ofgem | future insights

Ofgem's
Future Insights Series
Implications of the transition to Electric Vehicles

Executive summary

Electric Vehicles (EVs) currently represent a small but rapidly growing part of the transport market. Compared to internal combustion engine vehicles, they offer significant benefits in reduced environmental and noise pollution. The cost of the batteries that power electric vehicles has fallen rapidly, meaning that EVs may soon be as cheap to consumers as conventional vehicles. Increasing use of EVs could have considerable implications for the energy system. Inflexible EV charging could add to peak electricity demand and require expensive network reinforcements. But flexible charging could enable cost-effective decarbonisation of the transport sector, by ensuring that our network is used in a smarter and more flexible way.

The transition to EVs should provide substantial benefits to energy consumers, but we know it will also bring challenges. Electricity flows will become increasingly complex and bi-directional, particularly if EVs are used to feed power back to the grid through Vehicle-to-Grid (V2G) technology. There will be regulatory challenges too. The regulations that govern the energy sector were not explicitly designed with the foresight of EV charging and bundled energy and transport services. Regulation will need to adapt to provide predictability to the EV market and protection to EV users. Given the scale of uncertainty around uptake and charging behaviours, alongside the blurring of typically separated sectoral boundaries (energy and transport), this represents a challenging prospect.

This paper on the 'Implications of the transition to Electric Vehicles'[1] is the fifth in our Future Insights series. We aim to inform the debate on how the EV transition will affect the energy system, consumers and regulation in three key areas:

- **The evolving transport sector** - Much of the current public debate overlooks or underestimates the role of wider societal change, and how changes in how we access and use transport will manifest in the energy system. We explore the motivations behind current trends, and what they might mean for the energy and transport sectors.
- **Implications for consumers and the energy system** - We explore where and when EV owners are charging, and what that means, given current market arrangements. We explore the benefits of flexible charging, extracting value out of our existing system as an alternative to network reinforcements. We also examine how broader societal change could influence charging behaviour.
- **Considerations for regulation** - We explore key regulatory considerations such as efficient investment in infrastructure, improving access to charging, how costs and benefits are distributed, and technological interoperability.

[1] This paper focuses on electrification, but there are other low-carbon transport options, such as hydrogen and biogas. This is beyond the scope of this report.

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We also put forward analysis which shows:

- Impacts associated with EVs will not be distributed equally. This is true in terms of where flows on the network will change due to EV charging, and how costs and benefits are distributed across different socio-demographic groups.

- Flexible and fast charging is essential for facilitating the transition to EVs in the most cost-effective way, by enabling all consumers (including those who do not own an EV) to benefit from a more optimised energy system, and avoiding reinforcement costs.

Regulating in uncertainty

While continued and widespread deployment of EVs now seems inevitable, there is substantial uncertainty around the scale and pace of EV growth. Regardless of how the transition progresses, we consider two core principles should determine industry's approach to facilitating the EV transition:

- Industry should focus on minimising overall system costs for all consumers (including non-EV users), by seeking to make more efficient use of our existing assets, before considering reinforcement. The development of new markets that provide flexibility will play a key role here, by incentivising or automating the shifting of load away from peak demand, even if total demand increases. This means that network companies should not expect to be remunerated for reinforcement alone when more cost-effective solutions exist.

- Early adopters of EVs serve to promote an industry that brings both energy system and decarbonisation benefits, and contribute to learning and cost reductions that will benefit later adopters. However, if EV users choose to charge during peak times, under current arrangements they will impose considerable costs which will be borne by all consumers. An enduring charging regime should ensure costs are distributed fairly, and EV users face charges that are reflective of the costs (or benefits) they are imposing on the system. Vulnerable consumers, or those who are currently unable to share in many of the benefits of EVs, are likely to object to subsidising more affluent early adopters of EVs.

This paper is the fifth report in our Future Insights Series publications.

If you would like to engage with us on this report, you can get in touch by emailing: ResearchHub@ofgem.gov.uk

Context

The transport sector is in the midst of change. In the past, many of the major transformations in the transport sector have been accompanied by wider societal changes. The steam engine enabled cheap transport of goods and raw materials that allowed industrialisation to occur. It also allowed people to travel further and faster, introducing the concept of tourism. The internal combustion engine (ICE) introduced even greater flexibility in transport allowing goods and people to travel more freely.

EVs are no longer a far-off technology of the future but a rapidly growing feature of our transport sector. The number of EVs on UK roads has grown from fewer than 4000 in 2013 to around 160,000 as of June 2018.[2] While growth is significant, EV numbers still represent a fraction of the UK's 31.2 million cars. We must remain mindful that we are at the very beginning of a transition - much of the transformation (and uncertainty) is still ahead of us.

As with the steam engine and the motorcar, the EV transition may be linked to broader societal change. Beyond electrification, shared vehicle access and autonomous technology could change the nature of how we own and engage with transport. We do not yet have certainty over what the future transport system will look like or how it will be used, just as we do not have certainty over what our future energy system will look like.

Why is this important to us?

The transport and electricity sectors are becoming increasingly connected. Much of the 'fuel' for EVs will come from our national electricity grid - changing how, where and when electricity flows across the network. EV owners will not just be passive consumers of energy, but could also play an important role in the future, balancing the electricity network. New bundled offerings that combine energy and transport services will cut across traditionally distinct sectoral boundaries, and therefore regulatory jurisdictions.

As the GB energy regulator, our principal objective is to protect the interests of existing and future energy consumers. In seeking to understand how future consumers will use and benefit from tomorrow's energy system, we need to understand how the transport sector might evolve, and ensure appropriate protections are in place. Adopting the right regulatory arrangements in the near term will therefore be a crucial and challenging prospect, but one which offers the potential to create a more resilient and efficient system for the future.

[2] Historic annual EV registrations, dating back to 2012, provided directly to Ofgem by The Society of Motor Manufacturers & Traders (SMMT)

The evolving transport sector

The transport sector is now the primary source of greenhouse gas emissions in the UK.[3] Therefore, decarbonising the transport sector is essential to meet decarbonisation targets. As we look to the future, some elements of the transition to a low-carbon transport sector are clear. The UK government has set a firm direction in phasing out conventional petrol and diesel ICEs from 2040. Some UK nations or regions have set targets that are more ambitious. In Scotland, plans to phase out ICE vehicles will come into effect from 2032,[4] and some councils plan to establish emission-free zones more quickly – Oxford from 2020. There is a strong pull from industry too, with leading car manufacturers committing to producing a wider range of electric vehicles.

The role of decarbonisation and air quality

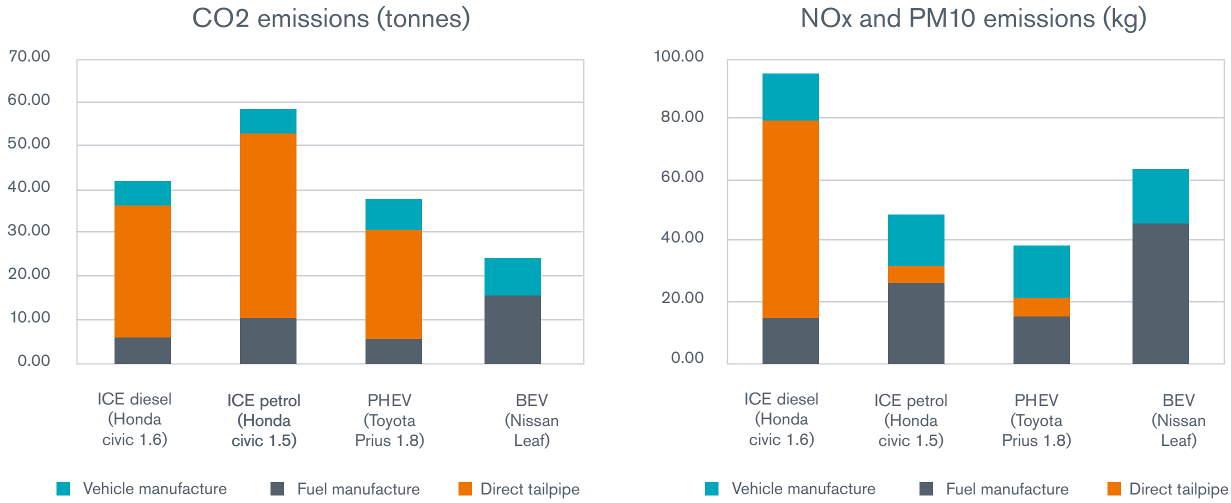

Fig 1. Comparison of lifetime emissions across ICEs and EVs[5] (Source: NextGreenCar).

Both Battery Electric Vehicles (BEVs), and Plug-in Hybrids (PHEVs)[6] offer carbon benefits relative to ICEs (Fig. 1). However, BEVs have zero tailpipe carbon emissions and lifetime carbon emissions that are considerably less than those of PHEVs.[7] BEVs carbon emissions are predominantly driven by electricity generated from the current energy mix, which will continue to decarbonise.

Air quality is another important factor in the move to EVs. A comparable BEV has no tailpipe NOx or PM10 emissions, meaning EVs will improve local air quality. Although our illustrative analysis suggests BEVs have the higher NOx and PM10 emissions than petrol ICE, the location of these emissions (unlike carbon) is the main factor when considering impact. The majority of NOx and PM10 emissions associated with EV use are from fossil fuel electricity generation, sited (generally) in sparsely populated areas. As the energy sector decarbonises, these emissions should also fall dramatically.[8] Moving to EVs will not represent a panacea for air quality, however. Like ICEs, EVs produce small particulates from braking, and stir up particulates / dust from the road.

[3] Department for Business, Energy and Industrial Strategy, 2017 UK Greenhouse Gas Emissions, Provisional Figures, March 2018.

[4] Scottish Government, Draft Climate Change Plan - The draft third report on policies and proposals 2017-2032, January 2017.

[5] We have calculated this on the basis that each car has a lifetime mileage of 200,000 miles.

[6] Throughout this paper, we refer to Electric Vehicles or EVs as both Plug-in Hybrid EVs (PHEVs) and Battery EVs (BEVs), both of which allow for a physical connection to the national electricity grid via a chargepoint.

[7] There is substantial variation in PHEV tailpipe emissions, depending on the size and range of the battery.

[8] Factors other than the location of emissions are important when considering the actual impact of NOx and PM10 emissions. For instance, measuring particulates by kg mass fails to recognise that the smallest (and lightest) particulates tend to be the most damaging.

The EV market today

EVs are not a new technology. In the early 1900s, EVs sat at the forefront of transport innovation and held a promising future. However, the rise of the ICE meant this early success was short-lived. Today, EVs are once again at the forefront of transport innovation. The UK has the second largest EV market in Europe in terms of total PHEV and BEV registrations (Fig. 2).

Top 10 European countries for EV registrations

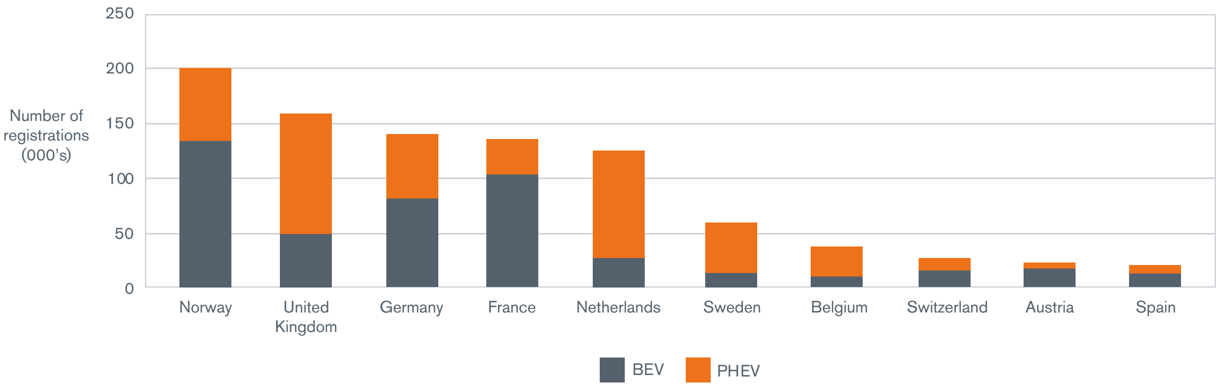

Fig. 2: Total number of PHEV and BEVs registrations across Europe (Source: European Alternative Fuels Observatory)

In the UK, since 2012:

- Annual EV uptake has increased from 2254 new registrations in 2012 to almost 50,000 in 2017.[9]
- The total number of public chargepoint connectors has grown more than 500%, now standing at over 16,000 across 5,600+ locations.
- The number of rapid chargepoints has grown from 79 in 2012 to over 3,400 in May 2018, now the largest rapid chargepoint network in Europe.

Although growth rates have been rapid, absolute numbers remain small. EVs currently constitute less than 1 in 200 of the cars on the UK's roads.[10] Moreover, growth is not equal among BEVs and PHEVs. In the UK, uptake of PHEVs accounts for about 70% of EV growth. The number of new registrations of BEVs each year has not materially changed since 2014, and March 2018 year to date figures hint at a potential slowing of new BEV registrations.[11] In the long term, efforts to decarbonise further will likely require a shift from PHEVs to BEVs.

[9] Historic annual EV registrations provided directly to Ofgem by The Society of Motor Manufacturers & Traders (SMMT)
[10] Based on 31.2m total registered cars (Source: Department for Transport) and approximately 160,000 registered EVs
[11] Historic annual EV registrations provided directly to Ofgem by (SMMT).

Certainty of direction, uncertainty of pace

While a transition to EVs seems inevitable, there is substantial uncertainty around the scale and pace of EV growth. Fig. 3 illustrates the growing range of uncertainty in National Grid's recent Future Energy Scenarios (FES) upper and lower bound EV uptake forecasts. This figure also signals another emerging trend - FES scenarios show a steady year on year upward revision of EV uptake forecasts. Other market commentators have made similar upward revisions. In 2017, OPEC revised their EV outlook upwards by more than 500%.[12] Recent BNEF forecasts of the market share of EVs in 2040 have been revised upwards by 54%,[13] and the distribution network operator UKPN has recently increased uptake estimates for its region by 25%.[14]

Range of EV uptake estimates from National Grid FES

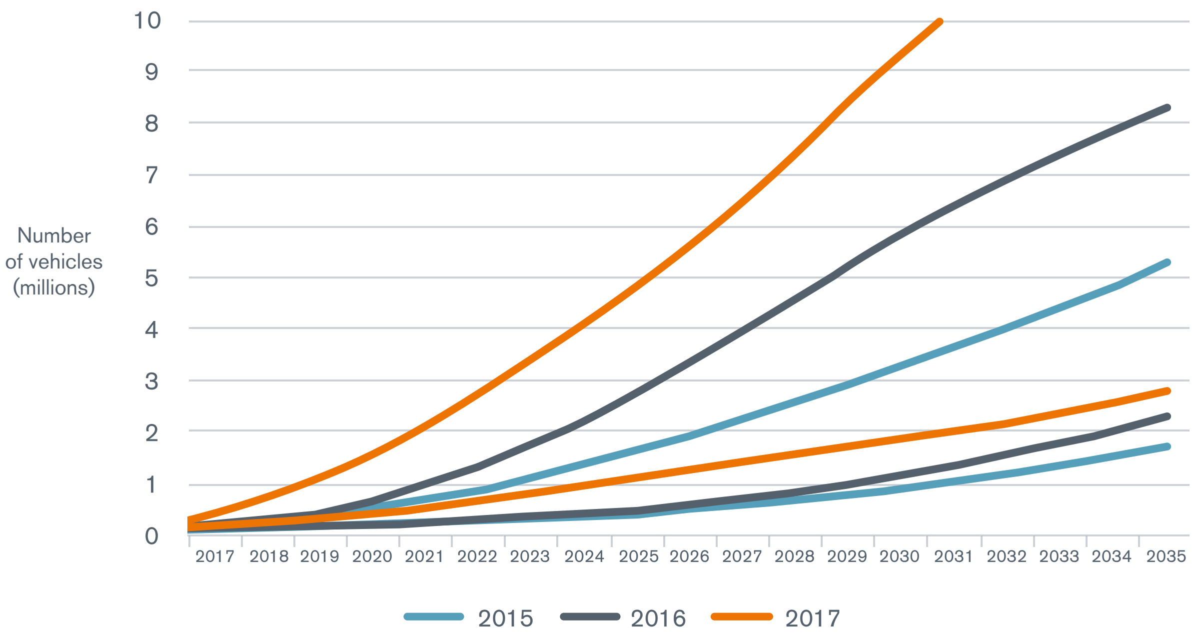

Fig. 3: National Grid EV uptake estimates across FES scenarios from 2015 – 2017 (Source: National Grid)

[12] Organisation of the Petroleum Exporting Countries, 2017 OPEC World Oil Outlook, October 2017, available: www.opec.org
[13] Bloomberg New Energy Finance, Electric Vehicle Outlook: 2018, May 2018, available at: https://about.bnef.com
[14] UK Power Networks, Electric Vehicles and the Grid, March 2018, available at: www.ukpowernetworks.co.uk

What does this mean for regulation?

- **We cannot readily rely on current forecasts to inform the rate of uptake.** The market will determine this. We can however ensure that we create a system that allows the uptake of EVs to happen without unnecessary barriers.

- **We must accept our powers of prediction are limited.** Recent uptake has exceeded many past expectations. We must at least be prepared for a pace of uptake that is greater than today's thinking suggests is possible.

We can learn from predictions or trends to inform our understanding of the future. But we must also look further afield - to improve our understanding of the factors that are influencing further growth in EVs, and wider changes in transport use.

Drivers of EV uptake

At a societal level, the need to decarbonise (and in many areas, the need to improve air quality) is primarily driving EV uptake. The complete phase-out of ICE sales across the UK from 2040 will serve as a backstop, forcing an eventual societal change. However, there is a complex range of factors influencing the pace of uptake by individuals, and this will change over time. EV uptake to date has been by early-adopters – individuals typically characterised by affluence, being less price-sensitive and having a greater appetite for risk.[15] This means that early adopters may have very different motivations and behaviours compared to the general population. As the transition moves past early-adopters to the mass market, key factors such as relative costs and an established secondary market will have more influence than today.

Relative costs

Relative costs of ICEs and EVs are a crucial determinant of purchasing behaviour, with consumers typically considering both lifetime costs and upfront purchase prices.[16] Different groups will respond to purchase and lifetime costs differently depending on whether they are a fleet operator, leaser or private owner. Fig. 4 below shows a lifetime cost of ownership comparison of an ICE and EV model of the Volkswagen Golf. In this illustrative example, the purchase cost of an EV (even with the addition of government grants) is still higher than that of a comparable ICE, but total ownership costs[17] are lower.

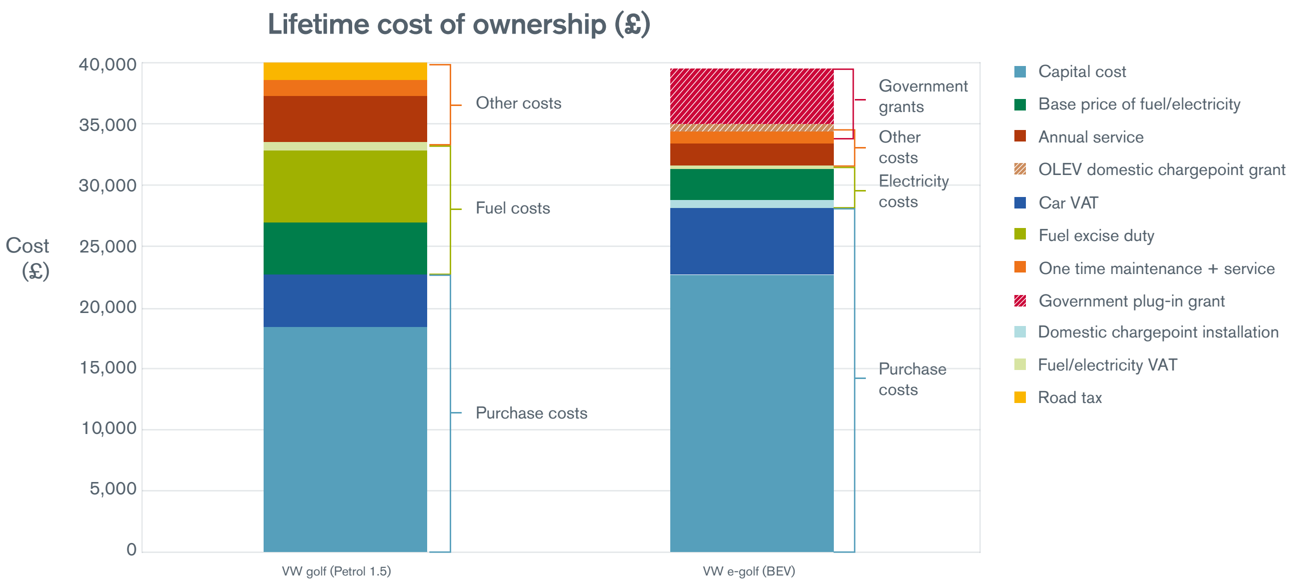

Fig. 4: Comparison of purchase and ownership costs of comparable ICE and EV (Source: Next Green Car)[18]

The costs of lithium-ion batteries are a key component of EV purchase costs. These have been falling rapidly, and now cost below $170/kWh; a cost that past forecasts have suggested would not be achieved until the 2020s.[19] Falling costs have been accompanied by marked improvements in range - in 2011, the greatest range an EV could achieve was 93 miles, compared to more than 330 miles in 2018.[20]

[15] E Rogers, 'Diffusion of Innovations', Free Press, 2003.

[16] PwC, Charging ahead! The need to upscale UK electric vehicle charging infrastructure, April 2018, Available at: www.pwc.co.uk

[17] Assumes 8-year ownership, and does not take into account depreciation.

[18] This analysis is provided as an indication only, and will differ across brands and models. Over the lifetime of a vehicle, both fuel and electricity costs could also change considerably.

[19] Bloomberg New Energy Finance, Lithium-ion Battery Costs and Market, July 2017, available at: https://about.bnef.com

[20] F Lambert, 'Median electric car range increased by 56% over the last 6 years', Electrek, 26 December 2017, available at: www.electrek.co

Government incentives

Government incentives have a significant impact on EV uptake. The UK has strong financial incentives in place, which include a discount of up to £4,500 from the purchase price of eligible EVs, a discount of up to 75% from domestic chargepoint installation, and various tax incentives.

Predicting the impact of incentives is difficult. Uptake will likely slow if incentives are removed too soon. EV sales in Hong Kong fell from over 2000 in 2016 to just 89 in 2017 after a generous incentive scheme was removed.[21] There can also be a surge of uptake in the period leading up to subsidy removal, such as the surge in solar panel uptake associated with changes to the Feed-in-Tariffs (FIT) subsidy.[22]

The financial incentives (car purchase grants) are designed partly to 'internalise' the externality of carbon dioxide emissions. Figure 1 suggests that a BEV currently saves about 35 tonnes of CO2 compared to a petrol ICE over its lifetime. The £5,000 subsidy therefore implies a cost per tonne of carbon saved of about £140, in line with the gross cost of the Renewable Obligation.[23] However, this calculation does not take account of higher fuel and road taxation of ICEs, which increases the scale of the effective subsidy.

Norway: Incentivising EV growth

Norway has the largest market share of EVs in the world. This isn't necessarily because Norwegian car-buyers place greater value on decarbonisation, or improving air quality – it is because they have the strongest incentives.

Norwegian EV owners benefit from a mixture of financial and non-financial incentives, including:

- No VAT on the purchase price (which would otherwise be 25%)
- No import tax
- Free parking
- Free access to toll roads, and ferries
- Access to bus lanes
- Well-developed public charging infrastructure

Impact

A Government target of 50,000 EVs by 2017 was met three years early, with the current number in excess of 140,000 at the beginning of 2018. EVs now represent more than half of new vehicle registrations.

[21] F Lambert, 'Hong Kong brings back some electric vehicle incentives that made Tesla so popular in the region', Electrek, 28 February 2018, available at: www.electrek.co

[22] Department for Energy and Climate Change, *Monthly MCS and ROOFIT degression statistics*, 22 January 2016, available at: https://www.gov.uk/government/statistical-data-sets/monthly-mcs-and-roofit-statistics

[23] Ofgem, State of the Energy Market 2017, October 2017, p.85, available at www.ofgem.gov.uk

[24] G Hartley, 'Going electric, second-hand', Energy Saving Trust, 28 January 2018, available at: www.energysavingtrust.org.uk

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A stable, predictable secondary market

Most consumers today typically do not replace old cars with new ones – rather, they buy a second-hand car. Used car sales are three times greater than new car sales, but the second-hand EV market is still developing.[24] This is due in part to the novelty of the technology, but also crucially due to EVs historically depreciating more quickly, and less predictably, than their ICE comparators. This has mainly been because of uncertainty over battery longevity.[25]

Speed and access to charging

There is approximately one public chargepoint for every eight EVs in the UK. However, the distribution is uneven (Fig. 5). The number of 'rapid' chargepoints, which facilitate enroute charging, has grown 900% since 2013, compared to just 30% growth in slow chargers over the same period.[26] Car owners are used to filling up at a petrol station in a matter of minutes, and many might expect the same from EVs. Despite considerable growth, the limited distribution of chargepoints (particularly 'rapid' chargepoints) in some regions is likely to be a barrier to uptake. Given the speed of recent improvements in battery size and vehicle range, the need for rapid chargepoints could change significantly in the near term.

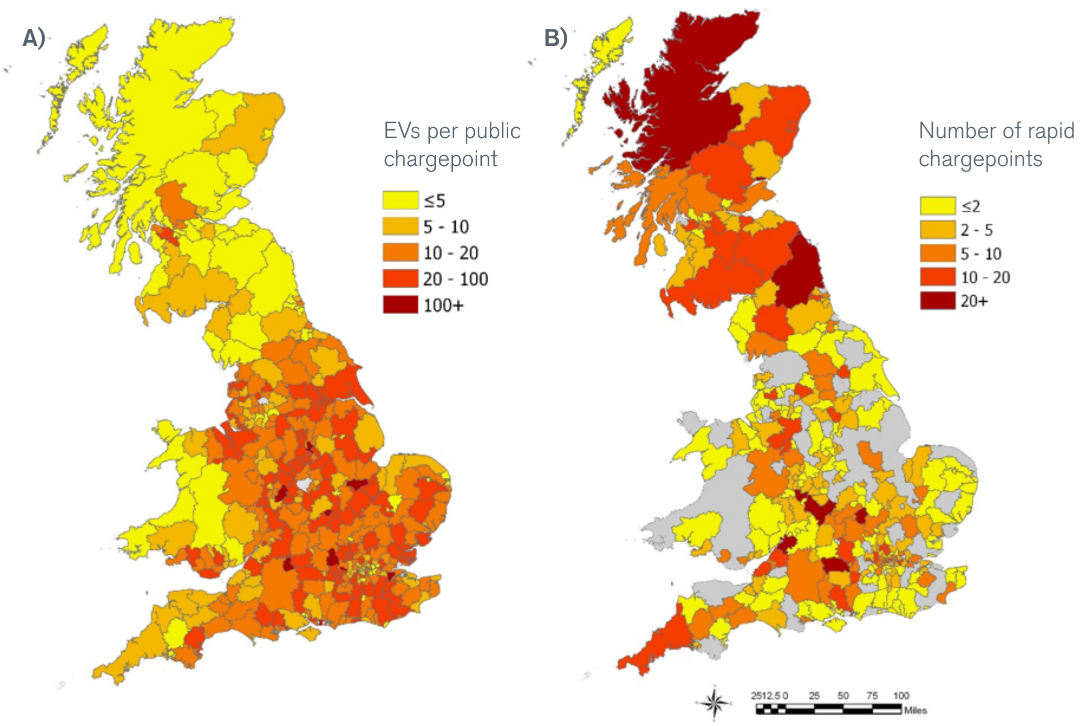

Fig 5: A) Ratio of EVs to public chargepoint by Local Authority, and **B)** Number of rapid EV chargepoints by Local Authority (Source: Zap-Map, Department for Transport (DfT) statistics).

[24] G Hartley, 'Going electric, second-hand', Energy Saving Trust, 28 January 2018, Available at: www.energysavingtrust.org.uk

[25] Palmer et al. 'Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan'. Applied Energy, vol. 209, January 2018, pp 108-119

[26] Zap-Map statistics, available at: www.zap-map.com/statistics/

Transformation beyond electrification

As well as electrification, we are seeing much wider technological and societal changes in the transport sector, which may have implications for how our energy system is used.

A growing, but underutilised vehicle stock

The total fleet of cars on UK roads is larger than ever with around 76% of UK households owning at least one car and one-third owning two or more.[27] Since 1995, the number of miles we drive each year has declined by 20% from a peak of 10,000 miles per year.[28] This implies that we have a growing stock of vehicles that are being used less on average (Fig. 6).[29]

Total number of registered cars and average annual vehicle mileage

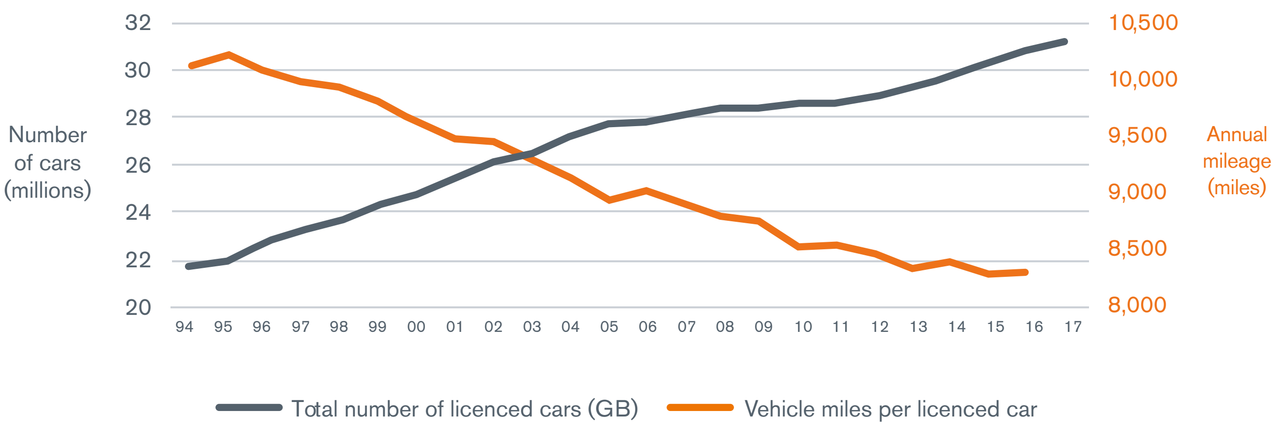

Fig. 6: Total number of registered cars vs. average annual vehicle mileage
(Source: Department for Transport statistics)

Most cars are used for a fraction of the time we own them.[30] From an economic perspective, this leads to inefficiencies. If we assume the average value of a vehicle is between £5,000 and £10,000, the value of our car stock is in the region of £150-300bn.

[27] Department for Transport. *Road Use Statistics Great Britain 2016* www.gov.uk/government/statistics/road-use-statistics-2016

[28] Department for Transport (DfT) Road Traffic Statistics (Table TRA0101)), available at: www.gov.uk/government/organisations/department-for-transport/series/ road-traffic-statistics

[29] A growing number of households with more than one car may contribute to this trend. However, on a per capita basis, people are still making fewer trips and driving fewer miles in cars.

[30] Ovo Energy, Vehicle to Grid: Your electric car as a power station', available at: https://www.ovoenergy.com/guides/electric-cars/vehicle-to-grid-technology.html

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In comparison, gas and electricity network companies have invested around £100bn in maintaining and upgrading the networks since privatisation.[31] As many of the costs associated with car ownership are not connected to usage (purchase price, insurance, tax etc), this means that the financial incentives for moving away from owning a car increase as car use falls.

Access vs ownership

For a growing number of people, it is becoming more cost-effective to acquire 'non-ownership' access to a car than to own one directly.

Demand for access-based models such as ride hailing and car clubs has increased, and the adoption of these services could signal a societal shift away from ownership. Car clubs and ride hailing apps in particular are gaining momentum. The leading ride-hailing app, Uber, now has 40,000 drivers and 3.5 million users in London alone.[32] Car club use has grown from 32,000 members in 2008 to over 245,000 now, and evidence suggests some car club users are already moving away from ownership[33]. However, whilst these developments are interesting, absolute numbers moving away from ownership remain small. This may change in the future.

Peak ownership?

From 1995 to 2005, per capita car ownership increased 24% as more households acquired multiple cars. From 2006 to 2016, per capita ownership has levelled off, increasing by just 3.5%. Clearly, the economic climate has played a role in this, but it might also suggest a change in social preferences. The market could soon reach a point at which the population as a whole will start to shift away from ownership, with cities and urban areas having the greatest prospects for doing so.

[31] Ofgem, RIIO-2 Framework Consultation, March 2018, available at: www.ofgem.gov.uk
[32] The Economist, 'Uber runs into a wall in London', 30 September 2017, available at: www.economist.com
[33] Carplus, *Annual survey of car clubs 2016/2017*, available at: www.carplusbikeplus.org.uk

The economics of autonomy

Declining car usage strengthens the case for accessing transport through non-ownership means. The rise of autonomous vehicles takes this a step further.

Autonomous vehicles could allow for vast efficiency improvements, reducing the time a car is unused, and increasing the value of time spent travelling. Those who own a driverless vehicle could benefit financially from providing others with access when it is not being used. Those who don't own a vehicle could have near instantaneous access via commercial fleets or local peer-to-peer networks. Some of the more radical possibilities may seem to be the stuff of science fiction. However, there are economic reasons to expect autonomous vehicles to increase rapidly in number if the technology can be shown to be safe and reliable.[34]

This could have implications for the infrastructure we put in place today. The demand for daytime parking in the centre of towns and cities could disappear. Chargepoints that rely on active human connection could become obsolete over time, risking stranding many of today's chargepoints. The demand for travel could also increase significantly, if people find using an autonomous vehicle much less burdensome than driving themselves.

Improving efficiency: driverless cars

A day in the life of a privately owned vehicle (2018)

30 minute morning commute. Car rests in car park for 9 hours. 30 minute evening commute. End.

A day in the life of a privately owned autonomous vehicle (2035)

Vehicle drives children to nearby school, and returns home. Vehicle then takes owner to work. Vehicle is dispatched as a taxi, through a peer-to-peer ride hailing app. Owner receives £10 in service fee. Vehicle waits on an induction chargepoint bay until being called again. Owner receives further £15 in service fee. Local electricity demand increases. Vehicle discharges 5kWh. Owner receives £3 in flexibility services. Vehicle collects children from school. Owner is notified when pick up is complete, and children are safely home. Vehicle collects owner, returning home. Owner has a meeting the next morning across the country. The vehicle travels 300 miles through the night whilst the owner sleeps, as a cost effective alternative to flying.

[34] Autonomous vehicles will need to pass through a range of technological, regulatory and social hurdles before being adopted at scale.

What does electrification mean for consumers and the system?

The electrification of transport creates opportunities for consumers to engage in the retail energy market in new ways. Different types of service offerings may justify different levels of protection, depending on the service that consumers are engaging in.

The EV transition will also affect our energy system. Much of the electricity system was created decades ago to ensure there was sufficient generation and network capacity to meet peak evening demand from a predominantly passive consumer base. Generation was connected at the transmission level and demand flows were predictable and unidirectional.

In just over a decade, we have gone from a system characterised by several hundred generators to one with several million, the vast majority of which (in terms of numbers) are connected at distribution level. EVs, alongside other energy system innovations such as storage, demand side response and distributed energy resources, add an additional layer of variability to what is already a complex and dynamic system, but offer significant potential for enhancing the flexibility and resilience of our system.

EV impacts - Here and now

As the EV transition is still in its infancy, we have a limited but growing evidence base to inform **where** and **when** EV charging will occur as EV deployment grows. Improving our understanding of these factors is key in understanding the implications for our energy system and the impacts felt by consumers. From 2013-2015, Ofgem allocated funding through the Low-Carbon Network Fund for MyElectricAvenue - a three-year project looking at electric vehicle charging.

Other projects such as Western Power Distribution's Electric Nation are furthering our understanding of how early adopters choose to charge.[35] In addition to private ownership, falling EV costs are encouraging more fleets to turn electric, from commercial enterprises such as rental companies and commercial / delivery fleets to public transport services including taxis and buses. Fleets require different charging solutions from privately owned EVs, perhaps including large, depot-sized connections with faster chargepoints to ensure they provide an effective service.

[35] Electric Nation, Be Part of the Electric Nation Community, September 2016, available at: www.electricnation.org.uk

Where?

The majority of private EV charging currently occurs at home (Fig. 7).

Understanding where flows on the network are changing as a result of EV charging is crucial in understanding where impacts are most likely.

EV charging activity by location

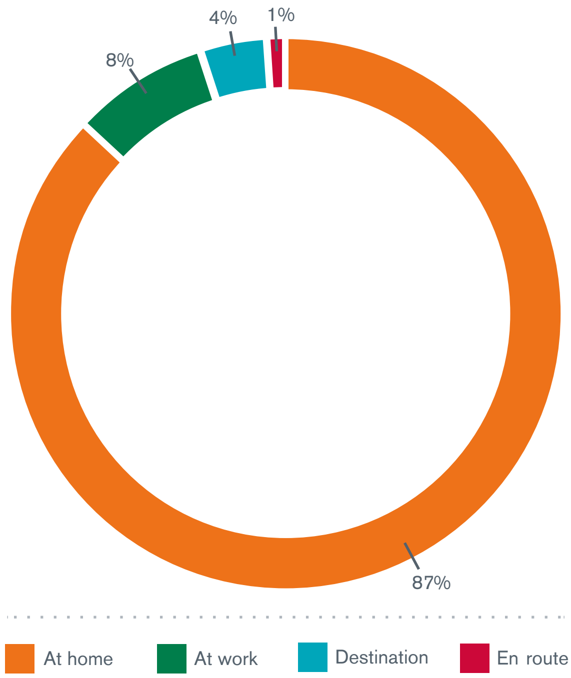


Fig. 7: Where EV users currently charge their vehicles (chart adapted from Regen[36]).

- **Home** - These chargers are typically slow (~3kW - 11kW).
- **Work** - Workplace charging is typically slow too, but charging is more likely to occur throughout the day (9am – 5pm).
- **Destination** – These chargers are generally slow chargepoints found in car parks to enable consumers to charge when they go shopping, for example.
- **En route** – reflects the 'petrol station' model of refuelling. These are often rapid chargers (~40 – 120 kW) which enable EV owners to top up their vehicle in minutes, rather than hours.

[36] Regen, Market insight series: Harnessing the electric vehicle revolution, April 2018, available at: www.regensw.co.uk

Fig. 8 below illustrates the considerable regional variation in domestic charging; unsurprisingly, most domestic chargepoints are in and around large towns and cities, where considerable numbers of EV users may be clustered on the same part of the network.

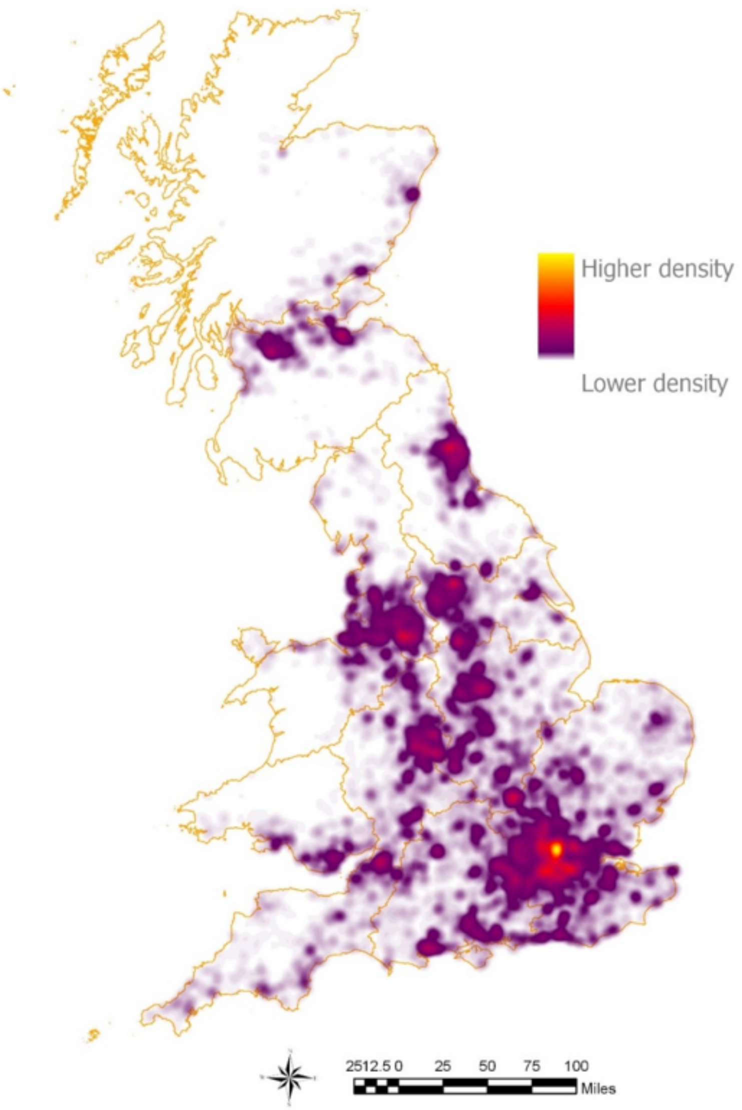


Fig. 8: Spatial distribution of installed domestic EV chargepoints (Source: OLEV).[37]

[37] Note – this only includes installations under the Electric Vehicle Homecharge Scheme (EVHS).

When?
Domestic charging

Trials looking at the behaviours of early adopters suggest that most EV owners do not charge every day, but still tend to charge at peak times when demand is already at its highest.[38]

Charging patterns

My Electric Avenue

200 participants used a Nissan Leaf over an 18-month trial. Findings included:

- 32% of low-voltage networks across UK would need upgrading once 40% of customers had EVs
- Demand management and managed charging could reduce the cost of managing this by around £2.2bn by 2050.

Electric Nation

700 participants are building on the findings of My Electric Avenue. It is investigating the impact of EVs on low-voltage networks and the best solutions. Early analysis shows:

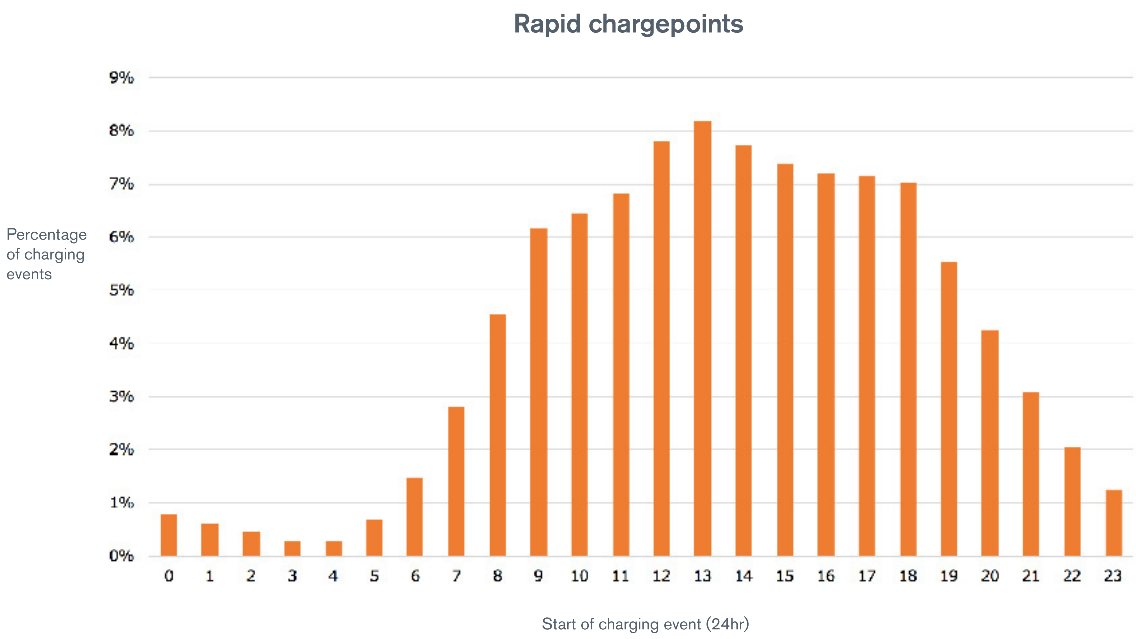
- Managed charging (through a mixture of curtailed charging, and reducing current per chargepoint) is only needed on some early evening winter days
- Most consumers are positive about smart charging

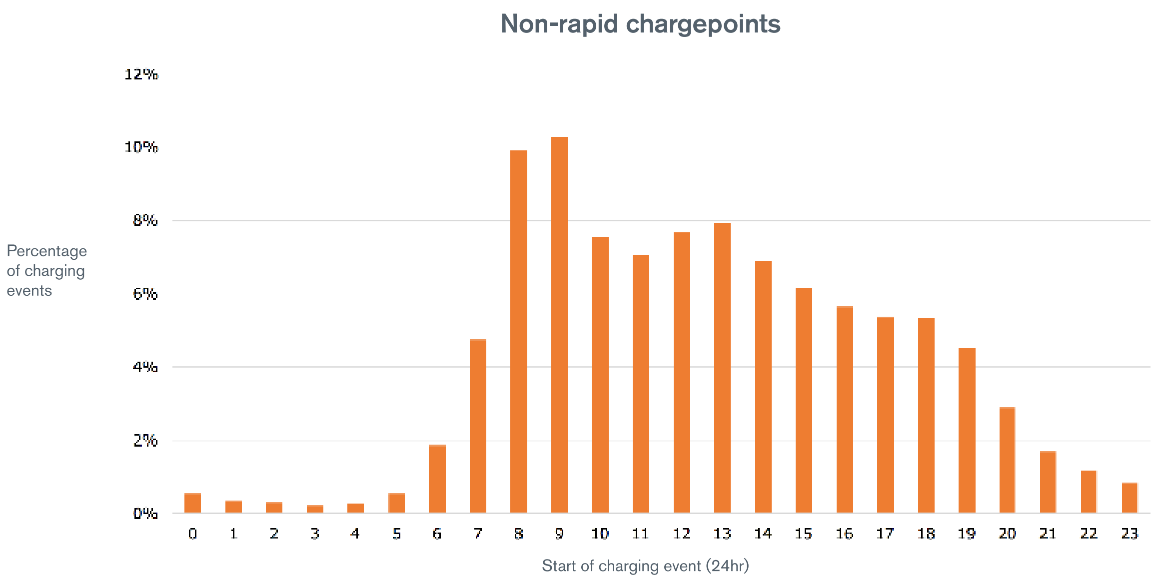
Public charging

Analysis provided by Zap-Map suggests that the use of public rapid chargepoints is evenly distributed throughout the day, with slower chargers typically peaking in the morning, and declining thereafter (Fig. 9).[39]

[38] More information about My Electric Avenue is available here. More information about Electric Nation is available here.
[39] Analysis provided courtesy of Zap-Map.

Fig. 9: Daily charging profile of a typical public chargepoint (by start time), showing top: rapid chargepoints (43kW or greater); and bottom: non-rapid chargepoints (under 43kW capacity) (Source: Zap-Map).[40]

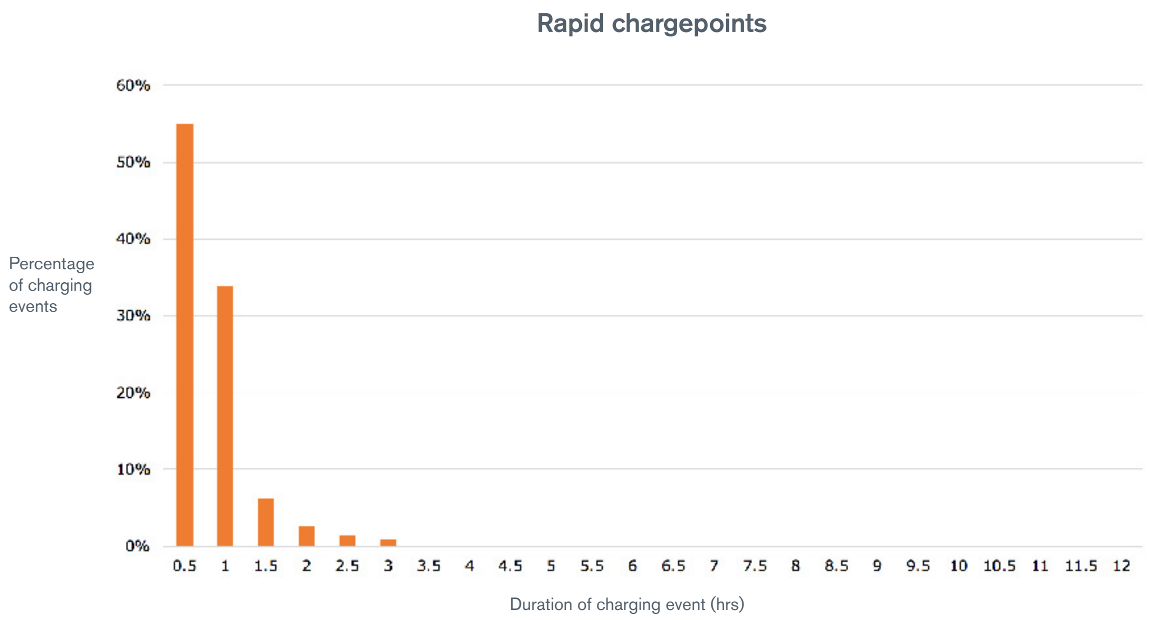


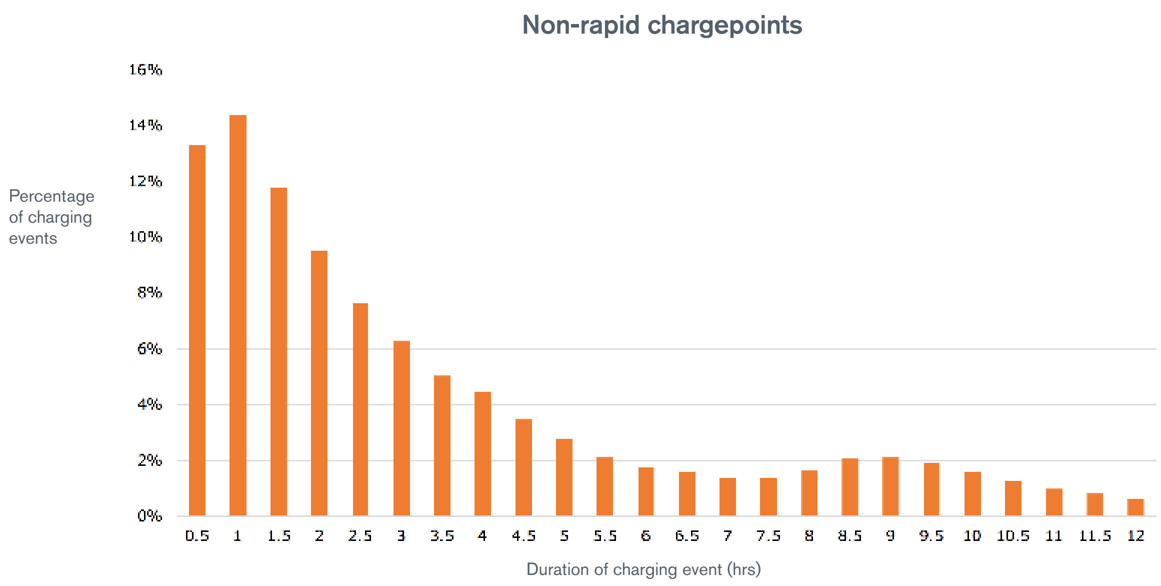


In terms of charge duration, not surprisingly, the majority of rapid charging events are less than 30 minutes, with very few lasting more than one hour. However, non-rapid charging events are frequently over several hours, and can be up 12 hours in length (Fig. 10).

[40] To note – this is illustrative only, and variation will exist, for example due to regional and seasonal factors.

Fig. 10: Duration of typical charge event showing top: rapid chargepoints, and bottom: non-rapid chargepoints. (Source, Zap Map)





Current charging behaviours - scale of impacts

Most EV charging currently happens at home, and at peak. This means impacts on the network will be greater in areas where constraints are already an issue. In local areas where EV concentration is highest, this may mean that some reinforcement will be required, potentially leading to higher costs for all consumers.

However, given current EV deployment levels, the scale of impact in the near-term is unlikely to be considerable - preparing for and addressing localised clustering is the key consideration. We discuss the role of charging flexibly in minimising impacts below, but as the EV transition progresses other factors will continue to influence how electricity flows across the network. Two factors are particularly important:

- **Microgeneration** – Domestic electricity generation (primarily through solar panels) continues to grow, and primarily connects at the Low-Voltage (LV) network level.
- **Electrification of heat** – There is considerable uncertainty around the pathway for decarbonising the heat sector, but electrification (through heat pumps, for example) is likely to play a role, and will connect mainly at the LV network level.

The installed capacity of EV chargepoints[41] (public and private) is considerably less than solar photovoltaics (PV) and heat pumps (Fig. 11). The incremental loads associated with heat pumps (particularly if these loads coincide with EV charging) could exacerbate impacts on the LV networks. However, the impacts of EV charging may be offset by microgeneration if charging occurs when nearby installed solar PV is exporting to the grid. As the economics of storage technology improves, this should also allow stored electricity to offset the demand from EV charging (and heat pump use).

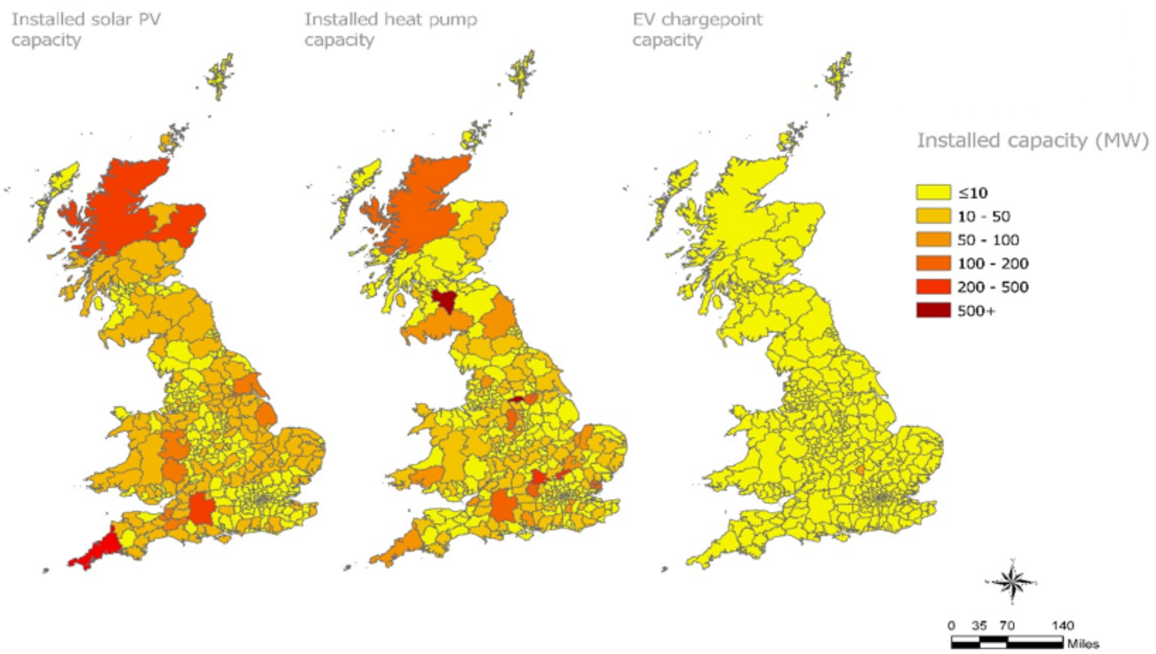


Fig. 11: Installed capacity of Solar PV, heat pumps and EV chargepoints (public and private)

[43] For public chargepoints, we use actual kW capacity figures provided Zap-Map. For private chargepoints, we use Electric Vehicle Homecharge Scheme (EVHS) data. We do not have exact information on the installed capacity of EVHS chargepoints but have assumed an average of 7kW as a conservative estimate (in line with National Grid FES assumptions)

The case for flexible charging

To maximise the benefits of EVs (and minimise the costs to both the system and consumers), EV demand should be integrated in a smart and flexible way. Flexible charging can complement a system with variable renewable generation in two ways: first, by promoting charging when there is excess generation on the system; second, by alleviating network constraints by shifting charging to times when there is also sufficient network capacity.

Fully flexible charging requires smart systems that communicate with the wider energy system in real time to understand the optimal time(s) to charge. For domestic charging, this will require smart meters, half-hourly settlement and time-of-use tariffs, which allow for price signals that reflect the current flows on the network, and communicate them to EV owners.

The system benefits of flexible charging could be significant (Fig. 12), and should be achievable automatically in the future, without requiring conscious consumer intervention. Consumers should be rewarded for being flexible with their demand, but may pay a premium if their behaviour adds to peak demand or local congestion - reflecting the benefits they provide to (or costs they impose on) the system. However, there may be limits to the extent to which price-signals should penalise consumers who are less able to engage.

'Dumb' energy system → **Smart energy system**

Inflexible EV charging

Impacts

- Increasing peak demand
- Risk of local outages
- Reduced system diversity
- Constrained areas become more constrained
- Reinforced costs paid for across energy consumers

Flexible EV charging

Benefits

- Lower increase in peak demand
- More efficient use of existing assets
- Improve system diversity
- Deferred/avoided reinforcement costs
- Market rewards consumers for their flexibility

Fig. 12: Benefits of flexible charging compared with inflexible charging

Smarter fleets

For new fleet initiatives, costs can be minimised by siting in locations where the prevailing network flows allow for new connections.

For existing depots (such as taxis and buses), the feasibility (or cost) of connecting or expanding existing connections will be harder to manage and may require reinforcement. Non-firm connection agreements may help, as may co-location with batteries or distributed energy such as solar PV, reducing peak usage at times of local congestion. However, the lack of capacity to upgrade connections may mean that in some circumstances, relocation will be the most economical option.

There are also promising developments in smarter fleet-level charging which will facilitate further EV uptake in a cost-effective way, through better use of our existing network. An innovative project from a consortium led by UPS demonstrates how inteligent and flexible charging should allow increasing numbers of fleet EVs to connect, without needing costly connection upgrades.

Flexible connections

Transport for London – Timed connections

Transport for London is beginning the process of electrification of its public transport fleet. Its battery-powered buses at Waterloo bus garage use a flexible connection agreement, with timed connections so that vehicles are only charged when overall electricity demand is low, such as during the night.

Impact

This allows up to 2.5 MW of flow, charging the fleet at times where there is sufficient capacity. This reduces the cost of service through avoided reinforcement, and reduces the need for depot relocation.

UPS - Timed smart charging

Smart Electric Urban Logistics, a collaboration between the courier UPS, UK Power Networks and Cross River Partnership is delivering smart charging for a fleet of delivery vehicles in London.

The project uses a smart-grid, relying on intelligent chargepoints that can communicate with onsite storage, and the national grid to determine optimal charging at lowest cost. Prospects for using second-life batteries from older UPS vehicles as onsite storage represent further opportunities for reducing costs.

Impact

Through the adoption of smart charging infrastructure, UPS has been able to increase the number of EVs operating from its central London site from 65 to all 170 trucks. This has been achieved without needing to upgrade its network connection.

Beyond Smart Charging – Vehicle to Grid (V2G)

V2G technology can provide additional system benefits, by allowing EVs to export back to the grid. Like smart charging, this will require sophisticated infrastructure to communicate with the energy system and determine when export is required. As a pooled resource, the growing number of EV batteries could provide a wider range of valuable grid services, from demand response and voltage regulation to distribution-level services, without compromising driving experience or capabilities.

vCharge V2G platform

OVO Energy, a UK energy supplier, is working with Nissan on a 2-year V2G project which will involve 1,000 households and specially developed charger technology. The project will also see the development of OVO's grid balancing platform 'vCharge', which aims to optimise smart charging and discharging according to the status of supply and demand on the national grid. The findings will assess the technical feasibility of V2G at the residential level and provide an understanding of how residential customers choose to participate in V2G services.

The benefits of smart charging – low-voltage network analysis

To assess the potential impacts on the grid of increased EV charging, we undertook some high-level analysis focusing on the LV network. This analysis complements a more comprehensive study on longer-term EV integration - the ENA DS2030 study.[42] Rather than replicate this large-scale model, we sought to provide an indicative view of the challenges with EV integration on a typical urban LV network today. EV connection constraints were dictated by the transformer capacity, feeder capacity and feeder minimum voltage limit.

We investigated the impact of EV charging on a typical household demand profile[43] across five scenarios. The scenarios considered flexible and inflexible charging, different charging speeds and durations over peak and non-peak periods, and one case included the integration of Air Source Heat Pumps.[44]

Key findings

- Flexible fast charging allowed the greatest number of EVs to connect to the network, due to higher load diversification compared with slow charging.
- Inflexible fast charging allowed the smallest number of EVs to connect, due to the limited capacity available at peak.
- Flexible EV charging, even with the additional demand of heat pumps, allowed a comparable number of EVs to connect compared to inflexible slow charging, and considerably more compared to inflexible fast charging
- For all inflexible charging (at peak) cases, EV uptake is constrained first by the transformer limit.
- For all cases with flexible charging, EV uptake is constrained first by the feeder limit.

Description	Number of EVs Connected		
	Transformer Capacity Limit Reached	Feeder Capacity Limit Reached	Feeder Minimum Voltage Limit Reached
Case 1 Inflexible Slow Charging (Peak)	33	36	72
Case 2 Inflexible Fast Charging (Peak)	9	12	18
Case 3 Flexible Slow Charging	102	54	84
Case 4 Flexible Fast Charging	108	60	96
Case 5 Heat Pump Operation with Flexible Fast Charging	60	30	72

Table 1: Summary of LV network model analysis.

[42] Energy Networks Association, DS2030 project, Stages 4 & 5, Project Results, 2016, available at: www.energynetworks.org
[43] We use Elexon residential home average half-hourly (HH) daily data
[44] For this analysis we define slow charging as 3.3kW, and fast charging as 11kW (it is worth noting that many domestic chargepoints also operate at ~7kW). For duration, slow charging occurs over 6 hours, fast over 1.75 hours.

Implications

This analysis has clear implications for policy – as smart, flexible solutions allow at least 60% more EVs to connect to our existing network, before reinforcement need be considered. If 'fast' charging is adopted, flexible solutions may allow up to six times more EVs to connect. It also demonstrates that should electrification of heat continue, there are still sufficient troughs in demand flows for EV charging to fill, rather than add to peak demand.

This analysis comes highly caveated. Rural and urban feeders differ considerably in their characteristics, flows across the LV network follow variable seasonal patterns, and half-hourly demand data does not capture the size of shorter peaks that may occur within the half-hourly period.

However, it does provide an indication of the benefits of charging flexibly. Experience from retail energy markets shows that consumers do not always engage in the market even when there are financial benefits in doing so. In facilitating flexible charging, numerous options are available requiring different levels of consumer participation, including:

- Consumers could be actively incentivised through price signals to charge at off-peak times.
- Consumers could opt-in to agreements for automated charging, within defined parameters, or other options for access such as off-peak or timed acces.
- Through new flexibility markets, DNOs could contract directly with EV users or aggregators for flexibility services.
- Flexible charging could be established as the industry 'default', where domestic charging would only happen at off-peak times, unless an override (requiring consumer action) was triggered.
- Flexible charging could be bundled with the cost of vehicle purchase (eg discount on the purchase price), on a fixed term or opt-out basis.
- In rare cases where flexible charging fails to prevent constraint issues, curtailment of EV charging might still serve a role as a last-resort backstop to avoid domestic outages. We envisage that this however would only be in extreme situations, where adequate governance structures are in place and would be treated as a disruption.

The UK government is in the process of facilitating the move to smart charging[45] through the Automated and Electric Vehicles Bill which aims to ensure all chargepoints are smart-enabled, to improve Distribution Network Operator awareness of EV growth, and provide funding for innovations such as V2G technology. The Government Road to Zero report, which sets out its strategy for decarbonising the transport sector, also emphasises the importance of smart and flexible EV charging in moving to a zero-emission transport sector.[46]

[45] Automated and Electric Vehicles Bill (2017-2019), available at: https://services.parliament.uk/bills/2017-19/automatedandelectricvehicles.html

[46] Department for Transport, Road to Zero: Next steps towards cleaner road transport and delivering our Industrial Strategy, July 2018, available at: www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy

Looking ahead

The longer-term impacts of EVs are even more uncertain.[47]

Lower marginal costs of travel may result in more EV activity than expected, possibly shifting people away from traditional public transport in some areas. Growing use of shared vehicles and fleets may mean larger charging connections, with depots seeking to connect in unconstrained areas to reduce impact on the networks. Shared autonomous vehicles could mostly charge at night, when electricity is cheaper, with top-ups during the day. New technologies such as induction charging, and innovations in battery storage may further revolutionise the EV space.

The longer-term uncertainty means that there is a risk of overinvesting in infrastructure that may become underutilised in the face of the changing landscape. However, this must be balanced against the potential benefits of encouraging faster EV uptake by investing in infrastructure ahead of need.

[47] MIT's 'Mobility of the Future' project is examining some of the possible long-term dynamics. See http://energy.mit.edu/energy-research/

Considerations for regulation

The regulatory framework that governs the energy sector was not designed explicitly with EVs in mind. The framework that exists today assumes supply of electricity to a 'premises', not mobile demand that could draw electricity at home, at work, or at potentially thousands of chargepoint locations across the country. The EV transition challenges key industry arrangements such as settlement – how industry balances and settles demand and supply. It also challenges current arrangements for accessing and use of the network.

However, EVs are not the only disruptive technology we are facing. Recent growth in EVs corresponds to a time of unprecedented innovation in the energy sector, and many of these innovations serve to challenge long-established regulations and processes. Ofgem is in the process of taking a more holistic view regarding what regulatory arrangements are appropriate for the future energy system. For example, our Targeted Charging Review is considering fundamental changes to how we recover the costs of building, maintaining and operating electricity networks. Our Future Retail Market Design work is investigating whether alternatives to the current 'supplier hub' model better allow for opportunities for consumers to access and manage their supply in new ways.

We do not seek to explore all of the wider regulatory challenges that will affect the EV market, however there are some regulatory considerations that are particularly relevant to facilitating EV deployment in a cost-effective and equitable way.

Role of network operators

Network companies have strict obligations to maintain an efficient, reliable and safe network. They have obligations to plan for increasing numbers of EVs connecting to their networks, and have been already received funding to do so under the current price control framework (RIIO1). Network companies will play an integral role in enabling and promoting flexibility markets, and rewarding network users for being flexible. Looking to the future, particularly in designing our next round of price controls (RIIO2), we must consider how best to incentivise network companies to create the right conditions for flexible EV charging.

In terms of network investment decisions, these should focus on ensuring our existing networks are used efficiently, and flexibly. Network companies should not expect to use the EV transition as a mechanism to earn revenue for new assets when off-peak capacity can accommodate charging demand.

Efficient investment

Range anxiety is currently a key barrier to uptake,[48] as some consumers are concerned that they may not be able to charge their EV comfortably away from their homes. Roll-out of chargepoint infrastructure is important to stimulate adoption, but there is an argument that the level of charging infrastructure required to alleviate range anxiety may go beyond what is economic and efficient. Vehicle range is rapidly improving, and the charging infrastructure required for today's EVs is unlikely to be the same in even a few years' time. This poses a challenge. In the short term, rolling out infrastructure ahead of need would promote decarbonisation by potentially accelerating EV uptake, but might lead to underutilised assets in the future, and higher costs for consumers. There are also considerations about how to future-proof investment needed today.

[48] PwC, Charging ahead! The need to upscale UK electric vehicle charging infrastructure, April 2018, available at: www.pwc.co.uk

There is a risk that today's infrastructure will not be designed with bi-directional charging capabilities, or automation in mind. As (or if) these technologies progress, this may also lead to costs associated with retrofitting, or asset stranding.

Improving access to EV charging

For EV owners to benefit from EVs, they need a convenient, accessible and reliable way to charge. Energy consumers have a guaranteed right to the supply of electricity and this is enshrined in legislation and regulation. ICE vehicle owners have similar levels of access to fuel through the network of petrol stations, established through market forces.

In an electrified transport sector, access to charging will be equally essential, but access will likely be through a mixture of home and public charging methods. Off-street parking will be an important factor for domestic charging, but this is varied across the UK, with city-dwellers faring the worst; in London, only 48% of households have access to off-street parking compared to the national average of 84%.[49]

Chargepoint operation is currently a competitive market, and market dynamics should generally determine when, where and how EV charging points are built. In some areas, competitive pressures alone may not deliver socially desirable levels of chargepoint infrastructure. For example, as in broadband markets, society may wish to intervene in rural areas to support infrastructure deployment.

Improving access: lamppost charging

Ubitricity

Ubitricity has joined up with OVO to run a trial in London. This involved turning 50 lamp posts into charging points using Ubitricity 'SimpleSockets'. Residents can use their SmartCables to charge their EVs on a lower tariff than most on-street charging options. This improves access to charging infrastructure for those without off-street parking in particular.

Lamp-post charging, which utilises existing infrastructure, is more cost effective and less obtrusive than alternatives and quicker to install as no planning permission is required. With its lower cost, an entire street can be electrified, which avoids the need to designate parking spaces for EVs only - a key barrier to urban charging.

Improving access: P2P platforms

Peer-to-peer (P2P) platforms can improve access to charging by making better use of the existing charging infrastructure.

Zap-Map P2P charging platforms

Zap-Map has launched two P2P EV charging networks (Zap-Home and Zap-Work) to enable charge point owners to share their privately owned devices with other EV drivers. This follows research that shows around half of EV drivers on the Zap-Map network are willing to share their home charge point.

Potential impact

This means up to 60,000 charge points could potentially be available to EV users. This will improve access to charging, particularly for those who don't have access to off-street parking. Market based approaches will enable chargepoint owners to charge a competitively priced fee, and recover their installation costs faster.

[49] PwC, Charging ahead! The need to upscale UK electric vehicle charging infrastructure, April 2018, available at: www.pwc.co.uk

Distributional impacts

EV owners will have access to a wider range of energy products and services than non-EV owners. Under current charging arrangements, the costs and benefits of the EV transition will be unequally distributed across consumers, with lower income households likely to be paying a disproportionate share of the costs. The Index of Multiple Deprivation (IMD) provides a measurement of deprivation across England. To date, EV uptake and chargepoint installation has been significantly lower in areas that are more deprived (Fig. 13). The least deprived decile accounts for more EV chargepoints than any other decile, with the mean EV user in the 7th decile, and the median in the 8th decile - a strong indicator that current uptake is heavily linked to socio-demographic influences.

This raises concerns regarding how system costs are currently allocated. If inflexible charging leads to reinforcement, poorer consumers may reasonably object to paying for system costs associated with EV ownership by predominantly wealthy consumers. However, if EV charging is managed flexibly, all consumers (including those who do not own an EV) should benefit from a more optimised energy system, and avoided reinforcement costs.

There are equitable arguments for adopting a charging regime that ensures costs are imposed on those who create them. For EV users, this can be facilitated by cost-reflective charges for connecting EV chargepoints to the network, and cost-reflective price signals that mean consumers who choose to charge during peak times will pay proportionately for the system costs incurred from their behaviour.

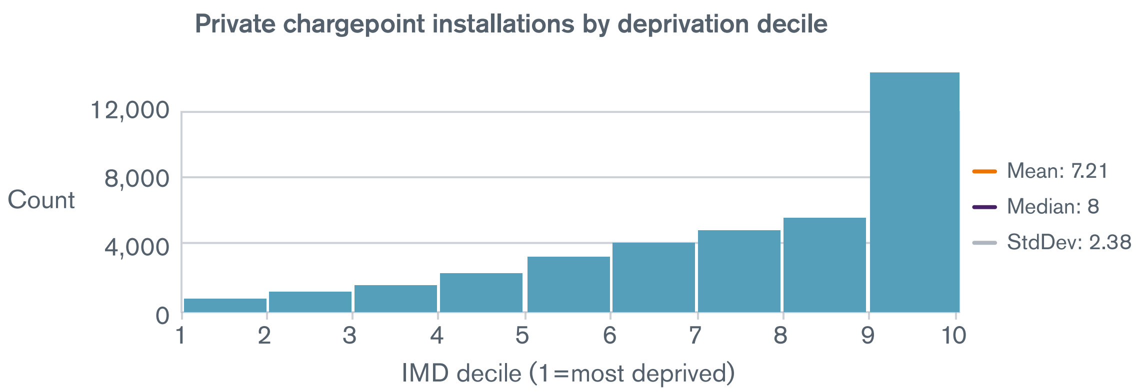


Fig. 13: Relationship between chargepoint uptake and indicators of deprivation[50]

Interoperability

Experimentation and differentiation is a key feature of the early stage of a transition, but it can lead to multiple devices, systems, processes and infrastructure that aren't compatible with one another. For EVs, interoperability issues relate to the compatibility of the technical connections between chargers and EVs, and memberships required to access charge points. Issues around interoperability will become more pronounced as new proprietary data and communication platforms emerge, each potentially communicating with the energy system in isolation, or in inconsistent ways. This risks consumers being 'locked in' to a brand, model, or service. The UK government is legislating to improve industry standards on interoperability through the Automated and Electric Vehicles Bill.[51]

[50] Note – this only includes chargepoints under the Electric Vehicle Homecharge (EHVS) scheme. IMD decile values are aggregated at the Lower Super Output Area (LSOA) level.

[51] This aims to ensure that all publicly accessible charge points are accessed by the widest section of the population.