, 2015

In addition to lithium-ion batteries, there are many other battery chemistries under development, such as lithium-air batteries, that are considered highly promising because of their potential for delivering higher energy per unit of mass and volume. Lithium-air batteries have a number of drawbacks[4] such as lower energy efficiency and faster degradation rates. Still, Li-air technology offers key performance attributes beyond the technical limits of conventional lithium-ion batteries.

MIT researchers developed a new concept of li-oxygen that could be used as lithium-air batteries, while overcoming its drawbacks. For fast-charging lithium-ion battery production, a start-up in Israel has been established. This company used nanotechnology to create new organic materials for batteries that can recharge in 30 minutes[5]. These materials have the potential to increase charging speed in comparison with conventional lithium-ion batteries.

Apart from the evolution of batteries, scientists and experts have seen a huge potential for ultracapacitors as an alternative or supplementary electricity storage device that could lead to a major change in performance of EVs. Lithium-ion batteries convert and store energy by means of a chemical reaction, whereas ultracapacitors store energy by employing an electric field.

As a result, while batteries take a long time (hours) to discharge, ultracapacitors can quickly discharge (in seconds or minutes) with large bursts of power. Lithium-ion batteries can typically charge and discharge up to 10 000 times (cycles) whereas ultracapacitors have a cycle life of 1 million times. However, ultracapacitors typically have a low energy density compared to lithium-ion batteries, and are more expensive per kW of power. With significant improvements in energy density, ultracapacitors might penetrate the market and help improve EV performance.

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4   http://news.mit.edu/2016/new-lithium-oxygen-battery-greatly-improves-energy-efficiency-longevity-0725

5   http://fortune.com/2015/08/19/electric-car-battery-charges-minutes/

Light duty electric vehicle sales

As shown in Figure 3, PHEV and BEV light-duty vehicle (LDV) sales have grown rapidly over the past five years, reaching nearly 500 000 worldwide in 2015 in the world's eight largest markets (China, US, Japan, Germany, France, UK, Norway and the Netherlands), representing more than 95% of EV sales worldwide. PHEVs started a bit slower than BEVs but their share of overall sales has risen and was about 45% (with BEVs representing the remainder 55%) in 2015. However, these combined sales represent only about 0.5% of the nearly 90 million LDVs sold worldwide in 2015. In 2016, sales are expected to be close to 1 million EVs, with nearly half the sales coming from China.

As shown in Table 1, EV sales and market share are quite variable across different major car markets, with the 2015 market share over 20% in Norway, nearly 10% in the Netherlands, 3% in California (though less than 1% in the entire US), and less than 2% in other countries (though with China showing the highest overall sales and biggest sales increase over the past year or two). Worldwide, the close-to-half-million sales of EVs in 2015 was about 0.5% of the LDVs sold around the world.

Figure 3: Electric vehicle sales in world's eight largest markets, by type
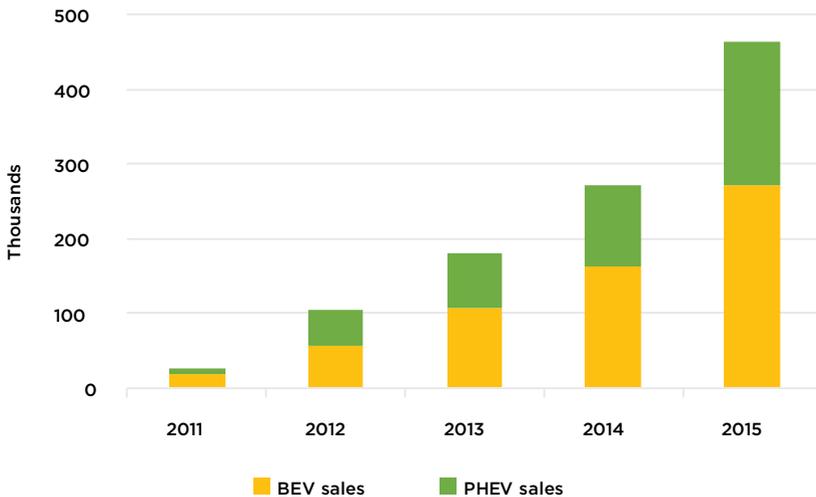
Source: UC Davis market data

Table 1: Global EV sales by country, 8 biggest markets

	Country	Est Total PEVs. Feb 2016	Est. PEV Sales 2015	PEVs as % of 2015 market	Total LDV market 2015
1	USA	>415 000	>115,000	0.6%	17 500 000
	California	>189 000	>62 000	3.1%	2 100 000
2	China	300 000	207 000	0.8 %	22 000 000
3	Japan (est)	150 000	25 000	>1.0 %	4 200 000
4	Netherlands	91 000	43 000	9.6%	420 000
5	Norway	90 000	34 000	>20%	170 000
6	France	>70 000	27 000	1.5%	2 000 000
7	Germany	>50 000	24 000	0.75%	3 500 000
8	UK (est)	>38 000	>28 000	>1.0%	2 700 000
	Europe		>193 000		
	World	>1 100 000	>450 000	0.5%	88 000 000

Source: UC Davis market data

Looking to the future, UC Davis has developed a four-generation model of passenger car EV technology development to characterise what will likely will occur with on-going market development, as has been the experience of other new technologies such as hybrid vehicles. Figure 4 shows these four generations of vehicles between 2010 and 2030, with new generations of EV emerging about every five years. Recent (2016) model introductions such as the updated Chevrolet Volt and Nissan Leaf indicate that EVs are entering the second phase.

Figure 4: EV rollout scenario to 2030

A plausible PEV rollout scenario based on technology change, incentives & history of previous technology rollouts

This sales curve would be similar to the rollout of HEVs in Japan & California, 1997-2015

4th generation: PEVs begin to dominate

2030

3rd generation: batteries, vehicles, core market PEVs competitive

2nd generation improved batteries, more driving range, followers Adequate infrastructure

California 2025 ZEV goal = 15% / 1.5 million BEVS, FCV & PHEVs

1st generation early policy converted vehicles, innovators & early infrastructure

2025

Main market 15-25%

2020

Early core market: 6-15%

2015

2010

1 - 2%

3-5% of market

| 700 | 200 | 300 | 150 | Lithium pack prices per kWh |

Source: developed by Tom Turrentine, UC Davis

Second-generation vehicles already on the market around the world show significant improvements in range and other attributes compared to first-generation vehicles (Figure 5). BEVs routinely show range over 150 km per full charge, with some models (notably the Tesla S and coming Tesla 3 and Chevrolet Bolt) showing 300-plus kilometres of range. On the PHEV side, low-range models such as the original plug-in Prius have given way to models with at least 30 km of battery range and some (such as the new GM Volt and Ampera models) exceeding 60 km. These higher range PHEVs typically are driven far more on electricity than lower-range models, partly because buyers are more interested in electric driving. These new models also tend to be cheaper than the older first-generation models.

Figure 5: Second generation EVs, 2015-2020

2nd Generation PEVs (2015-2020) include higher range and more efficient, popular designs

1st Generation

PHEV 20 - 30 kms

PHEV 60

BEV 120

BEV 250 -300

2nd Generation

PHEV 30 - 50 kms

PHEV 80

BEV 150

BEV 300 - 450
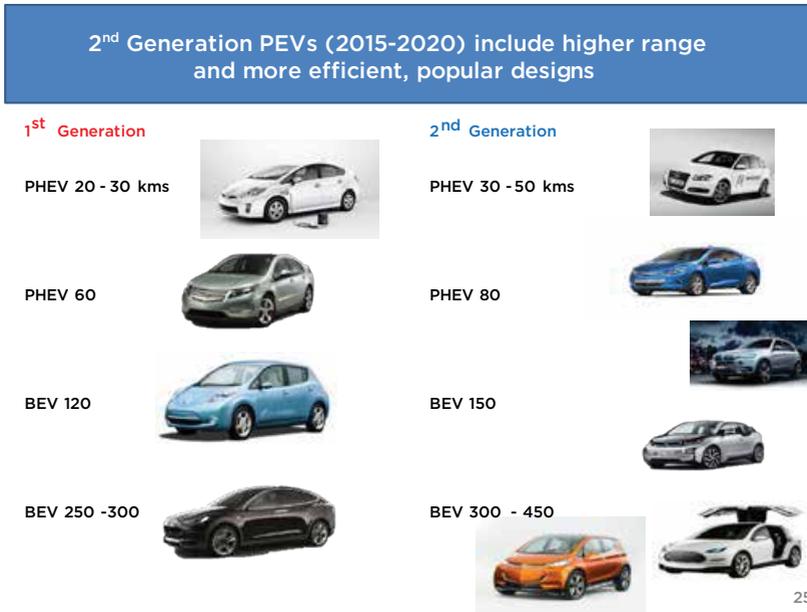
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Sources: Compiled market data from Blogspot website (http://ev-sales.blogspot.com); European Alternative Fuels Observatory (www.eafo.eu); Inside EVs website (http://insideevs.com); various manufacturer websites

Sales of other types of electric vehicles

In addition to electrified conventional LDVs, a significant market exists for low-speed electric vehicles (LSEV) – four-wheeled vehicles that are not certified for highway use, and typically lighter, have less power cost less. They typically have a top speed of 50-70 km/h. These are popular in Asia (particularly China); in Europe the most successful model is the Renault Twizy, with over 15 000 sold so far (Mark Kane, 2015).

There is also a large market for two-wheelers (including e-bikes) and an emerging market for electric trucks and buses. In fact there are far more electric two-wheelers worldwide than there are four-wheelers, thanks to the large numbers sold in China over the past decade. Sales in China over the past decade have been rising, with stocks now over 200 million units, including electric scooters, mopeds and electric bicycles (Cherry, 2016).

As shown in Figure 6, sales in Asia in 2015 approached 40 million units, mainly in China and Japan (ITDP/UC Davis, 2015). Sales in the rest of the world were estimated to be about 2 million, mainly in Europe. This study projects a sales growth to 60 million in Asia and 4 million elsewhere in a business-as-usual (BAU) scenario. Typically the two-wheelers sold in China and other developing regions have lead acid batteries, while those sold in Japan and Europe have lithium-ion batteries.

Electric trucks and buses are also emerging, with over 150 000 electric buses in service around the world, mostly in China (International Energy Agency, 2016). This represents a very rapid increase over the past two to three years, and the number is expected to continue to grow fairly rapidly in more countries. No clear data has been found on the sales or stocks of electric trucks, but these are mostly demonstration and small-production vehicles. However, there are certain niches where the use of electric trucks could rise rapidly such as smaller service and delivery trucks. Some countries have started deploying electric trucks and related infrastructure. For example, Sweden has established the world's first electric road (e-way) for electrically-powered trucks. This is still on a small-scale, a two-km strip, where electrified trucks receive electricity from a catenary system with pantograph power collector. These trucks are integrated with a lithium-ion 5 kWh battery that allows driving as far as three km when not running on the e-way (Scania, 2016).

Figure 6: E-bike sales in Europe, 2014
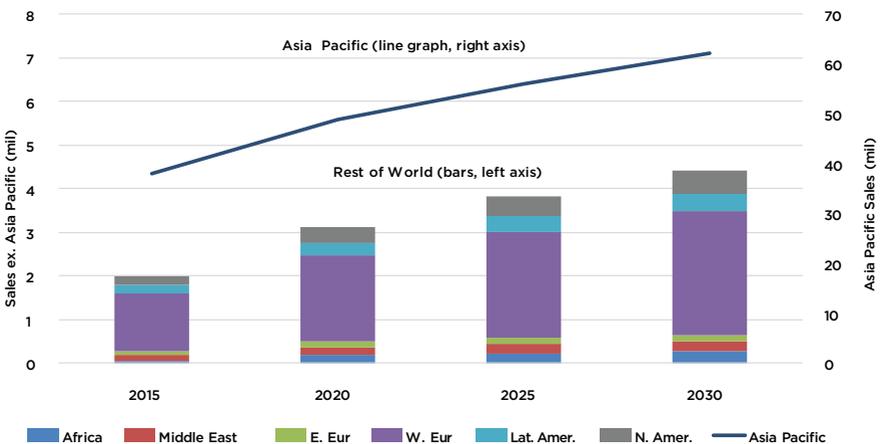
Source: ITDP/UC Davis, 2015

Costs, markets and consumers

Two main factors are needed to make the deployment of EVs a success: support of government actions and popularity with consumers. This means they must compete well with conventional vehicle models; thus they must have desirable attributes such as an enjoyable driving experience, sufficient driving range, and good "green" credentials.

Policymakers can make EVs more attractive with actions such as subsidies to lower upfront costs and urban-access measures such as premium parking spots. In addition, EVs must also be offered in a wide range of shapes and sizes (i.e. different market segments, price points, etc) and there must be a policy environment that is supportive and creates at least a level playing field for them to compete.

Consumers must be aware of vehicle models available on the market and gain a level of confidence high enough that they become willing to spend large sums of money on these models rather than conventional vehicles. Even in California, as of 2015 a relatively high number of new car buyers were not even aware they can purchase EVs at most of their local dealerships (Kurani et al, 2016). Buyers shopping in smaller-car segments tend to be particularly price sensitive, and this is where many of today's EVs are being marketed (Fulton et al, 2016). So these vehicles must compete on price, which is difficult given the low prices of competing ICE models. In premium markets, price equivalence is less important but high performance (such as acceleration and perceived overall quality) is a critical. Tesla has succeeded mainly by competing on this basis.

Thus the cost attributes of electric vehicles – such as first (purchase) cost, running cost and their combined "total cost of ownership" (TCO) –are important in affecting demand. And these attributes are changing rapidly, as described above, for example, with respect to declining battery costs. From the policy side, a key question is the extent to which subsidies (and the level of subsidies) will be needed in order to sell large numbers of vehicles. Related to this is the cost to society of such subsidies, and the explicit or implicit cost per tonne for the CO_2 emissions reductions that electric vehicles provide.

Estimating such costs, and likely costs in the future, is complicated by the large number of factors that could influence these calculations. One factor is how far individuals drive per year, since the fuel-cost advantage of EVs rises with the use of the vehicle. Another is the CO_2 savings of electric vehicles, which depend heavily on the CO_2 intensity of the electricity they run on. An EV that operates for 15 years can have an on-going reduction in its CO_2 intensity if the grid is decarbonised over this period,

which should be accounted for in comparisons with ICE vehicles.

A few examples illustrate the range of factors that may make electric vehicles more or less competitive with conventional vehicles. In Figure 7a a conventional ICE vehicle, "efficient ICE" vehicle (such as a non-plug-in hybrid), and a BEV are compared for a TCO across a range of driving levels per year.

In the 2015 calculation, with battery pack costs set at USD 350/kWh, EVs typically USD 10 000 more than conventional ICE vehicles, and the hybrids USD 3 000 more[6]. The net cost of all three vehicle types rises with vehicle use but EVs will never reach cost parity, even for heavy users who travel more than 20 000 km/year.

In Figure 7b a similar situation is shown for a future date (perhaps 2025 or even 2020), with battery costs dropping to USD 150/kWh and the incremental first cost of the EV down to USD 5 000 per vehicle. Fuel costs are somewhat higher by then (USD 1.25 per litre for gasoline and USD 0.14/kWh for electricity). In this case, anyone driving more than 15 000 km breaks even on ownership cost.

Figure 7c and Figure 7d shows these breakeven points a different way: based on the relative cost of gasoline (or diesel) and electricity. Here we take the case of a driver going 16 000 km per year and compare the three options for 2015 (Figure 7c) and 2030 (Figure 7d) across a series of different fuel-price combinations. In 2015, with the assumptions about vehicle technologies and costs, a breakeven point occurs at a combination of about USD 1.50/litre for gasoline with USD 0.14/kWh for electricity. In 2030, with the changes in vehicle costs (particularly the lower battery costs), the breakeven point is much more attractive for EVs: USD 1.25/litre matched with USD 0.16/kWh.

These figures are simply examples of possible breakeven points, and show the wide range of relative economics depending on a range of factors. They also suggest that the breakeven points may become much more favourable to EVs in the future. This could mean that no subsidies are needed and the cost per tonne is therefore zero (for whatever level of CO_2 emissions reductions are achieved). As noted, other non-cost factors also influence the demand for electric vehicles. The exact combination of attributes and costs that would create a robust EV market without subsidies or other promotional policies can be difficult to determine, as are the resulting costs per tonne of CO_2 reduction.

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6   The EV vehicle cost increment is based on a 35 kWh battery pack resulting in about USD 12 000 in battery costs, and USD 2 000 savings from eliminating the ICE engine/drive train and replacing with a motor system. The fuel costs are based on USD 1 per litre gasoline and USD 0.12/kWh electricity, with 10 years of driving and a 10-year discount rate. This analysis could be repeated based on many other assumptions.

Figure 7: Conventional ICE, Efficient ICE, and EV life-cycle cost comparison by: (a) driving levels per year, 2015, (b) driving levels per year, 2030, (c) combinations of fuel prices, 2015, (d) combinations of fuel prices, 2030
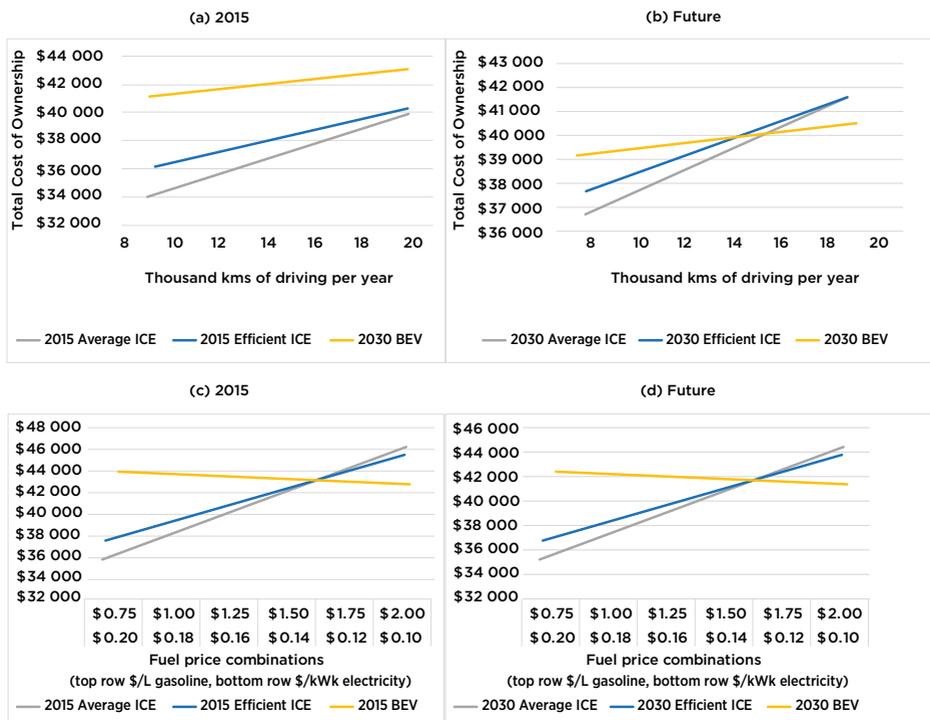
Costs of electric vehicles are not limited to ownership and driving. There are also costs associated with the infrastructure. The cost of chargers varies considerably, particularly for public chargers, and can depend on the extent to which electricity upgrades are needed and "brick and mortar" construction is involved. In the past two to three years, typical costs for home chargers in the United States have been around USD 1 200 per unit, with Level 2 (slow) public chargers anywhere from USD 5 000 to USD 10 000, and fast Direct Current (DC) chargers as high as USD 60 000 (Agenbroad, 2014). Data for other countries is difficult to obtain, and unit costs may be lower in some, particularly China. Total recharging infrastructure costs in the future will depend significantly on scale of production and installation and on the ratios of public slow and fast chargers to the numbers of vehicles.

Electric Vehicle Charging and Interactions with Electricity Grids

Electric vehicles need to be recharged on a regular basis, and this can occur either at home or at work, when shopping, or during other types of stops when travelling. A general issue for EVs has been the long duration needed for charging – typically up to eight hours for a full charge when using Level 1 "slow" chargers. Faster charging is desirable though not needed in all situations (such as overnight), and considerable research is emerging that suggests that the need for public fast charging stations may be modest, given that daily driving is often within the range of most EV models, and all PHEV models (since these can run on liquid fuel as well). In addition, fast charging increases battery stress and degradation.

Figure 8 shows the current numbers of different types of chargers by country and region for major EV markets in 2015. Given about 1.2 million EVs running in these countries, there are about the same number of private outlets (not surprisingly), while there are just under 200 000 public chargers, with over 80% of these slow chargers. The US has the highest number of private chargers, with China having the most public chargers and nearly half of the fast public chargers world-wide.

Figure 8: Numbers of electric vehicle chargers by major market, 2015
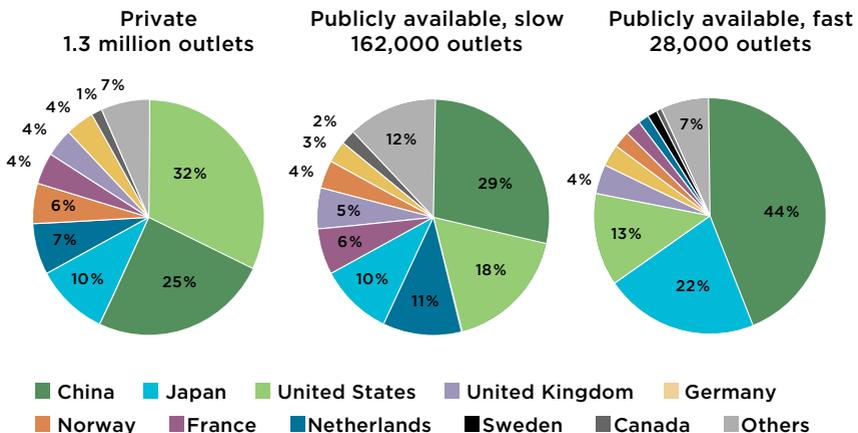
Note: Private charges are estimated assuming that each CV is coupled with a private chargers.
Global EV outlook 2016 (IEA)

EVs may interact with the grid via charging and discharging. The first mode is referred as grid-to-vehicle (G2V) where the vehicle is charged from the grid, while V2G refers to when vehicles discharge power to the grid. The V2G mode could also be considered as a bidirectional charging, in which an EV can charge from and discharge to the grid at regular intervals. There are also other charging modes such as vehicle to building (V2B) and controlled charging. V2B refers to a home storage battery usage with no feedback to the grid, while controlled charging gathers signals from the grid to optimise the charging speed and time based on grid congestion. Few charging systems around the world currently use bi-directional charging, but various testing programmes are underway (Mwasilu F.et al. 2014). REmap has set a target of 160 million EVs in operation by 2030, resulting in significant global EV energy storage capacity (IRENA, 2016a).

Electric vehicles and renewable energy deployment

Depending on the national circumstances of power markets, grids, fuel mix and other factors that can play a role for integration of VRE sources to the grid, electric vehicles are among the key technologies that can help to provide flexibility to the power system. This occurs by using EV batteries to store excess electricity and to provide ancillary services to the grid, such as frequency regulation, shaving peak demand and power support to enhance the operation, and reserve capacity to secure the grid. One of the main advantages of EVs are their high level of flexibility in charging times which can efficiently support operation of the grid. A number of studies have emerged finding value in the linkage between EVs and VRE.

For example, a study in Portugal modelled the integration between a high vehicle share of EVs and a large scale of deployed solar PVs on the grid by 2030 and 2050. It found EVs to be a solar PV enabling technology, and a potentially promising solution to the surplus electricity generated by solar PV (Nunes et al, 2013). Another possible value of batteries is for stationary storage at the end of the life-time of the EV (Mwasilu et al, 2014). China is expected to have 12 000 charging stations by 2020. A study by the China National Renewable Energy Centre CNREC/ERI, (2015) indicated that the storage benefits of the increased use of EVs will help China attain higher shares of variable renewable power (IRENA, 2016 b). Notably, storage might not be urgently needed before an 80%

of renewables share (Weiss and Shulz, 2013). EVs deployment levels are growing, which results in more demand for renewable power. This could make ambitious levels of as high as 80% for renewables in the power mix attainable, especially for countries with a high renewable energy targets.

IRENA's electricity storage roadmap indicates that EVs can be used to enable a higher share of renewables in three ways:

(1) The V2G scheme allows electric vehicles to participate in grid ancillary services such as frequency regulation, load shifting, demand response, or energy management support in home;

(2) EV batteries can receive a second life for stationary applications. For example, China is already engaged in a 14 MW project to assess grid support through the use of second-life lithium-ion batteries (IRENA, 2015);

(3) EVs could be designed so that batteries are replaced rather than charged at changing stations. This concept has been piloted in Israel and Denmark and is now being introduced to buses in China (IRENA, 2015).

According to IRENA's REmap analysis, if a target of 160 million EVs worldwide can be reached by 2030, this would provide around 8 000 GWh/year in battery storage that could enhance installed power generation capacity. This is equivalent to approximately 1 200 GW of battery storage capacity. Along with the pumped hydro storage and second-hand batteries estimated under REmap by 2030, this adds up to a total of 1 650 GW. This compares with approximately 3 700 GW of variable renewable power capacity.

Figure 9 shows the usage factor (battery storage capacity of deployed EVs in GWh/deployed VREs in GW) per country. For example, in Australia, Denmark and the US, the usage factor shows potential for deployed battery storage capacity, which could help scale up variable renewable power.

EVs could be an enabler to achieve a higher share of VRE in the power system. To achieve this, some or all of the following will probably be necessary:

(i) Actively using the mobile battery storage system in the vehicle in V2G applications.

Figure 9: The usage factor of EV's battery storage capacity with respect to the VREs installed capacity
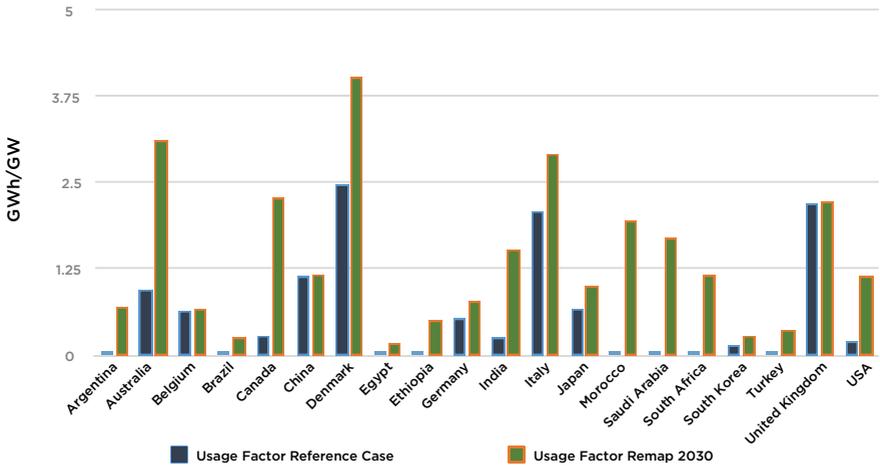
(ii) Use of second-hand batteries in a "second life" role as stationary battery storage systems;

(iii) Widespread deployment of charging technologies and infrastructure.

(iv) Evolution in consumer behaviour of EV owners, for example, becoming comfortable with variable charging rates and times.

(v) Provision of other ancillary services from EVs to the grid.

Figure 10: How electric vehicles could attract more renewable power

Use of mobile batteries in vehicles

Use of second-hand stationary batteries from EV

Variable Renewable Power (VRE)

Electric Vehicles (EV)

Provision of ancillary services from EV to the grid

Deployment of charging technologies and infrastructure for EVs

Evolution in consumer behavior
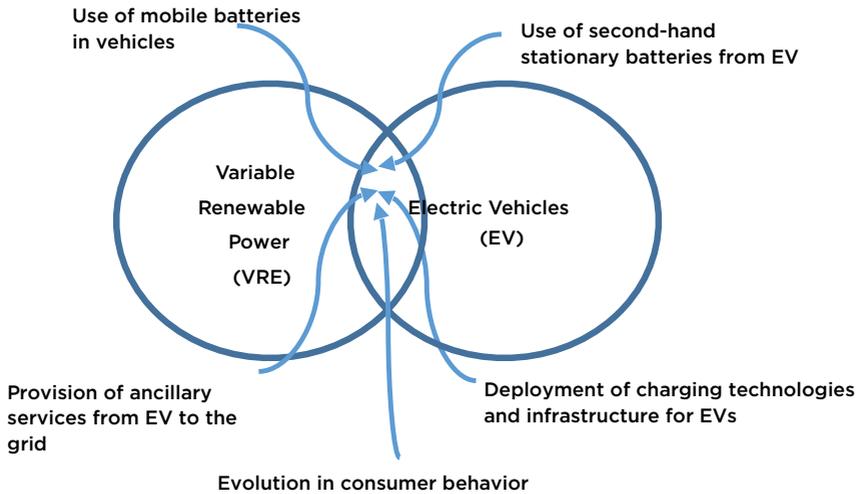
In Figure 10, a schematic diagram illustrates the interaction of the various key factors.

To investigate the impact of EVs on the grid and how EVs can be best integrated, two main aspects must be considered. First, driving and charging behaviour, which can be collected by daily travel surveys to develop charging load profiles. Second, the types of charging used and charging frequency to identify the proportion and typical daily patterns of slow and fast charging demand.

There is a strong interlinkage between charging patterns and the other parameters on the grid, such as

(i) impacts on distribution networks,
(ii) load duration curves involved,
(iii) the role of DSM, and
(iv) the degradation of the battery.

Therefore, the way these parameters can positively enhance the integration of EVs with the grid needs to be analysed. A number of studies already have been undertaken, but ongoing research is needed as charging patterns will likely evolve as more people purchase EVs, vehicle driving ranges increase with newer models, and more charging options become available.

One key type of EV impact is on distribution grids. As a result (shown

in figure 8), grid topology is a key area for research. Uncontrolled charging of EVs could significantly increase the evening load peak. One study that investigated a local grid with uncontrolled charging of EVs found that Load Management Systems (LMS) could play an important role in stabilising grid operations as the number of EVs rises (Probst et al, 2011). In this study, there were two different concepts of LMS investigated to solve this problem of uncontrolled charging. The first concept was G2V, where grids charge vehicles by calculating the desired load profile for the transformer.

The second concept was V2G, whereby grids charge vehicles, allowing power to flow from the vehicle back to the grid. The aim was to control the charging of the EV in a way that the load at the transformer is always balanced. Both concepts could yield a decrease in the transformer load by shifting the charging of EVs to lower demand periods (such as night time) or to PV peak times in the early afternoon. Further, the use of V2G allows feeding energy back to the grid in evening hours at peak load times.

Figure 11: A diagram shows the concept of a load management system
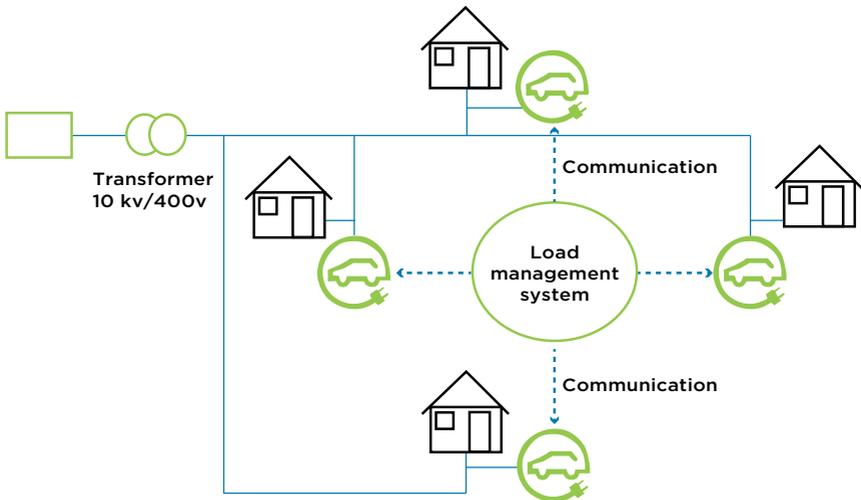
Adapted from Probst et al., (2011)

The role of demand-side management

Given the rise in the supply of variable renewable power, the evolution of smart grids is very important as it allows customers to control and make well-informed decisions on their consumption of electricity, as well as minimise their bills. This kind of consumption control is called DSM (Davito et al, 2010). DSM can help customers in optimising their consumption through an intelligent system, and can greatly support customers in shifting their loads during peak periods. For residential consumers, DSM systems inform them about when they can cheaply consume electricity.

An example now available from Honda is the Home Energy Mangement System (HEMSx). This is a stationary battery-storage system that monitors and controls household electricity consumption, including EV charging. It can help consumers decide when to buy power and when to sell it back to the grid. The value of this system is simply to calculate when to buy and to sell the power. Honda is trying to make the most efficient home and vehicles by actively coordinating energy production and consumption (Honda, 2016).

The integration of EV with the manufacturing industry could also improve the integration of renewable power. A recent study developed a model to assess how using EV batteries in manufacturing influences VRE integration The model indicates that the energy flexibility of manufacturing systems supported by embodied energy storage can improve VRE integration, offering an alternative to the EV battery. However, stationary batteries are shown to be more effective than EVs due to uninterrupted availability (Beier et al, 2016).

Another element that strongly impacts the grid is charging schemes. Efficient charging schemes can significantly boost the deployment of EVs. Studies have shown that the G2V mode can provide ancillary services like frequency regulation to the grid and also indicate that most benefits of the V2G mode could be gained by using G2V. However one concern is that repeated charging cycles from V2G/G2V may have unfavourable effects on the battery. A study examined the lithium-ion battery performance based on the V2G scheme, taking into consideration the driving scenarios, charging schemes, and peak shaving.

The results indicate that the V2G scheme could reduce the battery lifetime by almost 3 years due to the extensive discharging cycles. However this may be mostly avoidable by applying smart charging schemes which carefully manage charge cycling. (Guenther

et al, 2013). An analysis on using different charging modes indicated that EV impacts on the system peak load could be reduced if EVs will not have full battery capacity charged as soon as they connect to the grid. Since there is a strong interlinkage between the charging schemes and consumer behaviour, the policy support could be a key role in enhancing the integration of the EV in the grid. These aforementioned benefits of integration of EV into the gird could allow more penetration of renewable power, which will result in decarbonisation of the power sector.

Smart charging

Slow charging is typically referred to as overnight charging which typically takes between six and eight hours. Fast charging can be defined as any scheme that is faster than slow charging. Fast charging is more convenient, in particular for vehicles that require frequent trips, such as taxis. In a single ten-minute charge cycle, a fast charger can provide enough energy to drive 300 miles (the range achieved by Tesla). Fast charge scheme can help enabling rapid growth of the EV market. An experimental study on Nissan leaf battery, in Nebbenes (around 60 km from Oslo) with a capability of charging 28 EVs simultaneously. With all of recent models with driving ranges up to 480 km, the more battery capacity is, the longer time takes to recharge. Therefore, Porsche is taking the lead on building such a fast-charger for the whole VW Group to support the new versions of EVs with high batteries capacities.

Porsche also in touch with other car makers and suppliers around the world to build a fast-charging network.

The need to understand how to best charge, aggregate and control EV load on the grid is a fundamental and on-going issue. EV smart charging can be used to support the distribution grid management, and efficiently improve the operation of EVs.

The increased use of different electro-mobility mainly depends on the charging network infrastructure, whereas they act as an energy buffer for the grid. Some studies demonstrate the attained great benefits of using V2G scheme. They indicated that adoption of V2G requires an aggregator that controls the information exchange between the EV and the grid to facilitate the interaction. The EVs can be aggregated and controlled under the virtual power plant (VPP). This aggregator changes operation and controlling ways of the grid.

The VPP approach aims to effectively regulate and control the interaction between the EV with the grid. For example, sMobilitTy (Smart Mobility Thüringen) is a project developed to investigate the role of smart charging technology among electro-mobility technologies. This smart-charging technology enables charging of batteries when surplus electricity is available at low prices, providing balancing capacity. The EV's batteries can form a large virtual storage unit. Through the application of a smart-charging tool, EVs will be able to feed all stored electricity back into the grid whenever electricity demand is high, via a continuous connection with the grid infrastructure.

Several projects are currently considering how to deploy EV smart charging, such as. PlangridEV and Green-eMotion, but there is not yet a real commercial project implemented. Green-eMotion calls for open access to all public charging spots, which requires ICT systems to enhance interactivity between the EV drivers and charging locations. Establishment of a framework will govern the process of installation of charging infrastructure which requires ICT systems. ICT counts as a main enabler of connecting all of e-mobility technologies, such as EVs, e-buses, e-bikes and e-scooters.

German carmakers – BMW Group, Daimler AG, Volkswagen Group and Ford – have signed a memorandum of understanding (MOU) to establish Europe's biggest fast-charging network. This MOU has specific targets for deployment: about 400 fast charging stations for electric vehicles by 2017, and several thousand by 2020. The MOU is separate from government plans for more 400 fast-charging stations, which would bring to total to 800. This fast-charging network will be based on Combined Charging System (CCS) technology, which charges DC up to 350 kW in comparison with Tesla's deployed superchargers which delivers about DC 120 kW.

In China, Beijing had about 8 000 public and private charging stations as of 2016. Beijing plans to install 435 000 more charging stations between 2016 and 2020. However, more than a million EVs will be sold over the same period. The Beijing Development and Reform Commission has set out to bring all EVs and charging stations in one platform. This platform will facilitate the charging process for consumers, in which they connect and pay for electricity at charging stations. Such platforms could reduce risk of peak demand on the electricity grid (Chun, 2016).

Strong coupling between the electric power and transport sectors is a target for many countries. Some countries have already taken initiatives to electrify their transport sector. For example, the Swiss Federal Government has assessed

the interplay between the electricity and transport sectors, considering both electricity supply and EV fleet scenarios. Their modelling work estimates that in a scenario where the EV fleet reaches between 30% and 75% by 2050, the significant resulting electricity demand could be met with variable renewable power as nuclear power plants are phased out. Such a strategy could play a major part in decarbonisation of both the Swiss electricity and transport sectors (Ramachandran Kannan, 2016).

Considering the Future: Electric Vehicle Market Projections

According to IRENA's global renewable energy roadmap (REmap 2016a), worldwide there is a potential to increase the total number of electric vehicles to 160 million. This is a very challenging target, but if achieved would provide an important step toward raising the renewable-energy share of the transport sector. As a target, this total is split into 1 58 million passenger or LDVs, 1.4 million buses and 900 000 commercial vehicles.

With constant sales growth (a geometric increase), from the 500 000 units sold in 2015, sales of electric vehicles would need to rise to about 50 million units in 2030 to hit 160 million around the world. This would represent nearly 40% of the IEA's projected total LDV sales of 138 million in that year (IEA, 2015). Growth in LDV sales could vary considerably, depending on the ownership rates at different income levels around the developing world. The IEA assumes relatively low rates. New mobility systems, such as car- and ride-sharing, could greatly reduce the number of vehicles needed to move passengers.

Figure 12 shows one possible manner in which the 50 million sales target for EVs could be reached: 30 million in "major markets" (OECD countries plus China), and 20 million in the rest of the world. In this scenario, EV sales in major markets would need to grow by over 30% per year for the next 15 years; developing countries would not see significant take-up of EVs for perhaps five to ten more years (providing more time for technology cost reduction as well as electricity grid improvements and reductions in carbon intensities), but then show growth of over 60% per year through 2030 to "catch up".

Figure 12: Projections of EV sales required to meet REmap estimates, shown with the global passenger car sales by market, 2015-2030
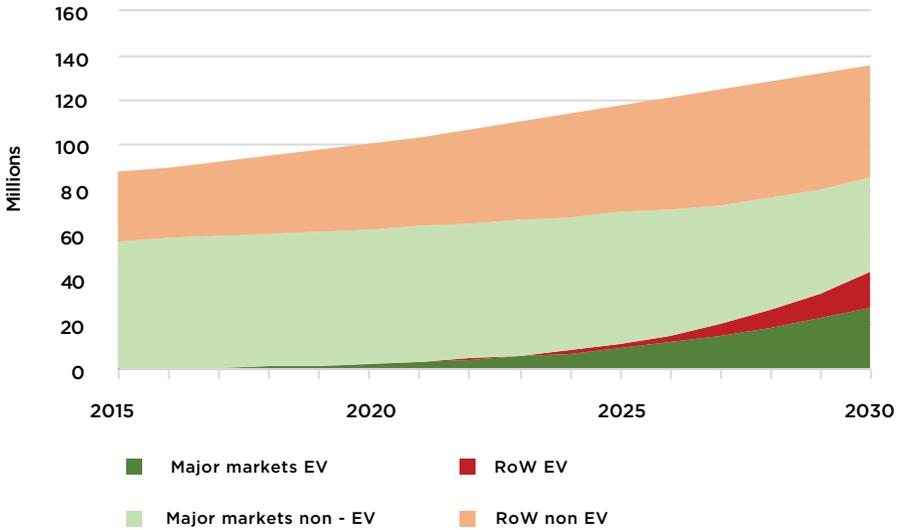
Source: Base LDV sales projections from IEA ETP 2015, with EV projections developed for this technology brief.

RoW= Rest of World.

In terms of total EV sales in different years, the scenario has global sales hit 5 million by 2023, 10 million by 2025, and over 40 million by 2030.

Figure 13: Global annual EV sales to 2030 based on REmap
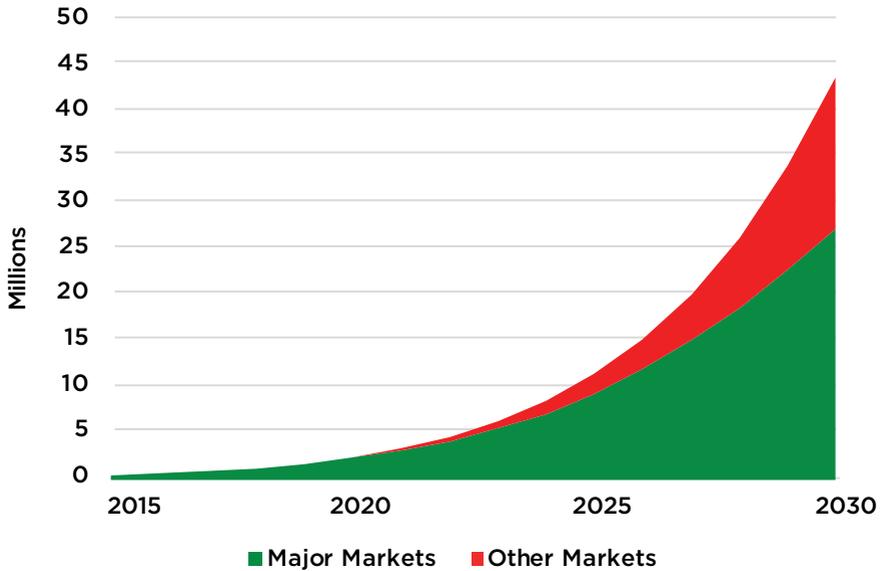
As Figure 13 shows, the steep growth rates needed suggest that a "tipping point" may need to occur somewhere between 2020 and 2025 – that is, the point at which EVs become truly mass market and start to increase their overall market share rapidly, in place of ICE vehicles. Given the trajectory and the 40% market share position in 2030, EVs would become dominant by 2040, accounting for well over half of LDV sales around the world.

Figure 14 shows the resulting total stock of electric vehicles across major world countries and regions, based on higher growth early in the current "leader" markets but then similar growth across all countries, as shown in the figures above.

Figure 14: Total stock of electric vehicles by region
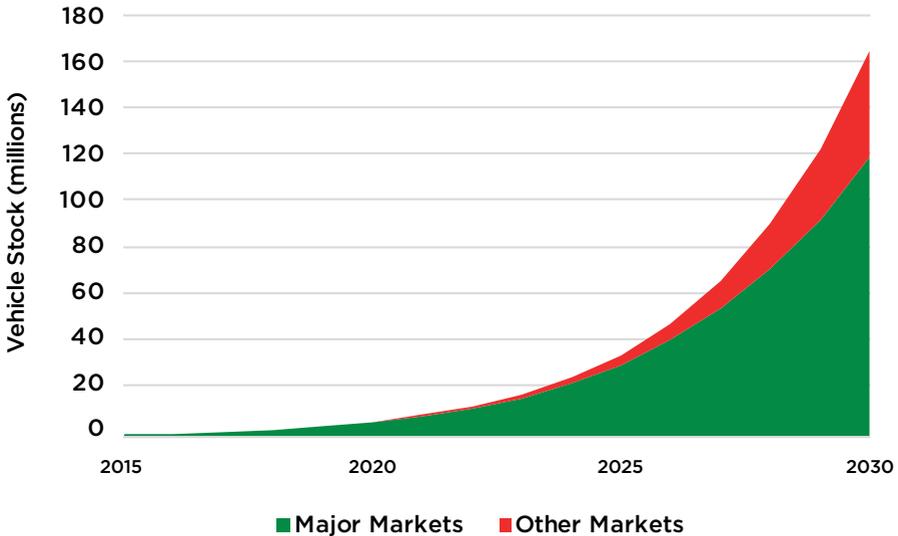
Projections of batteries and electricity demand

As discussed above, storage capacity from electric vehicles can be used for V2G and G2V applications. Batteries can also be used once the car reaches end of its life. Battery packs typically offer a lifetime of between eight and ten years. Even after the lifetime is exceeded they offer storage potential, but with lower capacity that can be as high as 80% in some cases. Electricity stored in such stationary systems provides flexibility, as it can be released when the user needs it, such as when the electricity supply from VRE is unexpectedly low. This can help also to reduce grid-integration costs and eliminate the need for most costly flexibility measures.

Figure 15 shows the estimated battery storage in kWh of capacity from the stock of electric vehicles, consistent with the IRENA future EV scenario. We assume that the average battery storage in EVs is 30 kWh in 2015, rising to 60 by 2030, and is 10 kWh in PHEVs in 2015, rising to 30 kWh by 2030. Given the vehicle sales projections, this results in an estimated 8 000 GWh of batteries in operation in LDVs around the world.

Figure 15: Total battery capacity on electric vehicles by region
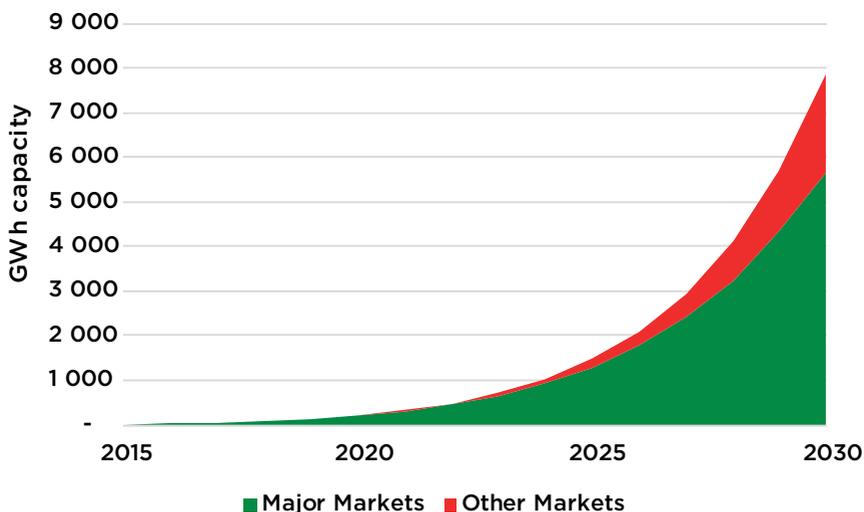
A significant amount of batteries also could be in service from other modes such as two-wheelers, buses and trucks. These vehicles individually have very different battery capacities, and buses and trucks are used much more intensively than privately-owned vehicles, complicating that analysis. Those modes are not included in the estimates here.

The total battery capacity on electric vehicles by region links to the stock and travel of EVs, with the following assumptions:

• It is assumed that the end-use, on-road efficiency of BEVs starts at 0.21 kWh/km, with PHEVs (when operating on electricity) at 0.27 kWh/km; each improves by enough (both new vehicles and in-use performance)

to achieve a 1% improvement in stock-average on-road efficiency per year through 2030.

• It is assumed that on average, BEVs travel 12 000 km per year on electricity, while plug-in hybrid electric vehicles travel an average of 7 000 km (plus considerable additional driving on liquid fuels). By 2030, total distance driven rises for both types, to 15 000 km and 12 000 km respectively.

The results in terms the annual demand for electricity by region for BEVs and PHEVs are shown in Figure 16. Total demand for electricity reaches about 450 TWh per year, representing about 1.5% of IRENA's projected 2030 global electricity generation.

Figure 16: Total electricity demand by electric and plug-in hybrid electric vehicles by region
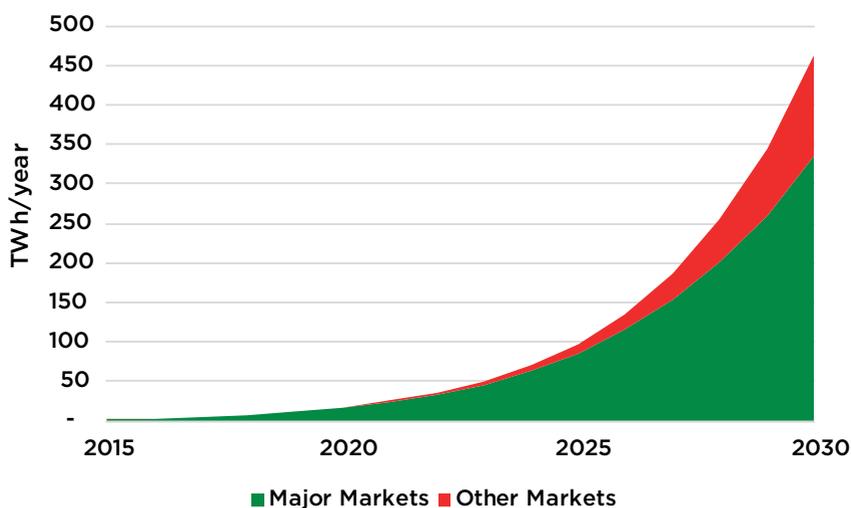
EVs and VRE: Combining for low environmental impact

EVs offer a number of important environmental benefits. In urban areas, where most transport activity takes place, the impact of transport on air pollution is significant. EVs do not emit any air pollutants. Cities that have severe air-quality problems can embrace EVs in their stock (for both private vehicles and public transport) and substitute ICEs. Recently, a number of European countries and cities have announced intended bans on ICEs or some types of ICEs (such as diesels) (Pedestrian Observations, 2016). In order to provide the same transport service, cities are planning to increasingly rely on EVs or shift to other types of electric transport such as trams, buses, etc (Automotive News Europe, 2016).

While EVs do not emit any emissions during driving, the electricity they consume can be produced from fossil fuels that emit air pollutants or CO_2. Therefore, emissions must be considered on a well-to-wheel basis in comparing their CO_2 emissions to conventional vehicles. Well-to-wheel emissions depend on the efficiency of the EV and the fuel mix of electricity generation, which differs greatly across countries.

Figure 17 compares the CO_2 intensity of BEVs for "modest efficiency" and "high efficiency" cases, across

different CO$_2$ intensity levels, with the CO$_2$ emissions of various internal combustion engine vehicles. As shown, a BEV of even modest efficiency can provide reductions compared to an efficient LDV as long as the electricity is produced with CO$_2$ emissions below 600 g/kWh. However, to compare to today's best vehicles (such as small European or Japanese hybrids that can achieve below 100 g CO$_2$/km), the BEV must be driven on electricity with a CO$_2$ emission factor below 400 g/kWh for moderate efficiency.

A very efficient (and likely quite small) BEV can beat today's best ICEs as long as the electricity intensity is under 600 g CO$_2$/kWh. By 2030, ICE vehicle emissions will have to fall below 80 g CO$_2$/km, at least in Europe, where the European Commission is considering a 2025 standard of 68-78

g CO$_2$/km (ICCT 2016). Electricity must therefore be deeply decarbonised for average-efficiency BEVs to have a significant advantage. Of course, this decarbonisation is also necessary for BEVs to eventually provide a near-zero CO$_2$ performance, which is a long term goal.

Notably, Figure 17 uses tested efficiencies, which can be up to 50% better than actual in-use performance. This is true for EVs as well as for ICE vehicles, and more research is needed to better understand how a wide range of vehicles performs in the real world. Finally, plug-in hybrid vehicles are not easy to represent in a figure like this one since they use both electricity and liquid fuel. A well designed PHEV should be able to hit close to both the hybrid vehicle CO$_2$ and efficient-BEV CO$_2$ levels shown in the figure.

Figure 17: Relation between power plant CO$_2$ emissions and vehicle efficiency
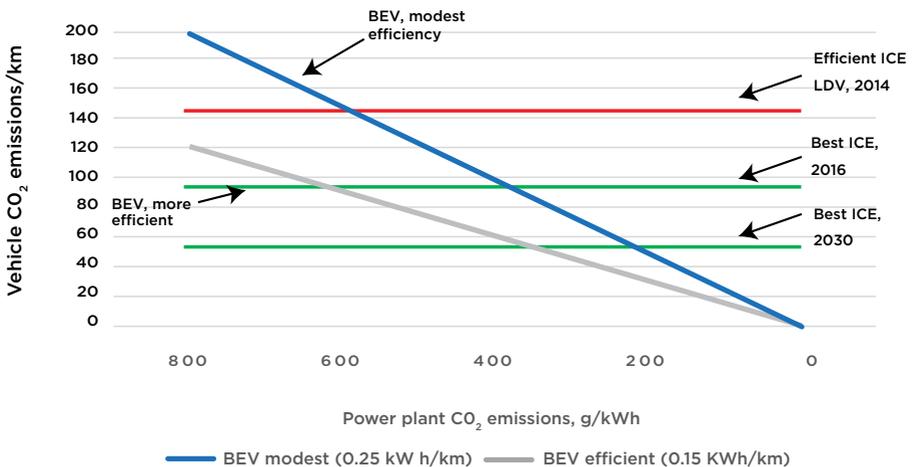
Figure 18 shows the same relationship from the perspective of entire countries according to IRENA's REmap findings (IRENA, 2016a). By 2030, countries would have a much higher share of renewable energy in their total power generation mix, displayed by the x-axis of the figure. With higher shares of renewables in the power generation mix, CO_2 emissions per kWh of electricity generated decreases, as does the well-to-wheel emissions of EVs. For example, the g CO_2/passenger-km emissions of an electric vehicle in Colombia or Denmark that has a renewable energy share of about 80% is in the range of 30 g CO_2/passenger-km. By comparison, in countries where coal dominates the mix, such as Kazakhstan or Poland, the emissions are on the order of 100 g CO_2/passenger-km, close to the level of an efficient petroleum vehicle. A similar relationship exists when power-plant emissions of air pollutants are considered. Hence, increased generation from renewable power is critical to improving the environmental benefits of EVs.

Figure 18: Relation between renewable energy share in total power generation and the electric vehicle CO_2 emissions, IRENA projection for 2030

Renewable share in total power generation (%)
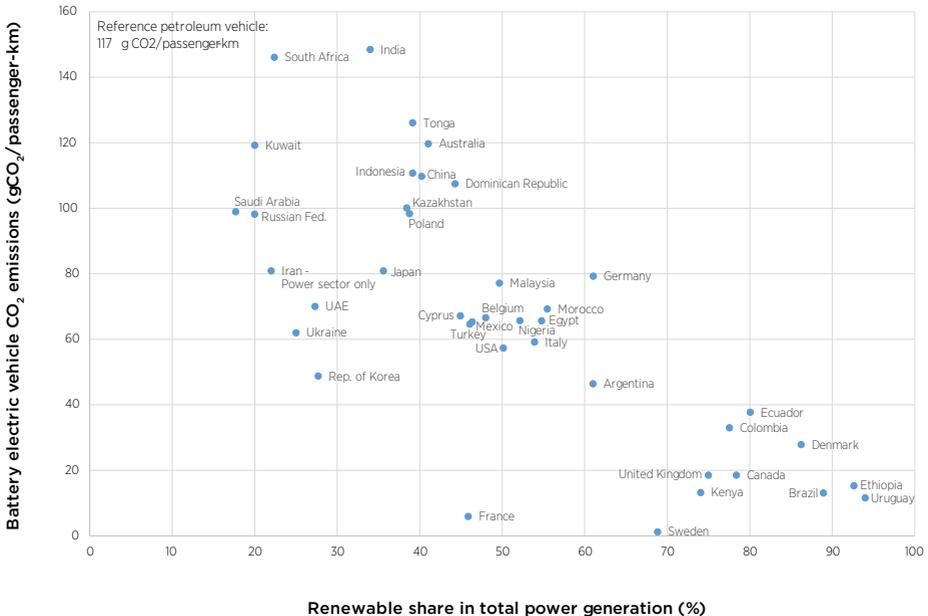
Source: IRENA, 2016a

The need to reduce air pollution in cities will remain a major driver for renewables in the sector. Transport's share of all energy used is 30% globally, but this differs between countries and regions, depending on such factors as population density, income level and weather. In many middle-income and fast-growing cities the transport sector makes up 50% or more of the energy demand for the city, with road transport the largest component. Therefore, the largest contributor to local air pollution in many cities is the transport sector. Benefits of EVs include less local air pollution and, depending on the power generation mix, lower CO_2 emissions.

Assuming all these EVs were to consume 100% renewable electricity, then 480 TWh per year of additional renewable power would be required in 2030 (approximately 1.5% of the total global electricity generation). The share of electricity in transport's total energy demand would increase from 1% to 4% from 2013 to 2030. EVs can also reduce noise pollution in cities. In many cities, noise pollution from transport systems can surpass 55 decibels (dB) in certain areas, which, according to the World Health Organization, can pose health risks. EVs can be much quieter than ICE automobiles, with many operating at just 21 dB.
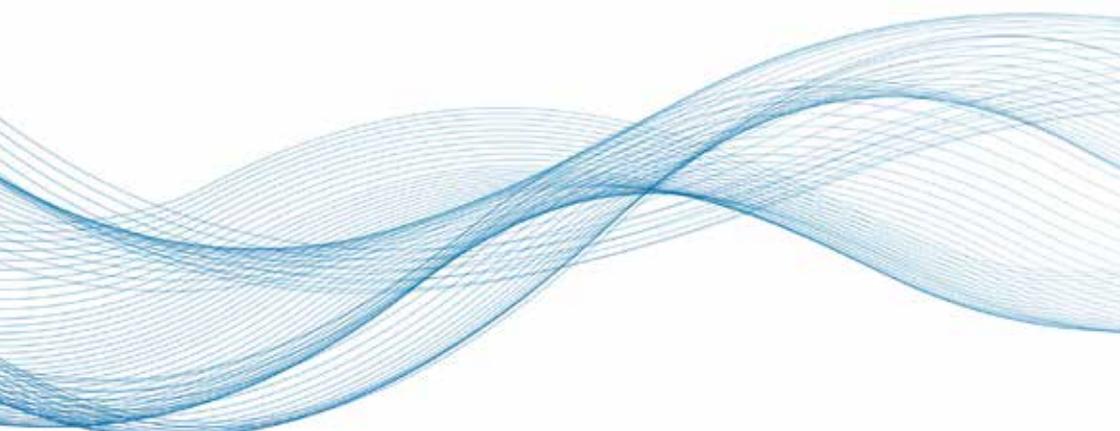
Material requirements

EVs have some materials requirements beyond those needed by conventional internal combustion engine vehicles. These include rare-earth metals for motor magnets and lithium for lithium-ion batteries. The supply of such materials, and risks associated with resource availability, are an important question. This is particularly true in a scenario where sales and stocks of EVs rise rapidly over just a few years, which would happen in the REmap scenario of 160 million EVs by 2030. Here we briefly consider the amount of lithium that would be needed in this scenario.

Lithium is produced from brine lake deposits and pegmatites, a type of crystalline rock. Brines account for about 60% of the total global production. Lithium demand has grown exponentially in the past years with the introduction of new technologies, not only in the energy sector, but also in communications and other sectors. Batteries account for about 20% of the total lithium demand today. This segment is expected to make up an increasingly higher share as EV sales drive demand for lithium (IRENA, 2016b).

As considered elsewhere in this brief, EVs have typical battery capacities, in recent models around 30 kWh. This is rising and is expected to reach 60 kWh average by 2030. Depending on the type, these batteries contain 2-13 kilogrammes (kg) of pure lithium. Based on the growth in EV according to REmap (all types, including two-, three- and four-wheelers), total battery capacity in use will grow by an average of 500 GWh per year between now and 2030 (though starting well below this and increasing over time to well above this by 2030). That average is equivalent to 75 kilotonnes (kt) per year of pure lithium demand to 200 kt, or 368 kt to 1 100 kt per year of lithium carbonate equivalent (LCE) production. This is more than three times the total production of lithium today for all applications, indicating a possible resource constraint given demand for lithium for other uses will also grow. This appears particularly challenging after 2020 or 2025, as the volume of cars sold reaches many millions per year (IRENA, 2016b).

Achieving future EV targets: Technology and policy aspects

Apart from on-going improvements in technology, hand in hand with government actions and initiatives on deployments of electric vehicles, in order to achieve significant market shares, EVs will need to be competitive with conventional ICE vehicles in multiple markets and with a wide range of consumers within those markets (Fulton et al, 2016). In every "beachhead" market for EVs around the world, policy makers have instituted a suite of incentives to encourage buyers to try this new technology. The main goals are to provide needed recharging infrastructure, reduce purchase costs of the vehicles and provide enough other advantages to initiate a sustained transition and get beyond a tiny fraction of sales within the LDV market.

In most countries these incentives have "sunset" provisions. However, there is increasing recognition that some sort of incentive may be needed for many years, perhaps until first costs equal those of conventional vehicles without subsidies. Incentives can also include taxes on ICE vehicles, as is done in many countries. High ICE taxes are found in Norway, with the highest EV market share in the world. Finland aims to catch up, with targets for 250 000 EVs and only 50 000 ICE cars in the country by 2030. To achieve this goal, they aim to provide a subsidy of EUR 4 000 for each of the first 25 000 EVs sold and to raise the tax rate on gasoline to 30% by 2030 to encourage people to buy EVs. Also, since EV technology will likely continue to evolve rapidly, along with infrastructure capacity and consumer awareness, a given level of incentive should yield increasing "returns" in market share for EVs, as has been the case in Norway.

Another approach is to require automakers to make some percentage of their sales be zero-emission, as is done in California (which will require an increasing share from 2017 until 2025, reaching 15% of sales in that year). More recently China has indicated plans to apply a credit point system where, as of 2018, car makers will need to achieve EV sales credits equivalent to 8% of their LDVs sold in China (Der Spiegel, 2016). This would represent a much steeper ramp-up than under the California programme.

Policy "packages" typically include national, regional and local incentives. National incentives generally include subsidies such as tax credits to reduce purchase costs. Regional (as in state, provincial) incentives have also included tax and registration reductions, and in some cases reductions at the point of sale. Regional incentives sometimes also include road-system privileges, such as exclusive access to special lanes on highways, or reduced tolls for highways or ferries.

Local (metropolitan) provisions may also include such advantages for EVs, and also often include special or discounted parking and charging, or special access to congested urban zones and to roadways such as bus lanes.

A full list of incentive policies and their variability is too numerous to cover here, but Table 2 provides a comparison of three successful cities (also including the regional and national policies affecting EVs in those cities). These are Shanghai, China; Oslo, Norway; and San Jose in the U.S. The relative importance of different elements of policy among these various cities and countries is difficult to know. In Norway, national tax breaks can exceed USD 30,000 (more than anywhere else) for some expensive EV models, helping to offset the price difference compared to an equivalent ICE vehicle. Significantly, the auction system for cars in Shanghai provides an exemption for EVs that can be worth more than USD 10 000 per car. Subsidies in the US (and in particular in California where San Jose is), generally don't exceed USD 7 500 for EVs.
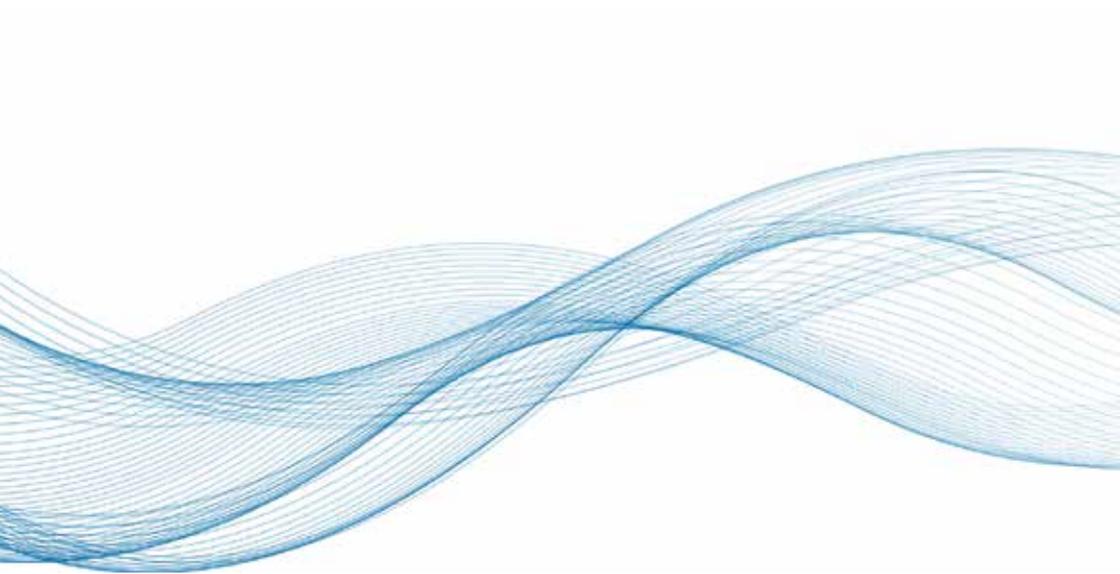
Table 2: Comparison of electric vehicle policy incentives in three cities

	China –Shanghai	Norway -Oslo	USA-San Jose
National 2015 EV Sales (share of total LDV sales)	209 000 (1%)	50 000 (30%)	115 000 (0.7%)
Leading region 2015 EV sales	44 000 (16%)	12 140 (4%)	15 000 (10%)
Leading region public charging points	13 400	1 820	1 200
Federal financial incentive	USD 3 500 – 8 500	Exemption of VAT (25% - value up to USD 25 000 on USD 100 000 price car)	USD 2 500 -7 500
Local financial incentives	USD 1 500 - 4 500		USD 1 500 (PHEV)/ 2 500 (BEV) California EV rebate
Sales Tax	Exemption of sales tax (10%)		
Registration tax	Free registration (avoidance of ICE plate auction price USD 11 000-13 000)	Exemption USD 3 500- 7 000; lower annual fee	
Roads	BEVs exempted from inner city road restrictions on vehicle registered outside Shanghai	Bus lane access, free toll roads (nationally worth USD 600- 1 200), reduced ferry rates	High-occupant lane access
Parking		Free parking in municipal garages	Free parking in metered parking; free parking at many hotels
Charging	Free charging at public charging stations, Mobile phone App to search charging stations	Free charging at public charging stations	Highest number of workplace charging points in US

Sources: Advisory Work on Global Benchmark Study on Policies Promoting Electro-Mobility – Europe Uwe Tietge, Alex Campestrini, Peter Mock ICCT (Draft Version January 2016; Analysis on China's New Energy Automobile Policies and Incentive Toolkits, China EV 100 , November 2015; Pathways to Electromobility – perspectives based on Norwegian experiences Erik Figenbaum, Marika Kolbenstvedt TOI Report Oslo May 2015.

Beyond the high levels of purchase incentives apparent in these cities and countries, some of the key takeaways from the experiences of successful cities and countries include the following:

• Markets with comparatively high consumer spending power (like Norway, or states in the US like California) can start by pushing to accelerate uptake, thereby increasing EV production and bringing costs down so that other countries with lower income levels can afford such vehicles. And any country can "afford" to tax higher CO_2 vehicles to help pay for incentives for low CO_2 models.

• Policy packages can incentivise electric driving, not just electric buying. In particular, incentives could encourage the driving of PHEVs in electric mode as much as possible. While this would be aided by high petroleum fuel prices, it could also be incentivised via charging a fee per kilometre, if electric kilometres can be tracked separately from (and changed a lower fee than) ICE-driven kilometres.

• Combinations of pricing measures and regulations, with direct government support for infrastructure development, appear to work well.

• Countries aiming for the systematic transformation of transport-related energy use need policies to promote EVs. This involves gaining EV experience, initiating domestic EV demonstrations, and understanding how increasing numbers of EVs will affect the transport and electricity sectors.

• Low-carbon electricity generation has to be scaled up at the same rate as EVs.

• Public charging facilities are important, but fast charging need not be over-emphasised in the early stages. The vast majority of private and public charging needs can be adequately fulfilled without fast charging. However, for households without private charging available, public charging becomes much more important, and the needs of such households are still poorly understood.

Overall, a combination of continued technological improvement, strong policy incentives, adequate charging infrastructure and much higher levels of public awareness and experience with EVs are all needed. All these factors would be essential to reach the EV stock target of 160 million in 2030, as set by IRENA's REmap analysis in 2016.

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