

The Importance of Charging Infrastructure to the Electric Vehicle Revolution



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The roll-out of charging infrastructure in the UK is critical to the transition to electric vehicles (EVs). The UK charging infrastructure network needs to be expanded quickly, not only to satisfy the rapid growth in EV ownership and driving but also to provide non-EV owners with the confidence to purchase an EV. Charging points need to be in the right place and of the right type, with more offering smart charging and vehicle-to-grid capability. The existing network will be technologically compatible with next generation batteries but needs to be future proofed with respect to charging behaviour.

Introduction

The transition to EVs requires charging infrastructure in the UK that meets consumer needs. Such a network is in the process of being delivered as EV charging demand, patterns of charging and EV usage become clearer. However, for the electrification of transport to occur at the rate needed to meet targets consistent with the UK government strategy,¹ charging points will need to be installed ahead of demand and across the entire UK. The private and public sectors need to work together to deliver this infrastructure and to ensure that drivers have access to reliable charging regardless of the UK region.

EVs and charging infrastructure with vehicle-to-grid (V2G) and smart charging functionality will help to manage UK electricity demand and the UK's increased emphasis on renewable energy. V2G itself could potentially save £3.5 billion per annum in grid and infrastructure reinforcement costs.²

This Insight explores the key issues associated with developing a robust, reliable and extensive charging infrastructure network in the UK. The performance of EV

batteries plays a significant role in determining infrastructure requirements. Larger batteries with more capacity and better battery performance, for example, will increase EV range and so require a less dense charging infrastructure network than would otherwise be the case. Likewise, batteries with increased charging speeds would make it far more convenient to charge EVs on long journeys, resulting in increased demand for public rapid chargers. The Faraday Institution's research into improving battery performance, understanding battery degradation processes and developing next generation battery chemistries will therefore directly influence the characteristics of the UK charging infrastructure network required for the 2030s and beyond.

Different Types of Public Charging Points

Given that EV owners drive and charge their EVs in a variety of ways, a wide range of different types of charging capability and infrastructure has already emerged in the UK. This variety in type and performance can be viewed as confusing by consumers, businesses and investors, so charging point technology is increasingly becoming standardised. The Office for Zero Emission Vehicles (OZEV), for example, recently defined a minimum technical specification for workplace charging and classified charging points into eight different

¹ HM Government (March 2022). Taking charge: the electric vehicle infrastructure strategy.

² Ofgem (2021). Case study (UK): Electric vehicle-to-grid (V2G) charging.

types.³ These definitions are likely to shift over time as the market develops and technology improves.

Descriptions of public charging points targeted at allowing EV consumers to make charging choices vary considerably by operator, but typically use more aggregate categories than the eight OZEV workplace definitions. Table 1 provides one example, where four categories are used depending on the charging rate: slow, fast, rapid and ultra-rapid.

Table 1: Characteristics of different types of public charging infrastructure

Type	Power	Typical charging time
Slow	3-7 kW (AC)	7-16 hours
Fast	11-22 kW (AC)	2-4 hours
Rapid	50-100 kW (DC)	30-40 mins
Ultra-rapid	100+ kW (DC)	10-20 minutes

Source: Transport & Environment (January 2020). Recharge EU

Slow chargers tend to be used at home or workplace locations, where consumers don't mind charging over many hours, with charging often taking place overnight or during periods of off-peak electricity demand. Fast chargers are common in locations where drivers are likely to park for a couple of hours, such as supermarkets, shopping centres, leisure venues, leisure centres, hotels, airports, railway stations, general car parks and park and ride schemes. Charging points are also classed as either direct current (DC) or alternating current (AC). Batteries can only be charged using DC, but as electricity supplied through the national grid is AC, the electricity supplied is converted by a rectifier.

Rapid and ultra-rapid charging is critical to the effectiveness of the UK's future charging infrastructure, enabling longer and quicker journeys. But rapid charging reduces battery life through battery degradation. Faraday Institution research is looking at improving cell chemistries and thermal management systems to help mitigate this issue.

When driving long distances, EVs need to be charged during the journey, which means there is a need for even faster chargers commonly known as rapid chargers and ultra-rapid chargers. These chargers deliver power faster, but at much higher tariffs, and are typically found at motorway service stations. Customers are willing to pay a premium to save time and alternatives have often been limited, although opportunities have recently been identified to "open up and increase charging competition within motorway services".⁴ Rapid charging also enables delivery vans to spend more time on the road or driving between sites than fast charging.

³ Workplace charging scheme: minimum technical specification (March 2020).

⁴ Competition and Markets Authority (July 2021). Electric vehicle charging market study.

⁵ HM Government (2022). Vehicle licensing statistics: April to June 2022.

⁶ HM Government (October 2021). Net Zero Strategy: Build Back Greener.

⁷ Department for Transport (April 2022). Technical Consultation on Zero Emission Vehicle Mandate Policy Design.

⁸ Zap-Map EV charging stats to September 2022.

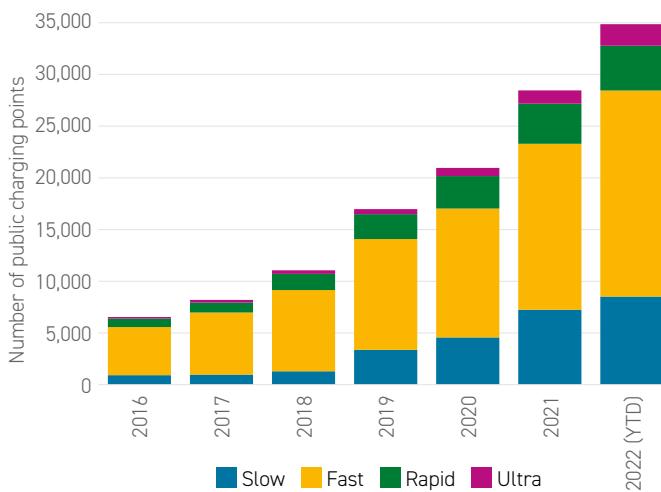
The specified power of a charger is directly proportional to the voltage and current of the supplied electricity. Increasing the power by increasing the current requires thicker cables, which limits the maximum viable charging rate. On the other hand, increasing the voltage enables faster charging without increasing the cable thickness. Most cars currently operate with 400V battery packs but newer models, such as the Porsche Taycan and Hyundai IONIQ 5, are entering the market with 800V battery packs that offer increased charging speeds with ultra-rapid chargers.

Key Characteristics of the UK's Public Charging Infrastructure

Transport in the UK is becoming electrified at a considerable rate with 492,000 BEV and 361,000 plug-in hybrid cars already on UK roads in 2022.⁵ By 2030, around 24% of the total car fleet in the UK is expected to be made up from zero emissions vehicles (ZEVs)⁶ with a minimum of 80% of all new UK car sales expected to be ZEVs.⁷

The UK charging infrastructure network is also growing at pace. At the end of August 2022, there were around 400,000 charging points installed at home and workplace locations in the UK, with a further 35,000 charging points across 21,000 public charging locations.⁸

Figure 1: UK public chargers by speed

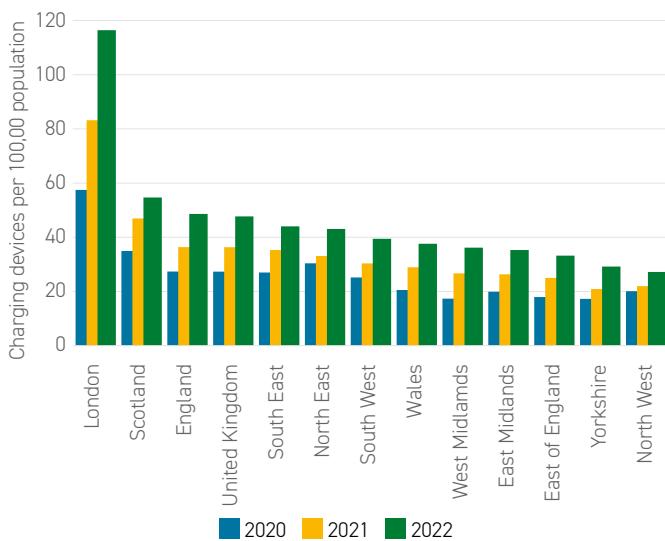


Source: Zap-Map (YTD: to end September 2022). Numerical data for figures.

There is a wide variation of charging point coverage across the UK. Charging infrastructure is currently disproportionately established in regions where there is both high population density and high rates of EV adoption, such as London and the South East (Figure 2). Scotland is a notable exception with high levels of infrastructure per head of population despite having a lower population density. Regions such as the North West, Yorkshire and the East of England, as well as Northern Ireland, need attention to increase the number of chargers per head of population.

Coverage is more concentrated on motorways and key roads. Around 97% of the strategic road network now has a rapid charging point every 20 miles.⁹ The rural population is, however, substantially less served by public charging points. The economics of making charging infrastructure affordable but profitable in rural areas is challenging and so the public sector will need to lead initiatives to establish a network that enables EV uptake for all. Lessons could be learnt from the deployment of broadband in rural areas to understand how the government and the private sector successfully worked together.

Figure 2: Publicly available EV charging devices by UK region (2020-22)



Source: [Electric Vehicle Charging Device Statistics, Department for Transport \(July 2022\)](#). Numerical data for figures.

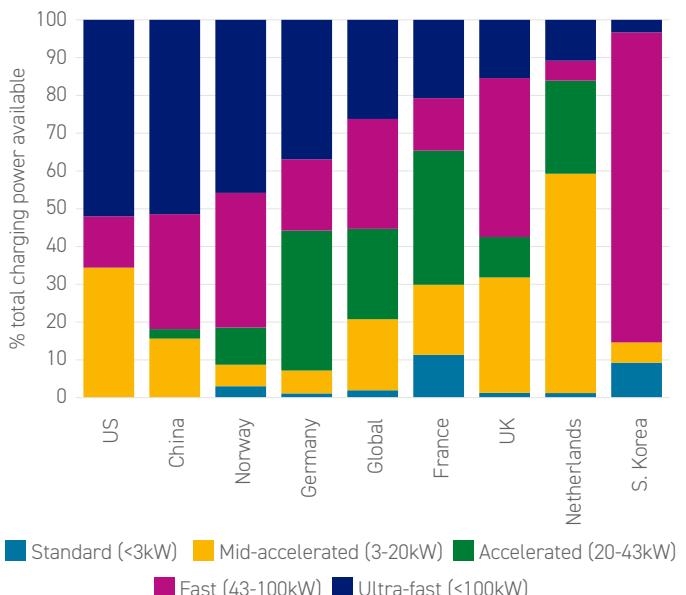
Charging infrastructure is increasing across the world to keep pace with the uptake of EVs and demand for charging outside the home. The number of public chargers reached 1.8 million globally in 2021, with China accounting for 63% of the market followed by Europe with 23%.¹⁰ Whilst slower chargers (<20kW) make up the majority of public charging networks, relatively more power is delivered through faster chargers (Figure 3). For example, in the UK 100kW+ chargers accounted for 3% of charging points but delivered 15% of EV energy demand.

Future Projections of the Public Charging Infrastructure Requirements

A future public charging infrastructure network that is affordable, efficient and reliable is vital to the take-up and use of EVs, as it will enable EV drivers to charge quickly and to undertake longer journeys and give assurance to consumers looking to purchase their first EV.

Around 10 million zero emission cars and vans are expected to be on the road in the UK by 2030, with an associated

Figure 3: Public chargers by power category by key countries (2021)

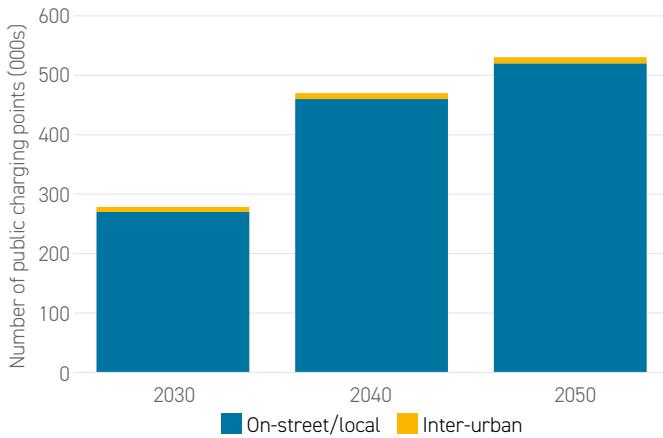


Source: BNEF (2022). Global EV Public Charging Update.

requirement of between 280,000 and 720,000 public charging points.¹¹ The wide range in the estimates of the level of future infrastructure required reflects the uncertainty in future consumer preferences and charging behaviour. Other studies, for example, suggest that between 148,000-285,000¹¹ and 375,000-500,000¹² public charging points will be required by 2030, with the Climate Change Committee estimating that around 525,000 UK public charging points will be needed by 2050 (Figure 4).

Similar network density is needed in Europe with between 2.3 million¹³ and 4.5 million¹⁴ public charging points estimated to be required by 2030, with an associated investment of around US\$34 billion.¹³

Figure 4: Public chargers required over the 2030-50 period



Source: Climate Change Committee (December 2020). The Sixth Carbon Budget Methodology Report. Numerical data for figures.

⁹ Arup Report, Creating a sustainable future for the strategic road network in England.

¹⁰ BNEF (2022). Global EV Public Charging Update.

¹¹ Climate Change Committee (December 2020). The Sixth Carbon Budget Methodology Report (Table 2.3).

¹² Transport & Environment (January 2020). Recharge EU: How many charge points will Europe and its member states need in the 2020s (under the Road2Zero scenario).

¹³ BNEF (June 2022). Electric Vehicle Outlook 2022.

¹⁴ Bernstein (August 2021). Electric Revolution 2021.

The UK Government is playing its part in delivering the future charging infrastructure network, with the ambition to ensure "the UK's charging infrastructure network is reliable, accessible, and meets the demands of all motorists".¹⁵ Of the £2.5 billion of Government funding committed to the EV transition since 2020, over £1.6 billion will be used to support charging infrastructure. Initiatives include the £450m Local EV Infrastructure Fund, which will provide capital and resource funding to support local authorities to work with industry and transform the availability of charging infrastructure for drivers without off-street parking, and a £950 million Rapid Charging Fund to support the rollout of high-powered chargers on motorways and major A roads.¹ These initiatives continue the support and intervention that the UK Government has been providing to the charging infrastructure industry since 2011.¹⁶

Other bodies are also supporting the development of charging infrastructure. National Grid is implementing a plan for 95% of drivers to be within 50 miles of the 50 strategic motorway service locations.¹⁷ Investment to ensure that local grid connections are resilient to the new energy charging requirements is also underway.¹⁸ There is a significant market opportunity for charging point operators (CPOs) to build up a mass-market customer base and exploit economies of scale. The installation and operation of the chargers will require

an investment of about £16.7 billion in the UK by 2035,¹⁹ not including the additional investment each year required for maintenance and repairs.

Improvements to charging infrastructure that may facilitate a change in consumer charging behaviour include the emergence of rapid charging stations, smart charging with flexible tariffs and the use of V2G²⁰ to offset peak surges in electricity demand from the grid. Whilst there will be benefits to both consumers and providers in utilising these technologies, both affect battery degradation. Degradation can lead to premature failure, decreased performance, product replacement and retirement, with associated economic and environmental costs.

Consumer Attitudes to UK Charging Infrastructure

The perception of the quality, scope and availability of the UK's charging infrastructure is one of the major influences behind the decision to purchase an EV, motivated largely by concerns about the driving range of EVs.

Many consumer surveys cite a perceived lack of public chargers as a barrier to purchasing an EV.²³ A review of 45 surveys found that nearly all of them identified range anxiety and the inability to complete any journey as conveniently as with a petrol or diesel vehicle as a key barrier to EV take-up.²⁴

Box 1: Charging behaviour and battery degradation

Battery degradation can lead to premature failure, safety issues, decreased performance, product replacement and retirement, with associated economic and environmental costs. Charging behaviours (for example, repeated use of rapid chargers, repeatedly depleting the entire battery capacity or storage at high states of charge for long durations) affects the rate of battery degradation. Degradation rates also depend upon charging conditions including temperature, charge current magnitude, cycle frequency and state of charge (SoC).

Temperature and battery voltage will be controlled by the onboard vehicle battery management system (BMS), whilst the cycle frequency and SoC is pertinent to driver behaviour and the type of charger used. For example, battery life can be increased if the SoC target is at a lower value (i.e. <80% instead of 100%), or the time at high SoC is minimised.

The charge rate (C-rate) is the rate at which a battery is fully charged or discharged. Rapid charging will impact the C-rate and numerous studies²¹ have identified a

relationship between higher C-rate and accelerated battery degradation, where a C-rate greater than 1 contributes to increased capacity loss. The charging rate impacts degradation more than discharging, with more stress on the battery arising from rapid charging compared to slow charging. At a higher C-rate, a large number of lithium ions rapidly accumulate on the electrode reaction surface. This causes the mass transfer of lithium ions to be a diffusion-limiting step,²² which can also lead to irreversible reactions and further safety concerns.

The frequent use of rapid charging proportionally increases the likelihood of accelerated degradation through increased stress on the battery. As a result, automotive manufacturers advise against the frequent use of rapid chargers in order to prolong battery life.

Through increased investment across R&D programmes, cell chemistries will evolve, and thermal management systems will improve (reducing temperature increases during rapid charging), such that battery degradation from rapid charging is expected to become less significant as technology matures.

¹⁵ HM Government (October 2021). Net Zero Strategy: Build Back Greener.

¹⁶ Office for Low Emission Vehicles (June 2011). Making the Connection: The Plug-In Vehicle Infrastructure Strategy.

¹⁷ National Grid. Electric Vehicle Charging. Enabling the Switch.

¹⁸ Ofgem (May 2022). Changes to charging: How Ofgem is preparing for a very different grid.

¹⁹ SMMT (September 2020). Billions invested in EV range but nearly half of UK buyers still think 2035 too soon to switch.

²⁰ Vehicle-to-grid (V2G) is a bi-directional service where owners can plug in their battery-powered vehicle and energy from the onboard battery pack can be transferred back into the grid. This can collectively provide the grid with a surplus amount of energy capacity that can be managed to deal with spikes in demand during peak times or as an emergency backup. Car owners are compensated for allowing their EV batteries to be used to support the grid.

²¹ Preger et al. (September 2020). Degradation of commercial lithium-ion cells as a function of chemistry and cycling conditions. *Journal of Electrochemical Society* 167 120532.

²² Chen et al. (March 2020). Li-Ion battery performance degradation modelling for the optimal design and energy management of electrified propulsion systems. *Energies* 13(7). 1629.

²³ Mobility Insights Report (February 2021). EVs and Sustainability Edition.

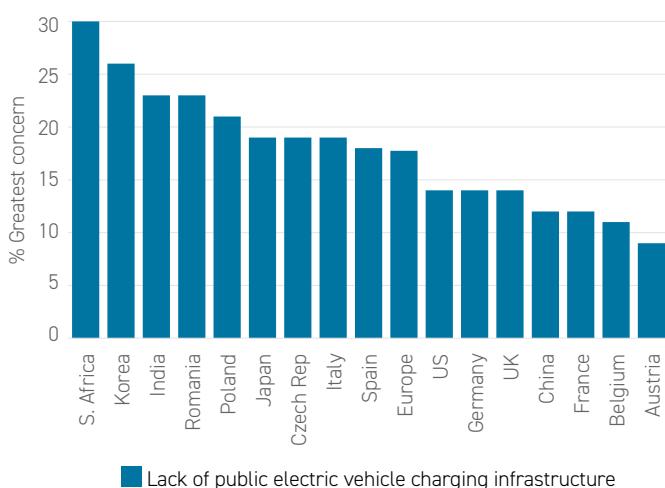
²⁴ PWC (May 2019). Consumer Research into Rapid Charging. PwC Strategy, commissioned by National Grid.

Although range awareness often replaces range anxiety after EV adoption, concerns are particularly acute for people without off-street parking. A 2021 study of drivers without off-street parking found that two-thirds of these respondents cite the inability to access an EV charging point as a key barrier.²⁵ For people not expecting to purchase an EV in the next year, the main reasons cited were cost (72%), availability of charging points (47%) and EV reliability (18%).²⁶ Accessibility for disabled users of public chargers, particularly on-street infrastructure, is also a concern according to interviews with key market players.²⁷ The development of a new BSI standard for accessible charging of EVs will start to address these barriers.²⁸

Consumer perceptions of ownership can be different to experience. EV owners' concerns are much more specific, related to maintenance, availability and location of charging stations. The distance to chargers and the time taken to charge are of relatively less concern.²⁹ EV drivers cite preparation and routine as key to EV ownership. Common practices include topping up charge often, full charging once a week and planning to use public charging points at less busy times.²⁵

Concerns about EV infrastructure are fairly common across European and other countries (Figure 5). Of those intending not to purchase an EV, the greatest concern across the selected countries was public charging infrastructure (17%) on average for Europe compared to the UK (14%).³⁰ Other key concerns from European consumers included driving range (20%) and purchase price (18%).

Figure 5: Concerns with charging infrastructure and driving range by country



Source: 2022 Global Automotive Consumer Study, Deloitte.

²⁵ Britain Thinks (2022), Public Electric Vehicle Charging Infrastructure: Deliberative and quantitative research with drivers without access to off-street parking.

²⁶ ONS (October 2021). Opinions and lifestyle survey: electric vehicles.

²⁷ Motability & Ricardo (2020). Electric vehicle charging infrastructure for people living with disabilities.

²⁸ BIS (March 2022). Consultation open for new standard seeking to ensure accessibility of EV public charging.

²⁹ Northern Ireland Assembly (June 2021). Electric and ultra-low emission vehicles: public survey results

³⁰ Deloitte (March 2022). 2022 Global Automotive Consumer Study (EMEA and Global Focus Countries).

³¹ National Travel Survey, Department for Transport.

³² Renewable Energy Association (2019). REA Position Paper. The interoperability of public EV charging networks in the UK.

³³ National Infrastructure Commission (September 2021). Rolling out charging infrastructure to enable 100 per cent electric new car and van sales by 2030.

³⁴ Coleman, Herron, Watson (2022). A longitudinal study of electric vehicle charging behaviours in an urban environment.

³⁵ The Electric Vehicles (Smart Charge Points) Regulations 2021.

³⁶ PWC (April 2018). Charging ahead! The need to upscale UK electric vehicle charging infrastructure.

³⁷ Ofgem (2021). Consumer Survey 2021 – Electric Vehicles.

³⁸ DfT (April 2022). Electric Vehicle Charging Research. Survey with electric vehicle drivers.

Although concerns about range are common, long journeys by car are fairly infrequent. Around 99% of journeys by private car are less than 100 miles, with 87% of distance travelled taking place during car trips of less than 100 miles.³¹ Providing potential EV owners with this information on how EV batteries are able to largely fulfil the current patterns of use will be key to driving EV take-up.

Another common complaint by EV drivers is that there are currently too many different connectors and charging types. The importance of interoperability was emphasised by the Renewable Energy Association (REA), which concluded that mass adoption depends on the charging industry and government collaborating and embracing common protocols and standards.³² The National Infrastructure Commission also advocated the government should set minimum standards for a network of interoperable smart charging points.³³ Significant consolidation in standards has recently taken place, with the Combined Charging System standard now being included on all new plug-in models for example, with other connectors (e.g., the CHAdeMO charging standard) in the process of being phased out.³⁴

The Automated and Electric Vehicles Bill 2018 standardised the requirements for public and private charging points. This and the compatibility of public charging points, and standards for payment and reliability, should all help to address consumer demands. More recent regulations on smart functionality for private charging points, with protection around grid stability, cyber and data security and interoperability, further support the development of the UK charging infrastructure fit for the future.³⁵

The Role and Importance of Home Charging

Around 78% of homeowners who are vehicle drivers have access to off-street parking³⁶ and so a substantial proportion of charging is expected to continue to occur using home chargers, with relatively more energy delivered per year via each home charger compared to non-home chargers. Charging at home takes longer but is convenient and low cost. There is still some uncertainty and difference in opinion about how home charging use will change over time. For example, Ofgem's consumer survey found that 59% of EVs owners 'usually' charged their vehicle at home at present³⁷ whereas a DfT survey found 78% and 52% of EV drivers said they 'regularly' (i.e. once a week or more often) charged overnight and in the daytime respectively.³⁸ Furthermore, BNEF estimated that by 2040, around 65% of electricity demand for EVs could be delivered outside the home by the public charging network, even though public chargers are

only expected to account for 13% of charging points.³⁹

Currently, most EV owners opt to install a 3-7kW home charger as their dedicated home charging point, which can be installed for around £750-£1000.⁴⁰ Charging with a standard single-phase home UK 3-pin plug can be performed on compatible models but is very slow. A Tesla Model 3 would, for example, take 24-36 hours to charge from 20% to 80% capacity with a standard home plug compared to 10 hours using a dedicated slow charger.

It is estimated that more than 25% of households (6.6 million homes) in Great Britain do not have access to off-street parking.⁴¹ This issue is particularly acute in major cities, such as London. Among EV drivers who do not charge at home, 36% said that it was not possible to install a home charger, 28% said the installation cost was prohibitive and 19% were not sure how to install one.⁴² Dedicated on-street charging points are increasingly being provided by local authorities. This mitigates the problems involved in people running cables from their homes across pavements, which creates trip hazards and liability issues. OZEV offers grants to local authorities to encourage the installation of on street parking, such as the On-street Residential Chargepoint Scheme,⁴³ which covers up to 75% of the costs of the charging point and parking bay, and the Local EV Infrastructure Fund, which will provide capital and resource funding to support local authorities.⁴⁴

Box 2: Why are home chargers not rapid charges?

Rapid chargers are not used for home charging because they are expensive and need to deliver very large currents, which would require a 3-phase plug and thicker power cables to be installed to tap into the grid. There is also less of a consumer need for rapid charging at home, as a slow charger can be used overnight to fully charge an EV.

Charging points also need to convert AC to DC using a rectifier but charging at faster rates requires much more expensive high wattage rectifiers. An alternative to using a rectifier is a charging point that supplies the vehicle with high voltage DC, but these are even more expensive to build and operate than rapid chargers and are therefore less common.

Energy Supply, the National Grid and Bilateral Charging

The electrification of transport and heating of homes could lead to a doubling of demand for electricity in the UK by 2050.⁴⁵ Flexibility in how the future net zero grid will operate

will be essential, especially given that generation will be more weather dependent, with new opportunities for flexible demand management.⁴⁶

Increased demand from transport could be mitigated, for example, through smart charging (Box 3) and vehicle-to-grid (V2G) applications, which reduce and shift energy demand. National Grid's Future Energy Scenarios suggest that peak energy demand could be reduced by 32 GW⁴⁷ through the use of these applications, so that EV adoption would increase peak energy demand by only 7 to 16 GW by 2050. V2G applications mean that EV batteries will become a substantial energy source in their own right, responding to the needs of the electricity grid by supplying services to the National Grid system operator at periods of high demand.

Global electricity demand is expected to increase by 5% by 2030 and 25% by 2050 as a result of the transition to EVs.¹⁴ V2G applications or bidirectional charging capability is an important part of the future EV business model and will increase the resilience of the UK energy system.

Upgrades to the electricity grid will also be necessary particularly in reinforcing local distribution networks where EV demand is likely to be high. In the UK, nearly £1 billion has been made available through the Rapid Charging Fund⁴⁸ to support the upgrading of the grid at strategic locations. More generally, Ofgem's Green Recovery Scheme is facilitating £300 million of investment in upgrades to the electricity network for low carbon development.

If half of the EVs on the road in the UK in 2030 were V2G compatible, around 16 GW of daily flexible grid capacity could be provided.² Estimates of the financial returns for each consumer from using V2G technology vary considerably by circumstances but could be worth around £436 each per annum.⁴⁹ However, the financial and economic benefits provided by EVs supplying energy to the grid needs to be balanced against the impact on battery degradation (Box 4).

Will the UK's Charging Infrastructure Network be Future Proof?

All current charging points should be capable of charging future battery chemistries, such as next generation lithium-ion, solid-state, lithium-sulfur and sodium-ion. The public charging network is likely to be fit for purpose to cater for trends in batteries with greater energy storage and/or longer range.

Future low-cost EVs with short ranges will have similar charging requirements to current luxury EVs and so will be compatible with current charging infrastructure. However, batteries cannot be charged at a faster rate than the

³⁹ BNEF (August 2021). Electric Vehicle Charging Infrastructure. What's in Store for 2040.

⁴⁰ PodPoint. The complete guide to the Tesla Model 3, 2022.

⁴¹ Field-Dynamics (June 2020). As fleets go electric, nearly 25% of drivers don't have anywhere to charge them.

⁴² Deloitte (March 2022). 2022 Global Automotive Consumer Study (EMEA).

⁴³ OZEV (April 2022). On-street residential chargepoint scheme guidance for local authorities.

⁴⁴ OZEV (April 2022). Apply for local electric vehicle infrastructure (LEVI) pilot funding.

⁴⁵ BEIS & Ofgem (July 2021). Transitioning to a net zero energy system.

⁴⁶ Energy Systems Catapult, The Faraday Institution and TNEI (April 2022). A Zero Carbon Energy System: The Operability Challenge.

⁴⁷ National Grid (July 2021). Future Energy Scenarios.

⁴⁸ Office for Zero Emission Vehicles (September 2021). Rapid charging fund.

⁴⁹ Element Energy (June 2019). V2GB: Vehicle to Grid Britain.

Box 3: The importance of smart charging

The projected increase from EV charging presents a particular challenge to the National Grid electricity system operator and local networks because charging tends to cluster around times of peak electricity demand. Initial pilot studies have revealed that a significant portion of EV charging commences between 5 pm and 7 pm, when large numbers of people return home from work.⁵⁰ Without action to offset this increase in peak demand, increased take-up of EVs will require considerable increases in both electricity generation capacity and reinforcement of the electricity network.

Many of the home chargers that have already been installed in the UK are so-called 'dumb' or non-smart chargers, which charge immediately when the car is plugged in.⁵¹ However, the need for additional electricity generation could be substantially reduced by the introduction of smart chargers. Large system costs can be reduced by smart charging as changing demands on the electricity network can be managed by using price signals to shift charging from the peak to periods of lower demand (e.g., overnight).

The use of smart charging for EVs is likely to reduce consumer bills.⁵² EV drivers can benefit directly by being able to charge their vehicle when prices are low and wider electricity consumers would benefit from avoiding the need to build new generating and grid capacity. However, at present non-smart chargers are much cheaper (< £450, including installation) than smart chargers (> £650, including subsidisation with an OZEV grant), but these costs are expected to decline as the technology matures.

In 2021, the Government introduced The Electric Vehicles (Smart Charge Points) Regulations⁵³ mandating that new charging points have smart functionality. Such smart chargers need to be able to send and receive information via a communications network and respond to that information by either increasing or decreasing the rate of electricity flowing through the charging point or changing the time at which electricity flows.⁵⁴

maximum rate of a given charger and some future batteries will be able to store larger amounts of energy than at present. For example, EVs that can drive distances of 500 miles or more, and vans and future luxury SUVs, may require battery packs with much greater energy storage than is presently commercially available. Longer charging times may therefore be required, or the demand for chargers with faster rate capabilities and higher voltages may be greater, but the basic technology of charging points will not need to be changed.

⁵⁰ Department for Transport (July 2021). Electric Vehicle Smart Charging.

⁵¹ What is a dumb EV charger? Is it all you need?

⁵² BEIS & Ofgem (July 2021). Transitioning to a net zero energy system. Smart Systems and Flexibility Plan 2021.

⁵³ The Electric Vehicles (Smart Charge Points) Regulations 2021.

⁵⁴ Department of Transport and OZEV (December 2021). Electric vehicle smart charging.

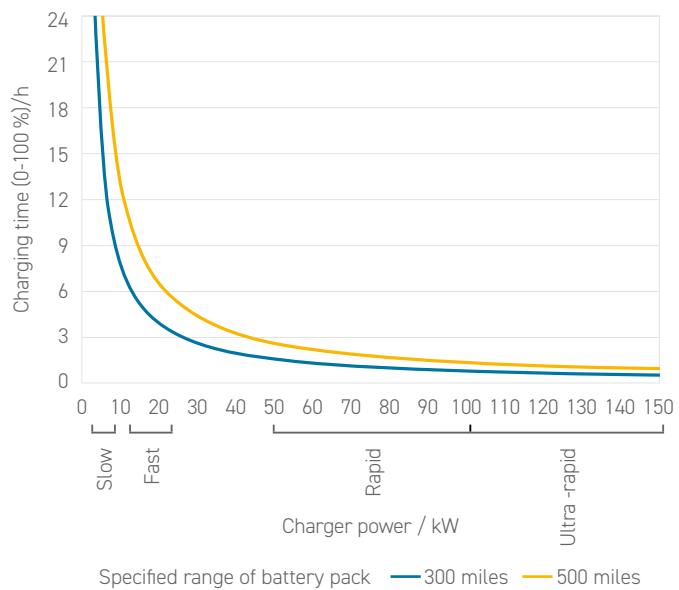
⁵⁵ In reality, such curves are specific to the particular vehicle under consideration. For illustrative purposes, we have assumed a (city + motorway) combined efficiency of 25.9 kWh/100 miles based on reported values for a 2019 Tesla Model 3 Long range EV and hypothetical battery packs of 77.7 kWh & 129.5 kWh. See PushEVs article [Electric car range and efficiency](#).

Whilst the currently installed charging infrastructure will be viable for future longer-range batteries, driving behaviour may change. With a rapid charger, for example, the battery pack is initially charged very quickly but the rate of charging is decreased as the battery approaches full charge to minimise accelerated degradation. EV drivers could therefore change their behaviour as battery packs with greater energy storage are introduced, by taking multiple short stops on a given journey to partially charge, rather than stopping once to fully charge.

In terms of the home charging network, the current home charging infrastructure will generally be suitable for the vast majority of EV driver behaviour. However, EV drivers who typically want to drive very long distances of more than 300 miles and prefer to use their home charger instead of the public charging network, may need faster chargers to be installed. An EV with a battery capable of storing the energy needed to drive 300 miles would take around 24 hours to be charged with a standard 3-pin UK plug.

The charging times with different charger powers are compared in Figure 6 for two EVs with hypothetical driving ranges of 300 miles and 500 miles respectively.⁵⁵ An EV with a battery capable of storing the energy needed to drive 300 miles would take around 12 hours to fully charge with a standard dedicated home charger (7 kW), whereas a battery capable of 500 miles would take around 19 hours. Whilst around 99% of journeys by private car are less than 100 miles, the roll-out of dedicated home chargers (rather than the standard home plug) will clearly be essential for the small percentage of people who regularly travel long distances.

Figure 6: Minimum time required to charge hypothetical battery packs with different maximum driving ranges



Source: The Faraday Institution. Numerical data for figures.

Box 4: Bidirectional charging (vehicle-to-grid) and battery degradation

The viability and consumer acceptance of V2G systems will be influenced by the effects it will have on EV battery degradation and therefore battery life. Views on battery degradation were covered in a trial (Project Sciurus)⁵⁶ to assess the technological and business cases of V2G in the UK. Degradation was a major concern prior to the start of the trial but after participants used V2G-capable chargers for 12 months, the concerns were significantly reduced.

The literature on the impact of V2G on battery degradation is evolving. For example, Wang⁵⁷ (2016) concluded that if V2G was only used on days of highest grid demand (20 days per year), there would be an inconsequential increase in battery degradation. Conversely, Dubarry⁵⁸ (2017) discussed how using V2G systems will lead to a higher cycling frequency, which is detrimental to lifetime.

A modelling illustration of the financial impact of V2G services shows that the use of V2G applications could initially outweigh the cost of degradation (Figure 7). The dotted black line shows the net profit of V2G (revenue earned utilising V2G minus costs from battery degradation) is initially positive because the cost of degradation will increase over time due to accumulated battery use. Degradation leads to increasing capacity reductions that will shorten the battery lifetime, as well as reduce the storage available to the grid and thus reducing potential revenue. However, current business models are not designed for bi-directional charging and the assumed constant revenue value is an oversimplification. This is because the value from firm frequency response (FFR); where the plugged-in car can quickly provide energy to balance the grid and avoid power outages, will drop as EV penetration increases and market saturation is reached⁵⁹, resulting in a decreasing contribution and therefore, revenue value over time to the car owner.

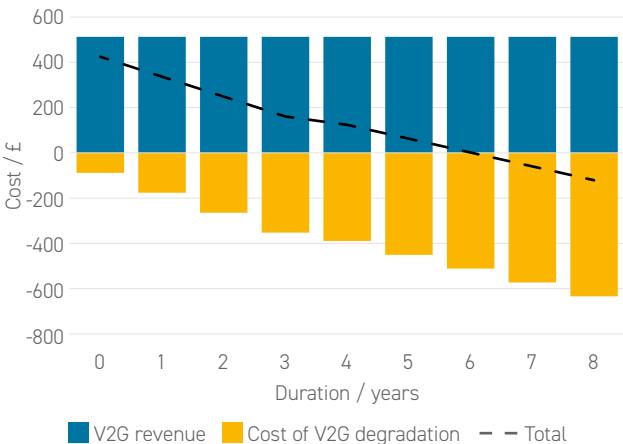
Limited real-world data is available due to the limited time this evolving technology has been on the market. Different experimental data, degradation models and input values are often used in studies, which partly explains the varying conclusions on the impact of V2G. Findings from the Faraday Institution Degradation project⁶⁰ can expand understanding to help identify a suitable degradation model. This highlights the need for a unified understanding

of degradation mechanisms and modelling parameters, especially given the difference in battery stress factors and duration between driving and V2G services. Driving, for example, typically draws around 100kW of peak power over 20 minutes compared to V2G discharging, which would draw around 7kW over 240 minutes.

The use of optimised intelligent V2G systems and two-way controllers could prolong battery life by reducing degradation that occurs when the battery is kept at a high state of charge (80-100%). Intelligent load management can be used to help balance supplying additional grid capacity via V2G without incurring additional degradation. For example, it could be controlled to only cycle the battery with a SoC in the 30-70% range. This could potentially improve battery longevity due to limiting the time left at an idle high SoC. A validated battery ageing model by Uddin⁶¹ (2017) was integrated into smart grid algorithms and showed a 6% reduction in battery capacity fade. Validation of numerous cell types, usage cases and battery management systems will be required.

Further research on V2G degradation effects and driver behaviour research will be needed to help support the implementation of an optimised smart grid and to maximise the viability and benefits of V2G applications.

Figure 7: Calculated revenue and degradation costs from V2G services



Source: The Faraday Institution, BNEF, CENEX.⁶²
Numerical data for figures.

⁵⁶ Cenex (2021), Project Sciurus Trial Insights. A trial involving OVO Energy, Cenex, Indra and Nissan.

⁵⁷ Wang et al., Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services, Journal of Power Sources, volume 332, 2016, pages 193-203.

⁵⁸ Dubarry et al., Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis, Journal of Power Sources, volume 358, 2017, pages 39-49.

⁵⁹ Element Energy (June 2019), V2GB: Vehicle to Grid Britain.

⁶⁰ Faraday Institution degradation project website.

⁶¹ Uddin et al., On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system, Energy, volume 133, 2017, pages 710-722.

⁶² Revenue value is assumed constant using an optimised V2G+ firm frequency response prediction on a 40kWh battery (CENEX 2020). Degradation is from V2G only and is calculated at a cost of £367 per kWh lost (BNEF 2021) due to grid services and excludes driving degradation or the cost of the charger. There is a 0.6% state-of-health (SOH) drop for every 12,500km for the first 50,000km and then a 0.6% SOH drop per 30,000km thereafter. An annual driving distance of 12,500km is assumed. The SOH refers to the percentage difference between a tested battery and a virgin battery capacity. Typically, battery replacement should occur when the SOH drops below 80%.

Conclusion

Developing a robust and resilient UK charging infrastructure will help to accelerate the transition to EVs. Improved perceptions and experience of using the charging network will reduce range anxiety. Currently, the charging infrastructure varies across the UK and the roll-out needs to be accelerated outside London and the South East, with intervention particularly needed in rural areas.

EV drivers have choices regarding where to charge and the type of equipment to use. These choices will determine the equipment split by type and the frequency of use will define the business case and the infrastructure landscape. The characteristics of the future charging infrastructure network (home, work, transit) will be determined by the charging preferences of the consumer (slow, fast or rapid). The performance of EV batteries will, however, influence these choices, as will a better understanding of the impact of rapid charging, smart charging and V2G applications on battery life. Using rapid charging, for example, has to be balanced against the impact on the battery, as continued rapid charging will decrease capacity and battery life.

Battery performance will also directly influence the characteristics of the charging network. EV batteries with longer ranges will reduce the demand for charging during transit, while improvements in battery chemistries that enable rapid charging without as much battery degradation will facilitate wider demand for rapid chargers.

Battery performance is likely to have less of an impact on the extent to which people charge at home, as this is driven by convenience, cost and access to a charger. Actions to improve the benefits of home charging include:

- Setting open data and software standards for home charging points.⁶³
- Making data on the EV battery SoC available to third parties, such as electricity service providers and data aggregators, to help manage the demand response of EVs.⁶⁴

V2G applications are at an early stage of technological deployment, but the impact V2G has upon battery degradation needs further research and monitoring as it will influence the viability of the V2G service, the ability of the grid to deliver electricity to the growing number of EVs, and stakeholder acceptance. Increased understanding of degradation and confidence around charging behaviour will not only incentivise the use of V2G applications but also the implementation of smart charging, which is also needed to maximise the uptake of EVs.

The capacity of batteries is increasing to cater for people who want to drive longer distances, whilst driving range is also increasing for a given battery capacity. However, current public charging infrastructure including rapid and fast chargers should also be fit-for-purpose for these longer-range batteries.

⁶³ Competition and Markets Authority (July 2021). Electric vehicle charging market study.
⁶⁴ Transport & Environment (January 2020). Recharge EU.

About the Faraday Institution and Faraday Insights

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis, and early-stage commercialisation. We bring together academics and industry partners in a way that is fundamentally changing how basic research is carried out at scale to address industry-defined goals.

Our 'Faraday Insights' provide an evidence-based assessment of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government. If you would like to discuss any issues raised by this "Faraday Insight" or suggest a subject for a future Insight, please contact Stephen Gifford.

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