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The UK Government published its “Clean Growth Strategy: Leading the way to a low carbon future” on 12 October 2017. It outlines how the UK plans to lead the world in cutting carbon emissions to combat climate change while driving economic growth.

Integral to the strategy is accelerating the shift to low carbon transport, including ultra low emission vehicles (ULEVs), the vast majority being plug-in hybrid electric vehicles or pure electric vehicles.

The UK Government is supporting the transition to EVs through funding and policy. This includes a proposed ban on the sale of petrol and diesel cars from 2040 and a range of financial incentives to kickstart the transition. In parallel, the automotive industry is bringing out a number of electrified vehicles which will cater to a wide range of consumer preferences and needs, thus further driving demand. Several major automotive manufacturers have announced that all of their vehicles will be electric or hybrid by 2020.

Energy Systems Catapult considers that no single technology is the answer to decarbonisation, and that a “whole energy systems approach” is the most effective way to reduce emissions. The use of EVs will be a key part of this approach and could potentially have significant implications for the support infrastructure including the transmission and distribution networks.

The purpose of this report is to highlight the effects of EV uptake on the electricity network and recommend how to avoid network capacity constraints impeding the roll-out of EVs. It is likely that the uptake of EVs will cause local shortfalls in electricity network capacity without investment2 within the RIIO2 Transmission and Distribution price controls. However, the current regulatory environment combined with investor pressure can curb transmission and distribution network operators’ ability and desire to invest.

"If these challenges are not addressed, the uptake of EVs will impact the UK’s electricity networks as they were not designed to cope with these additional, and significant, demands."

Executive summary

As households with off-street parking are expected to make up most short to medium term adopters of EVs, this report focusses on this scenario. Home-based charging, from analysis of travel patterns, property characteristics and electricity system dynamics2, is very conducive to providing the core of charging needs and evidence to date supports this.
Adapt demand forecasting arrangements: Forecasting future demands carry considerably more uncertainty than in previous decades, impacting the planning and financing of electricity networks. It will be necessary to improve forecasting arrangements, including the co-ordination between parties, in particular Distribution Network Operators (DNO) and Transmission Network Operators (TNO), and the automotive sector.

Progress with roll-out of smart systems: It is recognised that smart systems, including smart meters, smart charging and energy storage, could reduce the overall level of required investment and allow time for capital intensive/physical solutions to be deployed. However, there remain barriers to adoption centred around standards and interoperability of systems. It is recommended that standards to promote co-ordination of systems, recognising the specific, and often local, requirements of electricity network operators, are developed and implemented.

Develop a regulatory framework to enable investment: Network operators can be reluctant to invest in new infrastructure where they face forecasting risks, exacerbated by the fixed periods of the regulatory price reviews. Additionally, they may also face the risk of asset stranding. The key risk to the system and the smooth uptake of EVs is that capacity gaps form which cannot be filled with new infrastructure in a timely manner, as the lead times can be extensive. It is recommended that a regulatory framework is developed based on consistent and comprehensive distribution network asset data and better demand forecasting. This will improve network capacity forecasts. If necessary, policy and regulations could be updated to provide appropriate risk sharing across all stakeholders and make it easier to commit to and implement investment decisions ahead of potential capacity gaps emerging. Coupled with this the sector needs to take a whole energy system approach, with its portfolio of options for clean energy, to best serve the needs of consumers.

In the rapidly changing environment that EVs will bring, it will be necessary to improve forecasting through better demand data and network asset information, deploy smart system solutions to defer or avoid the need for investment, upgrade policy and regulations to achieve timely investment through appropriate incentivisation and risk sharing, and adopt a more whole systems approach.

"A key issue in rolling out new capacity is the lead times taken to construct and commission new infrastructure."
Electric Vehicle (EV) Terminology

In this report, we define an EV as any light duty vehicle that can plug into the electricity network.

This includes pure electric vehicles (battery), plug-in hybrids (combined battery and petrol/diesel engine) and range-extended electric vehicles (battery with petrol/diesel top-up).

Ultra-low emission vehicles (ULEVs) are also referred to. These may be EVs or alternatives that are virtually zero tail-pipe emission, for example, hydrogen fuelled.

Electricity Network Terminology

There are two types of electricity networks: transmission and distribution.

Transmission networks carry electricity long distances around the country at high voltages. Distribution networks run at lower voltages and take electricity from the transmission system into homes and businesses.

Transmission Network Operators (TNO) are responsible for running transmission networks, and Distribution Network Operators (DNO) are responsible for running distribution networks.

"To deliver on the government’s Clean Growth Strategy the UK must make decisions about its energy infrastructure by the mid-2020s..."
This report discusses the potential rate of change of EV uptake by considering the national carbon/air quality landscape and government drivers, as well as looking at market signals from the automotive industry. The primary focus is on households with off-street parking (about two-thirds of UK housing stock) who are likely to make up the majority of short to mid-term adopters of EVs. The report draws on existing published material only, pulling together disparate sources to review the impact EVs will have on the UK Electricity Networks.

The move away from Internal Combustion Engines (ICE) to EVs is real, and the UK is ideally placed to capitalise on this market growth. In parallel, it is incumbent on industry sectors to work together to ensure that the electricity system can accommodate the additional demand.

Our electricity network operators – three TNOs and six DNOs – hold the responsibility to ensure that the networks are not a barrier to the uptake of low carbon technologies such as EVs. While a range of projects and initiatives are underway to research ways to reduce network reinforcement spend, such as Energy Technologies Institute (ETI) (2018) Consumers, Vehicles and Energy Integration project, My Electric Avenue, Smart EV and Electric Nation, and the Future Power System Architecture (FPSA) programme, this report focuses on the benefits, limitations and enablers needed for smart solutions and conventional network reinforcement.

This report highlights the current situation regarding network demand forecasting, scrutinises the current infrastructure investment and regulatory environment for our network operators, and provides recommendations for the ways in which the whole system will need to co-ordinate, flex and adapt to allow investment in the networks to cope with the rapid changes ahead. It focuses on the impacts of EVs, particularly for homes with off-street parking.

To deliver on the government’s Clean Growth Strategy the UK must make decisions about its energy infrastructure by the mid-2020s, including for domestic electricity, heating and transport. Emissions from heating appliances and other forms of transport are also a significant contributor to UK carbon emissions. To address this, Energy Systems Catapult (ESC) believes that a whole energy systems approach, with its portfolio of options for clean energy, will best serve the needs of consumers. The approach will further endorse the need for flexible and adaptable electricity networks as proposed in this report.

Research shows that the number of EVs in the UK is rising rapidly.
2. Pace of change

"The government will end the sale of all new petrol and diesel cars and vans by 2040."

Key take-aways

- The UK Government plans to end the sale of all new petrol and diesel cars and vans by 2040. This goal will not be met if issues such as network capacity requirements are not addressed.
- The UK is not alone, many countries are introducing policies and incentives to promote ULEV adoption. Automotive manufacturers develop products for a global market.
- There are a number of plausible scenarios for the rate of EV uptake, but there are also uncertainties. This uncertainty makes it imperative that preparations are made for what might happen. There is the very real prospect of high uptake of EVs, and it might be faster than many expect.
- Automotive manufacturers are investing billions into new EV models and some have announced that all of their vehicles will be at least partly electric by 2020. These vehicles are being developed with lower upfront costs to appeal to consumers and drive demand. It’s reasonable to assume that consumers will become disenchanted if useability is compromised by poor home charging availability or long delays before home chargers can be connected, or be put off by bad experiences of others. This may undermine ambitions to decarbonise, improve air quality or realise industrial strategy goals.
2.1 UK Government policy

The transport policy to promote EVs was initially driven by climate change objectives, influenced by the Kyoto/Paris agreements and international carbon reduction targets. The policy to meet these objectives was set in the 2008 Climate Change Act\(^1\). More recently, the UK government has published the Clean Growth Strategy\(^2\) which supports the adoption of EVs mainly through:

- Spending £1bn on supporting uptake, including overcoming the upfront cost of EVs.
- A commitment to develop one of the best EV charging networks in the world.

To help smooth the transition, government incentives are directed towards provision of charge points (e.g. Office for Low Emission Vehicles (OLEV) HomeCharge for domestic charge points) and the Plug-in Car Grant to help counter the higher purchase cost of EVs compared with their ICE equivalent.

It should be noted that the funding is not directed at ensuring the energy system can cope with the uptake of EVs, this responsibility lies with the network and system operators.

The 2017 Queen’s Speech introduced the Automated and Electric Vehicles Bill 2017-2019\(^3\), which is currently at Committee stage in Parliament. This would allow the government to mandate charge point provision in public places, enact minimum standards to enable mass smart charging and provide common information on charge point availability. This is intended to remove some of the key consumer barriers to adopting EVs.

Also, the Department for Business, Energy and Industrial Strategy (BEIS) Committee has recently launched an inquiry into electric vehicles\(^4\), recognising that “the arrival of electric vehicles on the mass market creates substantial challenges for the electricity grid”.

Alongside this, some local authorities have already taken a lead towards the adoption of ULEVs. Greater London operates a Low Emission Zone and has recently introduced the Toxicity Charge, requiring drivers of affected vehicles to pay an additional daily surcharge to drive around most of Greater London. From September 2020 an Ultra-Low Emissions Zone\(^5\) will be created requiring all cars, motorcycles, vans, minibuses, coaches and heavy goods vehicles to meet strict emission standards or pay a daily charge. In advance of these requirements, all private hire taxi vehicles licenced for the first time from 1 January 2018 must be zero emission capable\(^6\).

Outside London, cities such as Nottingham, Oxford, Milton Keynes and Bristol have been awarded Go Ultra Low City status\(^7\), with funding support to introduce initiatives to encourage the adoption of ULEVs. Devolution and the election of local regional Mayors is likely to further accelerate this trend.

"From September 2020 an Ultra-Low Emissions Zone will be created requiring all cars, motorcycles, vans, minibuses, coaches and heavy goods vehicles to meet strict emission standards or pay a daily charge."

\(^{1-7}\) Source: Various governmental and policy documents.
2.2 Automotive market trends

The automotive industry has responded to the long-term steer by various Governments internationally, and invested heavily in EVs.

2.2.1 Automotive market trends

Many automotive manufacturers have acknowledged that the future is increasingly electrified, including Volkswagen Group, BMW, Jaguar Land Rover and Volvo.22, 23, 24, 25

A recent string of announcements highlighting manufacturer expectations of a strong EV market include:

- **Volkswagen Group** announced that it was increasing its investment in alternative drive technologies to nine billion euros over the next five years and will be rolling out more than ten new electrified models by the end of 2018. The company announced “The future is electric. We intend to be the No. 1 in e-mobility by 2025.”

- **Volvo** announced that from 2019 they will stop producing vehicles powered by internal combustion engines alone and that the move to the electrification of their vehicles will be at the core of its future business.

- **BMW Group**, who market nine different electrified models, announced that sales of its EV ranges increased by 74.8% to 50,711 worldwide over the first seven months of 2017.

- **Jaguar Land Rover** announced that all vehicles will be either hybrid or all-electric from 2020.

Combined, the automotive industry is investing tens of billions in EV-related research and development (R&D) to bring new models to the market and support mass manufacturing. In the UK, we are seeing rapid changes in EV availability: in 2011 choice was limited to less than ten models, in 2015 there were 32 types of EVs available and by September 2017, there were 59 models of plug-in cars or vans on the market from a wide range of major automotive manufacturers.

2.2.2 Cost and useability

A key consumer influencing factor is cost. EVs are currently more expensive to purchase than their ICE equivalents (recent studies have shown that upfront costs are a greater driver of demand than lifetime costs). However, economic predictions based on the falling cost of batteries and other reductions in manufacturing costs from the Dutch investment bank, ING, as well as from UBS, suggest a rapid transition from ICE vehicles. ING states that pure electric cars could “become the rational choice for motorists in Europe” between 2017 and 2024 and that they could account for all vehicle registrations by 2035.

UBS research shows that the cost of EV ownership is likely to reach parity with ICE equivalent as soon as 2018. ING further forecasts that the cost of manufacturing EVs will reach parity with ICE vehicles around 2027, coupled with lower servicing and fuelling/energy costs, EVs will therefore be significantly cheaper to run. EVs are increasingly being developed with lower upfront costs to appeal to consumers. Additionally, it’s reasonable to assume that consumers will become disenchanted if useability is compromised by poor home charging availability or long delays in the connection of their home charger or be put off by bad experiences of others. This may undermine ambitions to decarbonise, improve air quality or realise industrial strategy goals.

"EVs are increasingly being developed with lower upfront costs to appeal to consumers."
2.2.3 EV range and charging rate

The range (i.e. distance of travel before the battery needs re-charging) of pure EVs (i.e. battery only) is seen by the automotive industry as a key barrier to adoption. As the industry addresses this issue, assisted by falling battery costs, EV range is increasing, as illustrated in Figure 1. As affordable EVs enter the market with larger range, this will allow consumers that drive longer distances to make the transition, and the impact of charging on the electricity network will be higher.

In high-end vehicles, lithium ion batteries can now match conventional petrol vehicle ranges of 300 miles or more, but still cannot compete in terms of charge times. To address this, many billions are being invested in R&D programmes to develop solid state car batteries which have the potential to both double the range of lithium ion batteries and also dramatically shorten recharge times to a matter of minutes. For example, Sir James Dyson\(^2\) has committed £2billion to produce an electric car powered by solid state batteries by 2020.

2.2.4 Hydrogen fuelled vehicles

There is the prospect that hydrogen fuelled vehicles will form part of the future, but the technology is less mature, and so their future is even more uncertain and likely to take shape over a longer timescale than EVs. Work by the Committee for Climate Change expects that EVs will dominate\(^4\), however, looking further out to 2050, hydrogen fuelling could feature particularly if it is aligned with hydrogen infrastructure and carbon capture to support decarbonisation of heat. This view is underpinned by the Automotive Council’s suite of roadmaps which show fuel cell vehicles coming to the market later than EVs. Any infrastructure solution would need to take account of the prospect of hydrogen refuelling and the potential for change to power.

Figure 1 – Chart depicting vehicle battery capacity trends over time (source: EV author David J. Bricknell)
2.3 International EV landscape

The UK is not alone, many countries are introducing policies and incentives to promote ULEV adoption. Automotive manufacturers develop products for a global market.

UK Government policy should be seen alongside those of other countries. The list below includes headline policies from worldwide and European governments:

- European countries including Norway and France have announced goals to accelerate the adoption of EVs.
- France announced a ban on the sale of petrol and diesel cars by 2040, and Paris is considering an end to diesel cars by 2024 when it hosts the Olympic games.
- Norway has set a goal of 100% sales of zero emission capable vehicles by 2025.
- Germany and The Netherlands are expected to make similar policy announcements.
- California, which accounts for 35% of US car sales, has adopted strict regulations to reduce car emissions which are expected to be adopted by up to a dozen other US states.
- California’s regulatory approach is being mirrored by China. India’s government has stated a desire to be pure electric by 2030.
- Even the Organization of the Petroleum Exporting Countries (OPEC) believes that there will be 235 million electric cars worldwide by 2040, revising its forecast upwards, by a factor of five, from 46 million in just one year.
- As automotive manufacturers develop products for a global market, almost regardless of UK Government policy, petrol and diesel vehicles will be gradually phased out of the supply chain, based on economics, consumer needs and international policy.

2.4 Changing vehicle ownership models

There is potential for vehicle ownership to change in the decades ahead, with the prospect of new models becoming the norm. Technology is making this change possible in the form of today’s app-based taxi services and car clubs, to tomorrow’s autonomous “self-driving” vehicles.

The UK Government has stated that it will facilitate trials of autonomous vehicles and there is support for such in the Autonomous and Electric Vehicles Bill. Some estimates are that autonomous vehicles could be on our roads as early as 2030.

Regarding the electricity network there is much uncertainty:

- Ownership could shift away from the household and towards fleet operators. Fleet vehicles will potentially be connected to the electricity network in out-of-town depots.
- Vehicle ownership models and usage profiles are likely to significantly affect both where and when EVs are charged.

However, despite the uncertainty, there are some sound assumptions that can be made:

- Most EVs, whether autonomous or not, will still need to be charged from our electricity networks. This includes vehicles powered by solid state batteries which will increase the potential demand at each charge point as a result of rapid charging requirements.
- Consumers will still require transport services, whether they own the vehicle or not.
- The future trend is for a greater dependence on our electricity networks for transport, although factors such as ownership models and vehicle autonomy are likely to affect the extent to which network adaptation is needed and where it is needed.

"Some estimates are that autonomous vehicles could be on our roads as early as 2030."
2.5 EV forecasts

There are a number of plausible scenarios for the rate of EV uptake, but there are also uncertainties. This uncertainty makes it imperative that preparations are made for what might happen. There is the very real prospect of high uptake of EVs, and it might be faster than many expect.

Today, the number of EVs in the UK is rising rapidly. By the end of 2017 there were over 100,000 EVs registered in the UK, and EVs now represent 1.7% of the total new car market in the UK.

The Committee for Climate Change (CCC) scenario in which the UK could achieve the legally binding fifth carbon budget by 2030, estimates that 60% of new car sales need to be ULEVs by this date. The CCC expects these to be EVs rather than alternatives such as hydrogen fuelled.

This is aligned with National Grid’s work on Future Energy Scenarios, particularly their ‘Two Degrees’ scenario, where:

There are nine million EVs, around 30% of all cars.

Most cars are pure electric with few hybrids (only 6%).

There will be no new sales of hybrids after 2045 as hybrid EVs contain combustion engines (meaning that they are also emitters).

By 2045 there are only pure EVs for sale.

Further to this, analysis undertaken by Go Ultra Low in 2016 suggested that more than half new car registrations could be electric by 2027.

All forecasts carry uncertainty and a key question is how the network operators should be enabled to manage and mitigate the risks, and how discussions between the relatively separate electricity networks and automotive sectors can be facilitated.

Figure 2 illustrates the key events forecast to significantly impact EV uptake up to 2050.
3. EV impacts on electricity networks

"The focus of this report is home charging for households with off-street parking."

Key take-aways

- Our distribution and transmission networks were not designed for EV demand from homes with off-street parking and potentially we do not have sufficient network capacity for mass-uptake.
- It takes time to realise new capacity, and gaps could emerge that would lead to power outages or other constraints unless action is taken.
- The current approach to forecasting of electricity network capacity and associated investment may not be fit for purpose in the event of very rapid EV uptake. The current investment process has been designed to meet economic growth, rather than changes in modes of transport driven by consumers. To mitigate this, more co-operation is required between the TNOs, DNOs and the automotive industry. This is in line with the approach proposed by the FPSA programme.
- The infrastructure spend to prepare our electricity networks is likely to run to tens of billions but this is still a modest proportion of consumers’ bills.
- The impact is highly dependent on the charging profiles adopted: off-peak charging has a much lower impact than on-peak.

The pace of change in adoption of EVs is rapid. We now look at the impact this will have on the electricity network.
3.1 The parts of our network

The focus of this report is home charging for households with off-street parking. In this context, our electricity networks can be described in four parts:

1. **The Home**: the individual electricity usage of a single household, including those with two EVs

2. **The Street**: the “local” electricity assets that connect multiple homes (i.e. the low voltage distribution network)

3. **The Town**: the assets supplying power to conurbations (the high voltage distribution network)

4. **The Region/City**: the assets supplying bulk power to regions of the UK (the electricity transmission network)

It is necessary to consider each part to better understand the impact that EVs will have on our electricity networks. It should be noted that if EV charging increases national peak demand, then this will require a potentially significant additional generating plant, which could make other costs look modest.

At all levels, as network operators have no control over EV uptake, planners face a huge challenge to ensure that future network capacity remains adequate. There is a real risk the uptake of EVs is potentially much faster than the investment cycles within which network operators operate.

"It should be noted that if EV charging increases national peak demand, then this will require a potentially significant additional generating plant, which could make other costs look modest."

3.2 Impact on the home

Most households with off-street parking will have the capability to support EV charging. The impacts of charging can be managed within the confines of the home.

Within the isolated context of a single house, in the UK, a typical household is permitted to use around 20kW (80 – 100 amps) at any time, as defined by the fuse rating entering the property and the connection terms. This is enough power for most appliances to be used at the same time – a kettle, for example, typically uses 13 amps. An EV charger typically draws a maximum of 32 amps.

It is possible, and in some cases likely, that households would breach the service fuse rating where an EV charger is used along with multiple other high-load appliances (e.g. electric shower and kettle, or even a second EV charger). In these cases, the fuse would blow, the lights would go out and the householder would need to call the DNO to fit a new fuse. To prevent further incidents, the householder would need to ensure that the demand is managed within the household by, for example, either remembering to un-plug the car before showering or fitting an inexpensive device which automatically curtails the EV charging rate when the load of the household exceeds the fuse limit. Alternatively, systems to automatically manage household loads from discrete devices will shortly be available.

Figure 3 – Household appliance electricity usage

EV chargers are very different to other high-load appliances in the household. Whereas a kettle may take three minutes to boil, or an electric shower used for 5-10 minutes, to recharge an EV after a 40-mile trip would take around two hours. However, most households with the ability to charge a car will be able to use a dedicated home EV charger to recharge their vehicle.

Wider system benefits could be provided through EV charging schemes. For example, due to the relatively large amount of electricity required for vehicle charging, typically with significant flexibility, consumers can save money through systems that both manage household loads and enable charging at financially advantageous times or even through participation in the energy flexibility markets (e.g. National Grid’s Short Term Operating Reserve). Set against this, in affluent areas where finance is less of a consideration, there may be constraints issues due to fast charging of high-end EVs such as Teslas.
3.3 Impact on the street

In areas with off-street parking, EVs will ultimately double the load on the local distribution network during peak periods of demand as penetration reaches one EV per household, which will lead to localised power outages unless either the networks are pro-actively upgraded or extensive demand management (e.g. smart charging) is implemented.

When looking at street level, the effects from individual households are multiplied. A typical residential street will have a cable running underneath it, with individual connections to each property. Each cable can supply anywhere from one to 150 properties. There are also devices that convert high voltage to low voltage called transformers. Each transformer may supply a few streets, up to around 500 consumers.

The cables buried underneath our streets will be heavily impacted by EVs. In residential areas, peak local electricity demand is in the evenings and is particularly high on cold, dark winter’s evenings. Research conducted using charging data from hundreds of EV drivers have shown that unmanaged EV charging demand also peaks in the evening. This is illustrated in Figure 4.

The ultimate result is a doubling of peak demand at distribution street level as EV penetration rates reach 100%. It should be noted that this is in today’s energy market, where most residential consumers pay a flat rate for electricity regardless of whether the system is at peak load or not. Using different tariffs, i.e Time of Use (ToU) tariffs, where consumers would be charged more for using electricity at peak times may help offset a proportion of the local peak, but it is unclear how effective this would be. Additionally, ToU tariffs aren’t the only option for managing charging or providing a signal to manage charging. Technology to enable remote management of charging has been shown to reduce local peaks and there is initial evidence to support that this is acceptable to customers.

Each cable usually has some spare capacity, but very rarely enough to cope with a two-fold increase in demand. There is also the prospect of the voltage to consumers’ homes being lower than statutory levels.

Figure 4 – The (residential) demand (in kVA) by time on a typical winter weekday

Residential and EV charging demands
It will be necessary to:

- Proactively upgrade local networks where spare capacity is limited; and
- Enable the extensive roll-out of smart solutions that can alleviate network stress, such as smart charging and home storage, also allowing DNOs to take control when necessary (i.e. on those cold, dark winter evenings where demand is uncommonly high).

It should be recognised that apart from the costs, upgrading local networks is disruptive, typically involving road closures and civils works (e.g. digging cable trenches). Also, it takes time to plan and deliver new networks. This is before consideration is given to the cost and potentially long lead times to install any associated new generation capacity. A key issue in ensuring the local network can cope with EV charging, is the scale of the problem; there are around one million cables supplying households in our streets in the UK.

While DNOs are accustomed to reinforcing networks (mostly at higher voltages) to facilitate load growth or new connections, the prospect of reinforcing even a modest proportion would be on a different scale to their conventional levels of capital investment activity.

Given the time it can take to deliver new capacity for EVs, it is suggested that the electrification of other high carbon energy sources, such as gas for heating, is considered alongside EV uptake impact. The benefit of smart solutions is they can help prevent outages due to overloads. In some cases this may resolve the issue, while in others it will buy time while more permanent solutions are planned and deployed.

3.4 Impact on the town

It will become an increasing challenge to maintain reliability standards on our high voltage networks due to EVs. Mass smart charging and substantial investment in new capacity will be required when EV uptake becomes significant.

Our towns and villages are supplied with electricity by an array of high voltage overhead lines and underground cables, fed from a series of large transformers. A crucial design aspect of our high voltage network is that each area is fed from two or more supplies – in the event of a fault, power can be transferred through a different route until restoration. This means that latent spare capacity exists in our high voltage networks that is only used during faults or maintenance.

The impacts of EVs are varied. For networks that supply mostly residential areas, then the same doubling of demand that will be seen on low voltage networks will be apparent on high voltage networks. For networks supplying business districts or town centres, then the impacts of EVs would be a result of public or business charging points and the situation will be more complex. These connections usually require an application to the DNO, who then has the opportunity to upgrade the network in advance. However, a key issue will be the time taken to provide connections and there is a possibility that public EV charging would be held back waiting for additional capacity.

There is the prospect of utilising the capacity built into networks for fault resilience. This could release substantial capacity for EV charging quickly, but at the detriment of reliability, increasing the frequency and duration of power outages that consumers experience, requiring transformers to rely on cooling fans and pumps that normally operate very rarely and driving up network losses.

Smart charging, again, has a role to play. At high voltage, demand levels are larger, but smoother and less subject to minute-by-minute variations. As a result, smart charging would be activated for longer durations, more frequently and involving more EVs, however the aggregation effects will reduce the requirement for any individual EV. This level of curtailment, and its acceptability, has not yet been explored using real consumers.

In such circumstances, it may be necessary for consumers to be financially incentivised to participate, for example, through sharing in the savings they are helping to realise.

There are a range of solutions that may be appropriate to alleviate capacity constraints on high voltage networks, not just traditional reinforcement through new networks or asset replacement. Energy storage and industrial/commercial demand side response have been tested by the DNOs and may prove more cost-effective in some network areas.
3.5 Impact on the region/city

Our transmission networks will need investment due to increased peak demand across the system. A key issue is the lead time for commissioning new capacity, and the need for better forecasting and cross sector collaboration.

Transmitting power across the country from region to region is achieved through our electricity transmission network. This infrastructure consists of large bulk supply power transformers and large overhead power lines spanning the country. The assets are large, expensive and take time to deliver.

As discussed in 3.4, a crucial design aspect of our transmission network is that each area is fed from two or more supplies – in the event of a fault, power can be transferred through a different route until restoration. This means that latent spare capacity exists in our transmission networks that is only used during faults or maintenance. This is potentially available for use at times of peak load resulting from the charging of EVs, and could mitigate congestion issues, at least until more permanent solutions are put in place. Similar to high voltage networks, this would be at the detriment of reliability and potentially system stability.

The load carried by transmission assets is highly aggregated and therefore consists of a mix of residential, business and industrial demands. Whereas distribution level assets that supply towns and villages may see a doubling of peak demand due to EVs, the diversified consumer base across transmission assets will act to limit the overall percentage change.

There is sensitivity towards the dominant charging mode. Should domestic charging continue to dominate, then National Grid anticipate a large (potentially double) addition to peak demands as a worst-case scenario on transmission assets serving predominantly residential areas. However, a higher ratio of public and business charging, coupled with mass smart charging, will result in a smaller contribution to peak transmission demand.

In the optimistic case that smart charging is prolific and aggressively exercised (requiring considerable consumer buy-in), National Grid modelling shows that the contribution to peak demand could be kept to 8%\(^1\). In addition to peak capacity, load factors of equipment and their associated ratings (e.g. 12hr, 6hr and 20 minutes ratings for summer and winter) will need to be considered to ensure that the networks can provide the necessary capacity throughout the year, e.g. when equipment ratings are lower in the summer, during maintenance outages or where high utilisation levels are experienced for several hours.

"A crucial design aspect of our transmission network is that each area is fed from two or more supplies – in the event of a fault, power can be transferred through a different route until restoration."
Nonetheless, in all cases, investment is needed in our transmission infrastructure to facilitate the transition to EVs and there is much uncertainty in the costs, benefits and limitations of smart solutions. The level of transmission investment will be highly dependent on the charging behaviour over the national peak. Key issues are the lead time for commissioning any new capacity and the adoption rates of smart charging.

To ensure that network investment is undertaken in a timely and cost-effective manner that delivers optimal benefit to consumers, greater co-operation is required between stakeholders including TNOs, DNOs and the automotive industry (and their customers). Additionally, the investment process, visibility of the rate of EV uptake and its impact on the entire network, and future EV growth forecasts need to be considered.

Energy Systems Catapult also believes that a whole energy systems view would be beneficial to all stakeholders – for example looking at the impact on the generation portfolio (peak charging is likely to call on gas fired generation, limiting carbon benefits), cost optimisation across the whole transmission and distribution network, evaluating true carbon costs and the overall financial costs to the consumer.

ETI analysis across a range of scenarios indicates more modest costs for the transmission network to support EVs when compared to the distribution network and other electricity supply costs. Equally, savings offered by smart solutions for the transmission network are found to be noticeably smaller than for distribution networks and for system balancing.

As the assets take time to construct, it is necessary to forecast future load growth many years ahead and it is risky to assume that other solutions, such as smart charging, would achieve the required levels of performance, in terms of de-loading assets, within the constraints of consumer acceptability. Flexibility is needed.

Other solutions may prove more cost-effective than traditional reinforcement in the future. For example, energy storage could alleviate capacity constraints on transmission and distribution assets, but is expensive when used to mitigate network constraints. Demand side response (contracting with companies to reduce demand on request) may be used more extensively to de-load transmission assets in the future, however, there are challenges as the transmission asset owner requires a long-term commitment from demand side response service providers.

A typical major scheme to bring new capacity online takes five years of planning and delivery, sometimes longer, and is often dependent upon local sensitivities (e.g. visual amenity or heritage concerns). This places a large emphasis on forecasting and forward planning. It is often necessary to take a long-term view, sometimes decades ahead, to ensure that new capacity is adequate for future demands. It is also essential that the TNO works with the DNO to develop an integrated solution, and that the DNO provides early visibility of EV driven demand to the TNO.

3.6 The scale of infrastructure requirement

At this stage it is difficult to develop estimates of the expenditure required in our network infrastructure because of the significant uncertainty. However, various estimates show that it is likely to be a few tens of £billion.

This is potentially a significant spend, and although it is spread across the national consumer base and long asset lives, it still represents a modest proportion of consumer expenditure compared to existing fuelling costs and the investment in the vehicles themselves.
4. Enabling the transition

"The pace of change in EV uptake is rapid. Given the lead times to commission new capacity, traditional forecasting methods may no longer be appropriate."

Key take-aways

- A rapidly changing environment means that there are increased risks associated with demand forecasting. It will be necessary to adapt the current arrangements so that the risks are better understood, through improved distribution network data and information, and granularity of EV uptake forecasts.

- Policy and regulatory changes are potentially needed to make it easier to agree and implement investment decisions ahead of need, in order to allow greater flexibility in long-term investment in major infrastructure for EV-related demand.

- Smart charging has the potential to reduce costs but there are a number of enablers that must be realised soon such as standards to promote technical interoperability and coordinated commercial offers.

- There is an asymmetry to the risk. Delivering capacity a short time ahead of need carries only the cost of the rate of return for that period, while late delivery could disrupt the networks and deployment of EVs.

- So far, we have concluded that for the UK to facilitate the transition to EVs, electricity network investment is required at all levels of the system, from low voltage through to transmission. This section draws out the actions needed in the next few years to facilitate this.
4.1 A shared ownership of demand forecasting

The pace of change in EV uptake is rapid. Given the lead times to commission new capacity, traditional forecasting methods may no longer be appropriate. Consideration should be given to a risk-based approach to network infrastructure investment.

At present, network operators are responsible for their own demand forecasting and they are obliged to consult with stakeholders over their plans. The TNOs are largely reliant on the forecasts from DNOs to understand future demand, and cannot enhance their networks until they know the DNO’s plans for increased transmission network exit capacity. A key issue is that due to the regulatory mechanisms, DNOs make significant efforts to produce detailed forecasts to justify investment business plans up to eight to ten years ahead of when investments might be made. Since the TNO regulatory period is two years earlier than DNOs, but the forecasting/investment mechanisms are very similar, they are exposed to a misalignment of their own forecasts with those of the DNOs.

We are entering a period of immense change in demand patterns and given the lead times to commission new capacity, traditional forecasting methods are no longer appropriate. The FPSA programme has identified this as an innovation area of focus. Consideration should be given to a risk-based approach to network infrastructure investment whereby the risk of inaccuracy is better understood and shared. This should be supported by more effective data collection and more comprehensive asset information at the network level. At the core of this is improved information on the existing state of networks, including network capacities and the potential for reinforcement. Improved demand forecasting, in co-operation with the automotive industry and other relevant stakeholders, and a better understanding of what might be achieved by ToU charging and/or smart charging are also required, including potentially new market arrangements and business models.

4.2 Implementation of smart solutions

There is a range of smart solutions that could benefit consumers through reduced bills and ultimately improved reliability of the electricity system. However, there remains critical uncertainties on how and whether these solutions will proliferate; and considering the government mandated scale and rate of change of our transition to EVs, smart solutions will not prevent the long-term need to invest in our network infrastructure.

The front running new technology and commercial offerings that have the prospect of significantly altering power flows are smart meters, smart charging and energy storage, and associated market arrangements and business models. Each is briefly discussed here with a view of the enabling actions required to better assist electricity networks.

4.2.1 Smart meters

Regarding benefits to our electricity networks, all new smart meters have three important capabilities:

- Consumers can view their electricity usage in real-time, which can raise awareness and in limited cases also reduce demand. Data from smart meters can help better understand network capacity issues, potentially in near real-time, and help mitigate congestion issues resulting from EV uptake.
- Enable ToU tariffs that could incentivise consumers to use less electricity during peak times. In most cases it is expected that this process would be automated.
- Potential control of domestic appliances such as freezers, electrical heating and EV chargers, to defer their operation away from peak times.

A key driver for ToU tariffs is to lower the total cost of electricity supply and this benefit is mainly derived by allowing an overall lower cost generation mix through less reliance on more expensive peak generation plant. The price signals from the generation market however, do not necessarily align with the stress on the electricity network.

ToU tariffs should be geared to better serve consumers by passing on the benefits from both the generation market and releasing network capacity. As previously mentioned, from a whole energy system perspective, smart meters enable the opportunity for price signals to be acted upon to manage loads and reduce costs.
4.2.2 Smart charging

In the context of this report, smart charging refers to deferring the charging of EVs away from peak times and towards periods where there is spare network capacity and a less expensive generating plant available. This may be to manage capacity on the local cable supplying the street or the national transmission network.

Technically, smart charging can be facilitated by use of a dedicated smart charger, use of in-vehicle systems or using smart meter infrastructure.

Studies have shown that smart charging can defer investment in network reinforcement, and is acceptable to consumers, if it reduces the associated upheaval\(^\text{10}\). It remains a large unanswered question as to whether consumers, en-masse, will accept smart charging with the levels of incentives that make it a cost-effective solution compared with conventional reinforcement of electricity networks. Smart charging is more likely to be acceptable if the savings are significant, the consumer has the ability to over-ride if the vehicle is needed quickly and priority is given to ensuring that all vehicles have a minimum level of charge for emergency use.

Smart charging can also be used to limit the peak demand for electricity nationally, and hence the size of the national generation fleet. Given the high cost of building, operating and maintaining power plants, this could provide a significant saving to electricity consumers.

There is also the potential of vehicles back-feeding into the electricity system, termed vehicle-to-grid (V2G). This involves the charger containing an inverter to convert and synchronise the energy stored in the vehicle battery, so it can act as a local generator. Compared with average daily household electricity usage of around 10kWh per day, EV battery packs are often triple this capacity.

On this basis V2G is an attractive prospect for the networks, especially at time of peak. The technology is currently in its infancy and only supported by two automotive manufacturers at present. There remain significant barriers, not least in terms of technology, commercial models and consumer acceptance, however it is encouraging that Innovate UK and OLEV have recently announced funding for a range of projects to further explore feasibility and enable demonstrations. V2G could develop into a cost-effective tool to defer network investment, however, at this stage it is too early to assess its feasibility.

"Studies have shown that smart charging can defer investment in network reinforcement, and is acceptable to consumers, if it reduces the associated upheaval\(^\text{10}\)."

There are a number of enablers which must be put into place to allow smart charging to proliferate:

- Incentivisation for customers to adopt smart charging; and/or
- Technology standards to promote interoperability between smart chargers or vehicle on-board systems;
- Those standards to be applied widely, either by legislation to enforce the standard or an alternative measure (e.g. grants based on compliance);
- Co-ordination of commercial offerings and back office systems between DNOs, TNO and the System Operator.

This should be progressed as soon as possible while the EV penetrations are low to prevent stranded investment such as having to incur the cost of replacing EV chargers with smart equivalents, ultimately at the customer’s expense.
"Energy storage systems can offer significant benefits to consumers and the wider energy system. The costs of the systems continue to fall, driven by demand, not least due to the increased production rate of EVs."

4.2.3 Energy storage
Energy storage systems can offer significant benefits to consumers and the wider energy system. The costs of the systems continue to fall, driven by demand, not least due to the increased production rate of EVs.

The systems can directly benefit consumers in the future, coupled with ToU tariffs and other means of providing signals to aid management of charging, by allowing them to consume less electricity during peak price periods. However, there are other revenue streams including wider participation in the energy flexibility markets such as supporting the provision of ancillary services to the system operator. In smart grid technology, an ancillary service is anything that supports the transmission of electricity from its generation site to the consumer. Services may include load regulation, spinning reserve, non-spinning reserve, replacement reserve and voltage/frequency support.

The demand flexibility offered by storage systems could form a valuable tool to defer or avoid network reinforcement in the future. At this stage, there are limited studies to suggest the volumes of storage systems that may be installed in the coming decade and therefore difficult for the network operators to plan for its potential.

4.3 Investment in our networks
4.3.1 The regulatory context
The regulatory environment has served the industry and consumers well for many decades during periods of slow demand growth, ensuring capacity is only built as and when it is needed, keeping performance up and consumer bills down. However, it can mean that the power system struggles to keep pace with large-scale changes outside of these long timescales – recently exemplified with challenges in the connection of large scale solar generation to the distribution network.

While there have been many changes to regulation in the last 27 years, the core set-piece is a time limited Price Control period. In 2013 Ofgem moved from five-year price control periods in favour of eight years under the RIIO (Regulation = Innovation + Incentives + Outputs) model.

Critical for network operators are the Price Control Reviews, where the Regulator sets the policy, any incentives/penalty mechanisms, and the allowable revenues of a licensee for the coming period. Performance against agreed plans and benchmarking of costs are major components, with granular analysis taken to agree all manner of expenditure the network operator is likely to incur during the period.

Once investment levels are agreed, the Regulator sets an allowable cost of capital, giving the network operator the ability to finance the investment over a longer period to the Price Control, more in line with the life of the assets (typically 40-45 years). The network operator therefore, does not get the investment that might be needed in a given price control period, only the ability to fund the associated equity/debt. The network operator still needs to raise the capital either via its investors or via banks to fund the build.
4.3.3 Securing finance

Where a network operator faces uncertainty, it forms a poor foundation from which to secure finance from investors looking for stable, risk averse and long-term investment in our infrastructure. In an environment of ex-post approval, such as investment made outside of the Regulatory settlement, this results in poor investor confidence, making it difficult to fund at reasonable levels.

In contrast, for example where investment is needed to connect a single large power station, outside a price review, TNOs can secure finance as there is significantly more certainty in the outcome, plus the lead time to build a typical power station, is longer than the associated network infrastructure.

Given the potential rapid ramp up of EVs, consideration needs to be given to the prospect of not investing in time, and whether consumers are best served by lower spend, albeit at risk of capacity gaps and subsequent outages. Without change, capacity gaps will form and infrastructure expenditure could increase due to the higher costs of needing to commission capacity quickly.

4.3.2 Regulation in rapidly changing worlds

As electricity Price Controls in Great Britain are agreed up front, or ex-ante, infrastructure investment is locked into a regulated period, with limited room for movement outside of the regulatory settlement. While this is done to limit the exposure of price changes to consumers within a price control, it does require the network operator to accurately forecast over a long period of time. One approach to managing this is to agree “cost drivers”. For example, the allowed expenditure could be incremented by an agreed amount for every additional thousand EVs purchased. In extremis, if a licensee believes that the terms of a price control have become unreasonable then they can ask for it to be “re-opened”. However, this is not undertaken lightly as the whole price control is then re-examined, not just the issues that are concerning the licensee.

For the current Price Controls, forecasts were defined in 2010 and 2012 for RIIO-ET1 and RIIO-ED1 respectively, when the EV trends were highly uncertain (there were only 760 electric vehicles sold across the entire European Union in 2010). However, these plans were expected to hold true until closure in 2021 and 2023. For the next Price Controls, which will run from 2021 to 2029 for transmission and 2023 to 2031 for distribution if a similar model is followed, there is a risk that our Network Operators do not make inroads on the infrastructure requirements for EVs within this period, unless there is change.

This is recognised by Dieter Helm in his Cost of Energy Review. Considering the regulatory environment, he highlights that “Looking ahead to 2030 is an extraordinarily difficult task. It takes us well into the Fifth Carbon Budget… this is likely to be a period of even greater technical change, and a host of fundamental questions for the future of regulation will arise”.

There is precedent in this area and previous Price Controls have enabled the ability to invest ahead of need, but potentially not at the scale expected to satisfy EV-related demands. The Strategic Wider Works process facilitated investment in the networks to support the connection of renewables. There have also been efforts to coordinate the works to connect offshore renewables to the transmission network to avoid piecemeal and ultimately more expensive connections. These measures have been at a strategic, one-off level and in all cases have provided the network operator with certainty of outcome, leading to a secure foundation to raise funds. Alternatively, a cost driver, based on the total sales of EVs, could give the network companies confidence that reasonable costs can be recovered.
4.3.4 A need for proactive investment

The network reinforcement required to facilitate EV uptake has very different characteristics compared with previous works that have been funded ahead of need:

- Consumers could be severely impacted by not commissioning new capacity in time.
- There is more uncertainty in demand forecasting, mostly around when, not if, the demands will hit the networks.
- Reinforcement work will be highly distributed, involving all network levels (from street to national transmission) and will be spread across the UK.
- Levels of investment are expected to be higher, in the order of tens of billions\(^2\).

Whereas network operators have been able to solidly justify network investment in the past based on slow growth rates, now they face uncertainties in forecasting and will need to act earlier. This will require much greater collaboration with the automotive sector.

A lack of flexibility in the current regulatory mechanisms does not encourage any player to make an investment based on load that may or may not appear within the fixed time period of the Price Control. At present network operators take the risk of forecast inaccuracy with the potential of disallowed expenditure through ex-post (after the event) scrutiny.

It should be noted that a whole energy system approach and the development of a portfolio of options for clean energy in all its various uses, fitted together in the best combination, is likely to deliver optimal value to consumers.
5. Recommendations

"This report draws out that we are entering a period of rapid change with the advent of EVs and the effects on our electricity networks will be significant. To prevent capacity gaps, which would lead to increased power outages, it will be necessary to invest in our infrastructure."

The key recommendations in this report are:

- **Adapt demand forecasting arrangements:** Forecasting future demands carry considerably more uncertainty than in previous decades, impacting the planning and financing of electricity networks. It will be necessary to improve forecasting arrangements, including the co-ordination between parties, in particular DNOs and TNOs, and the automotive sector.

- **Progress with roll-out of smart systems:** It is recognised that smart systems, including smart meters, smart charging and energy storage, could reduce the overall level of required investment and allow time for capital intensive/physical solutions to be deployed. However, there remain barriers to adoption centred around standards and interoperability of systems. It is recommended that standards to promote co-ordination of systems, recognising the specific, and often local, requirements of electricity network operators, are developed and implemented.

- **Develop a regulatory framework to enable investment:** Network operators can be reluctant to invest in new infrastructure where they face forecasting risks, exacerbated by the fixed periods of the regulatory price reviews. Additionally, they may also face the risk of asset stranding. The key risk to the system and the smooth uptake of EVs is that capacity gaps form which cannot be filled with new infrastructure in a timely manner as the lead times can be extensive. It is recommended that a regulatory framework is developed based on consistent and comprehensive distribution network asset data, and better demand forecasting. This will improve network capacity forecasts. If necessary, policy and regulations could be updated to provide appropriate risk sharing across all stakeholders and make it easier to commit to and implement investment decisions ahead of potential capacity gaps emerging. Coupled with this, the sector needs to take a whole energy systems approach with its portfolio of options for clean energy to best serve the needs of consumers.
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Published July 2018