New Thames Valley Vision
Learning Outcome Report
EV Chargers Usage Evaluation and Issues
Scottish and Southern Electricity Networks (SSEN) is the new trading name of Scottish and Southern Energy Power Distribution (SSEPD), the parent company of Southern Electricity Power Distribution (SEPD), Scottish Hydro Electricity Power Distribution (SHEPD) and Scottish Hydro Electricity Transmission. SEPD remains the contracted delivery body for this LCNF Project.

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1 Executive summary

Electric vehicles (EVs) deployment could decrease greenhouse gas emissions from transportation sector and thus is a technology that is promoted by the UK government. However, potential EV uptake will increase the electricity consumption through distribution networks. Therefore DNOs need to better understand the potential impacts of EVs on their networks and particularly on the low voltage network where they currently have no visibility of new EV loads that are connected through existing customer connections.

There are four key factors that determine the impact of EVs on the distribution network: number of charging points, type of charging points and EVs, spatial distribution of charging points relative to the network and the temporal distribution of electricity demand. All these factors can be influenced by the developments in the commercial model and new technologies that will emerge.

- Charging points can broadly be split into three categories: home, workplace and public charging points. Their development will depend primarily on the uptake of EVs in coming years, around which there is still much uncertainty.

- The type of charging points adopted depends on EV characteristics and more specifically on their battery size (kWh), as well as the time within which charging needs to be completed. There are different battery sizes available in the market that relate directly to the range capability of the vehicles. There are three main EV charging speeds: Slow charging (up to 3kW) lasting 6-8 hours (depending on battery capacity); Fast charging (7-22kW) lasting 3-4 hours (depending on battery capacity); and Rapid charging units (43-50kW) which can provide an 80% charge in around 30 minutes (depending on battery capacity).

- The spatial distribution of the different types of charging points depends on the characteristics of EV owners and how they use their EVs. With regards to domestic charging points, by understanding the characteristics of early EV adopters it is possible to better predict areas of higher uptake. EV owners today tend to have relatively high incomes and live in single family houses, be more than 35 years old and are more likely than the average household family to have PV installed at their houses. It is also apparent that there is an element of peer influence in people’s decision making with a greater likelihood of take-up when neighbours have already got one.

- The temporal distribution of the charging of the EVs is likely to depend on the type of use and the behavioural characteristics of the EV user, such as when and for how long they use it and when they prefer to charge it.
In tandem with these physical factors associated with charging, the impact of EV development on networks will also be heavily influenced by the development of new business models and technologies. These include:

- the repurposing of EV batteries for grid storage that can drive EV prices down and lead to a higher uptake;
- the provision of mobility as a service for cities, which can allow the development of optimal infrastructure for EVs;
- the offering of driving subscription plans that can determine the development of charging points and the form of charging profiles;
- the development of Vehicle to the Grid (V2G) services can have a significant impact on charging profiles;
- new IT added value services for the user such as mobile applications for charging point locations and charging management that can influence charging profiles;
- innovation in driverless car technology that can improve energy efficiency and potentially change the way EVs are charged, leading to different charging profiles and charging point needs;
- the potential introduction of super-capacitors instead of lithium-ion batteries for EVs which could impact charging profiles.

Several metrics can be used to fully understand the impacts of EVs on the distribution network. Those that have been used before include: voltage levels, thermal loading, power losses, imbalance, harmonic distortion levels and transformer’s Loss of Life (LOL).

The initial results from the modelling work reveal that even under the Clustered high EV uptake scenario by 2022 the impacts on the low voltage distribution network are relatively small. There are no voltage issues identified and there are only small scale thermal capacity issues that fall under the category of increased risk areas (amber) rather than areas that would definitely need some reinforcements. The observation that thermal capacity related issues occur before the voltage related issues confirms similar findings seen in ENW’s Low Carbon Network Fund project, “Low Voltage Network Solutions”. Also it was found that parts of the feeders that may become overloaded due to EVs are generally located closer to the substations than expected. Initial results further indicate that smaller feeder circuits with fewer customers may face less impacts from EV uptake. Moreover, they show that impacts from EVs during summer may be more severe compared to winter due to the reduced thermal capacity of the circuits.
To alleviate potential impacts from EVs, DNO could adopt different approaches. These include:

- **Reactive approach to charging point deployment** – The reactive approach can involve an identification/licencing system that would require the declaration of the installation of a domestic charging point to the DNO so that the DNO becomes aware of where network reinforcements may be needed.

- **Proactive approach to charging point deployment with smart control charging** – A proactive approach with smart control charging would involve the promotion of two main strategies from the DNO to shift or reduce demand in order to minimise contribution to network peak and to match local demand with local generation. These could be implemented either through the adoption of market based mechanisms or direct load control methods.

Based on the modelling results, it is expected that in the medium term (by the end of RIIO ED1 price control review) the DNOs suggest a reactive approach is appropriate in order to better understand the areas of the network that may face a greater risk of failure and only undertake minor traditional reinforcements when needed. However, looking longer term when more EVs might be charging in the network, more proactive approaches may be needed to ensure the cost efficient deployment of traditional reinforcements or their deferral through the use of smart charging strategies.

In the short term DNOs could become better prepared for a potential high EV uptake in the future by:

- Close monitoring of EV market developments
- Building industry partnerships with EV car manufacturers
- Using a high level forecasting tool for the wider DNOs’ regions to predict specific areas with high concentration of early EV adopters
- Market education and outreach to customers regarding the potential impacts of EVs
2 Introduction

2.1 Criteria 9.8(a) Part 5

Successful Delivery Reward Criteria 9.8(a) Part 5
EV Chargers usage evaluation and issues

- Network effect (individual and aggregated demand, power quality, thermal and voltage limits)
- Impact assessment (assessed using network modelling and forecasting tools)

SSEPDP confirms that this criterion has been met.

Criterion:
EV Chargers usage evaluation and issues

Evidence:
This document details the completion of the EV Chargers usage evaluation and issues, discussing the network effects and presents the findings identified from the EV model through the Network Modelling Environment (NME) in line with the evidence criteria specified for the Successful Delivery Reward Criteria (SDRC). Graphical results produced from the NME are included.

2.2 Background

Electric vehicles deployment could decrease greenhouse gas emissions from the transportation sector, reduce the dependence on petroleum and potentially provide consumers a cheaper alternative to fossil fuels. The main types of electric vehicles that are currently considered include; Battery Electric Vehicles – BEVs, Fuel Cell Vehicles – FCVs, Plug-in Hybrid Vehicles – PHEVs and Hybrid Electric Vehicles – HEVs. Among them, according to the International Energy Agency’s (IEA) Blue Map scenario which is compatible with the IPCC’s 2050 Green House Gas (GHG) emission reduction targets (Fig. 1), PHEVs and BEVs (EVs hereinafter) are likely to prevail in the future car market.
Figure 1: Plug-in Hybrid Vehicles – PHEVs are expected to dominate the market in the future (future scenario in accordance with the IPCC’s 2050 GHG emission reduction targets)

The UK government has introduced the Office for Low Emission Vehicles (OLEV) which aims to support the early market for ultra-low emission vehicles including EVs and all major political parties in the UK support its programme up to 2020. However, the popularity of EVs also depends on how successfully EVs can be integrated in the broader power system. The deployment of EVs will change the typical load consumption patterns and thus the electricity systems’ carrying capacity may not be adequate to handle that change. The fact that the DNOs do not currently have a mechanism to control connections of new loads, including EVs, to the low voltage network that occur at the premises of a household or a Small and Medium Enterprise (SME) with an existing service connection, increases the risk for blackouts as DNOs do not have visibility of where in the LV network reinforcements are needed.

Research, including several large scale projects, have been conducted trying to identify and quantify the potential impacts of EV penetration on the distribution network through model simulation that takes into account the driving patterns of the owners, the charging characteristics of EVs, the charge timing, the penetration of EVs and the possible application of Vehicle-to-Grid technologies.

1 Grids for Vehicles (G4V), Mobile energy resources in grids of electricity (MERGE), EDISON project, SmartV2G project, Green eMotion, Mobincity: Smart mobility in smart city, EV project, Vehicle-to-grid demonstration project, My Electric Avenue project.
2.3 Aims and objectives

NTVV project aims to better understand the potential impact that EVs could have on the low voltage distribution network in the Bracknell area that cannot be predicted with certainty by the DNO and identify wider remedial actions that could help to alleviate potential network issues. By understanding the current developments in the EV market and technologies, simulating the future spatial uptake and charging of EVs and analysing the corresponding network flows the project will be able to fulfil the aforementioned aims.

2.4 Approach

DNV GL conducted a literature review to better understand the factors that determine the impact of EVs on the distribution network (Section 3) as well as the actual technical impacts on the network (Section 4). University of Reading has developed a stochastic model that simulates the impact of EVs on the overall demand profile of households which has been also informed by DNV GL’s study (Section 5). DNV GL also organised a workshop where key parameters of the model were discussed, with participants from University of Oxford, University of Manchester, De Montfort University and SSEPD. Results from the University of Reading Model have been used as an input to the Network Modelling Environment that GE has developed in the framework of the NTVV project, which allows the network flow analysis in the wider Bracknell area. DNV GL undertook a subsequent analysis of the modelling results focusing on providing recommendations for alleviating network issues.

2.4.1 Link to Methods and Learning Outcomes

Method 1 requires a linkage of network reinforcement to a better understanding of electricity consumers. As network reinforcements are primarily triggered by thermal constraints and voltage drop, an understanding of EV charging on these aspects of networks is needed in order to better understand what the future impacts on the networks might be. To meet SDRC 9.8(a) Part 5 a modelling tool that can predict the electricity demand consumption of EVs in the future under different scenarios (as well as the overall electricity demand) is needed to produce future load profiles that can be used as an input to the Network Modelling Environment and will allow the understanding of the EV uptake impact on the network. Method 2 refers to demand response and its use to allow the efficient integration of EVs onto the network. Different methods of demand response that can help towards this direction are analysed. Following the modelling work, consideration of potential remedial measures has been given to successfully complete Learning Outcome 4.1 (How could distributed solutions be configured into the DNO environment?).
3 Understanding the factors that determine the impact of EVs on the distribution network

There are four key factors that determine the impact of EVs on the distribution network which can all be influenced by the developments in the commercial model and new technologies that will emerge. As shown in Figure 2, these factors are: number of charging points, type of charging points and EVs, spatial distribution of charging points and the temporal distribution of electricity demand. The following sections discuss all these aspects.

Figure 2: There are four key factors that determine the impact of EVs on the distribution network

3.1 Number of charging points

The number of charging points is related to the number of EVs that are available in a certain area. Thus an analysis of the potential EV uptake and the need for charging points takes place below.

3.1.1 Uptake of EVs

There are many different scenarios regarding EV uptake in the future due to big uncertainties around the development of the technology and the availability of public infrastructure. These scenarios are mostly focused on passenger cars.

Worldwide forecasts vary between 2% and 12% of the total new car sales in 2020. The higher forecast seems to be aligned with the official targets that many countries have in place. IEA (2012) estimates that there will be approx. 10M sales of EVs by 2020 and approx. 25M by 2025 (based on the official targets of the countries) from sales of a few thousand in 2010. The Institute of Economic Affairs predicts 6.9 million by 2020. The central cluster for scenarios though would be around 6% of the total new car sales in 2020.

To put these scenarios into perspective, current EV uptake is relatively low with a global stock in 2012 of just a few hundred thousand as shown in Figure 3.
Figure 3: United States have by far the biggest EV stock in 2012 (‘000s)\(^6\)

For the UK, different forecasts provide a massive range from between 100,000 to 1.7m by 2020 \(^2\). Although EV sales have experienced significant growth since 2010 as shown in Figure 4, they still in 2013 represent only 0.17% of total car sales in UK\(^7\).

Figure 4: The market for Plug-in-Grant Eligible Cars in UK is undergoing almost 90% annual growth since 2011

DECC has developed its own detailed scenarios for the whole GB and each different region separately. The scenarios incorporate two different technologies for charging: slow and fast, and provide a forecast between approx. 350,000 and 2,000,000 EVs by 2022.

\(^2\) UK Department for energy, European Automobile Manufacturers’ Association, Morgan Stanley, Committee of Climate Change
3.1.1 Electric Vans

Apart from passenger cars, commercial users might also (or only) adopt electric vans in the future. However, their uptake compared to other technologies might be significantly lower compared to that of EVs in the passenger cars category.

In the UK, it is expected that the internal combustion engine and pure hybrids will continue to dominate sales of new vans in 2020 (approx. 80% of the market) and EV and hydrogen vans will account for 10% market share each. However, by 2030 hydrogen vehicles are expected to dominate the van market as they offer competitive ownership costs (approx. 43% of the market) whereas EVs will account for approx. 18% of the market.

3.1.2 Charging points

There are broadly three categories of charging point areas: home, workplace and public charging points. Whilst it is expected that the majority of charging will take place at home, which implies that most of the households will need to have a charging point, there will still be a need for charging points at workplaces and public places. Some early estimates reveal that public charging points required for the smooth operation of EVs amount to 8-30% of the number of EVs available on streets. Moreover, according to experience from the EV trial project in Victoria in Australia, the need for public charging points is around 10-25% of the number of EVs available on streets.

3.2 Type of charging points

The power (kw) of charging points that are required depends on the EV characteristics and more specifically on the battery size (kWh) as well as the time that a charge needs to be completed. These aspects are discussed below.

3.2.1 EV characteristics

A range of vehicles make up the EV fleet including PHEVs and BEVs and Extended Range Electric Vehicles (EREVs). They differ mainly in terms of vehicle drive trains and battery capabilities leading to different electricity demand profiles when connected to the grid. More details about the different types of EVs can be found below:

- PHEVs combine a battery pack and electric motor with an internal combustion engine where both the electric motor and the internal combustion engine can drive the vehicle. However, the battery pack is relatively small (5kWh -22kWh) allowing limited range when using electricity (e.g. modified Toyota Prius with plug-in capability).
EREVs also has both a battery pack (16-27kWh) that tends to be larger than in a PHEV but smaller than in a BEV and electric motor, as well as an internal combustion engine (e.g. Chevy Volt).

In BEVs the petrol tank and internal combustion engine of a conventional vehicle are replaced by a battery pack and electric motor, relying entirely on electricity for fuel. BEVs have large battery size of about 25-35 kWh allowing driving range of about 60-300 miles (e.g. Nissan Leaf, BMW i3 and Tesla Roadster)

Lately, the significant reduction in battery costs that has been achieved from $1,000 in 2008 to $485 in 2012, and the further cost reductions expected, are likely to boost the growth for BEVs. In addition, major car manufactures are entering the BEVs market (BMW, Nissan, Vauxhall, Renault, VW, Smart, and Peugeot). Some of them also follow quite aggressive marketing campaigns (e.g. BMW i3) aiming to achieve high sales.

It should be noted also that electric vans are expected to have different characteristics from passenger cars in terms of size of batteries that will have a significant impact on the type of charging profile.

3.2.2 Different power levels of charging points

Power (in kW) is primarily used to define the type of charging points. The higher the power of a charging point the faster the charge of an EV. There are three main EV charging speeds: Slow charging (up to 3kW) lasting 6-8 hours depending on battery capacity; Fast charging (7-22kW) lasting 3-4 hours depending on battery capacity; and Rapid charging units (43-50kW) which are able to provide an 80% charge in around 30 minutes depending on battery capacity.

- **Slow chargers** are suitable for overnight charging of EV in houses. While the first wave of public charging points were of this type, these are now being replaced by Fast and Rapid units.
- **Fast charging** reduces EV charge times to around half that of a slow charge by doubling the available current (7kW). Most commercial and many public on-street chargers already use this technology. In the future it is expected that fast charging points will replace slow ones. Whilst fast 3-phase charging is also possible (each phase delivering approximately 7kW to deliver a total of 22kW) this is mostly used for electric trucks and buses, which have much larger battery packs.
- There are both AC and DC **rapid chargers** available with power ratings up to 43kW and 50kW respectively. The rapid AC option is a relatively new development and less common than the rapid DC option.
There are different standards and types for the connectors that are used to allow the charge of an EV from a charging point. These vary depending on whether an EV is charged using AC (alternating current) or DC (direct current), the charging power and the safety protocol employed. No universal standard has been adopted yet.

According to DECC scenarios for EV uptake, slow charging technologies will be more widespread compared to fast charging in the immediate future, reaching their peak deployment in 2024 and fading out by 2030.

### 3.3 Spatial distribution of charging points

#### 3.3.1 Domestic charging points

When considering the potential impact of EV penetration on the distribution network, it is essential to recognise the geographical density of EV deployment.

As the EVs start to become more popular, studies have been conducted trying to analyse the characteristics of EV owners based both on empirical data on EV owners and non-EV owners survey data. Being able to predict which customers are more likely to adopt an EV in the future can help network operators to identify network areas that may be impacted and thus be prepared on how to best deal with any issues.

Initial empirical studies are mainly conducted in USA where the EV uptake is relatively significant especially in states like California. These provide insights about the demographics of EV owners but
they rather suggest correlation than actual causation. However, results from different studies tend to identify common attributes for EV owners.

It is important to note though that the literature suggests that the early adopters of EVs and thus their characteristics will not necessarily allow us to understand the early majority. Nonetheless in the next 10 years it’s not expected that the majority of people will have an electric vehicle and thus initial findings on EV owners characteristics could be a way to predict EV uptake from certain customer groups.

**EV owners tend to have quite high income and live in single family houses**

Income is one of the main factors related to the adoption of EVs that is captured and highlighted in all the reports reviewed related to the characteristics of EV owners. On average it seems that EV owners have household income significantly higher than the average household income of all new car buyers. More than 80% of EV owners have annual household income of more than £59,000 and more than 50% more than £88,000. A reason for this might be the higher cost for acquiring a new EV as well as that an EV might be the second car in a family (94% of them have a second car).

**Figure 6: More than 80% of EV owners have an annual household income of more than £59,000**

People with higher household income tend to have single family house which is the main reason why more than 90% of the EV owners reside in single family house. Single family houses typically have a parking place and thus installing a charging point in the household is relatively easy which may explain the very high percentage of EV owners living in a single family house.
**EV owners tend to be middle aged and older people**

Demographic analysis of EV owners from two studies reveals that approx. 80% of the EV owners are between 35-64 years old. It seems that EVs are more appealing to older audiences and people that have families\textsuperscript{15,17}.

**Figure 7: 96% of EV owners are 35 years or older**

![Bar chart showing percentage of EV owners by age group]

**Box 1: EV owners tend to be younger and wealthier than hybrid car owners**

A comparative analysis of demographics for EVs and hybrid-powered cars based on calendar-year 2013 sales conducted by Experian Automotive for US market revealed that EV owners tend to be considerably younger and more affluent than the hybrid-powered car owners. The study found that 55 percent of electric vehicle buyers are between 36 and 55 years old and nearly 21 percent have an average household income of $175,000 or more. On the other hand, 45 percent of the hybrid-powered car owners are 56 years old or older (compared to just 26 percent of new EV owners), with 12 percent having an annual income of $175,000 or higher. A possible reason for this disparity could be the growing popularity of the higher-end luxury electric models available that are more appealing to younger and wealthier audiences\textsuperscript{18}.

**EV owners tend to be very educated**

A study revealed that EV owners are very educated as the vast majority of them have a university degree\textsuperscript{15}.
Significant percentage of EV owners has also a PV installed at their place
On average it is estimated that approx. 40% of the EV owners also have a PV\textsuperscript{15,16}. There seem to be a correlation between the PV and EV ownership that may have to do with attitudinal factors potentially related to symbolic motives as both PVs and EVs express environmental friendly thinking. As attitudinal factors, particularly relating to symbolic motives, identity or specific attitudes about the technology are stronger predictors of the likelihood to adopt than demographic factors\textsuperscript{14}, such as correlation between PVs and EVs, these could allow more accurate forecast of the spatial distribution of EVs and PVs in the future.

“Keeping up with the Joneses” can influence the adoption of EVs
As people with similar demographic characteristics tend to live in the same areas it is likely that also the adoption of EVs could be also clustered in specific areas as long as demographics are a good way to predict the future uptake of EVs. However, apart from the demographics, social factors can play a bigger role in the adoption of new technologies\textsuperscript{19}. Hence, social influence factors such as the comparison to one’s neighbour as a benchmark for social caste or the accumulation of material goods (“keeping up with the Joneses”) can also have an impact on who adopts an EV. To fail to “keep up with the Joneses” is many times perceived as demonstrating socio-economic or cultural inferiority and thus creates pressure to follow a similar lifestyle with your neighbours. Some initial evidence around the clustering effect are identified in a US trial were 8,000 participants had to buy or lease their electric vehicle\textsuperscript{20}.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{bar_chart.png}
\caption{87\% of EV owners have at least a university degree}
\end{figure}
3.3.2 Commercial charging points

To the best of our knowledge there are no studies as yet regarding the characteristics of SMEs that are likely to adopt electric vans. However, DNV GL thinks that companies that promote sustainable products (e.g. organic food, energy efficiency services) are more likely to acquire an electric van. It is expected that these companies will install a charging point in their premises to enable the recharge of their vehicles.

Apart from the commercial vehicles, private EVs could also be recharged at workplaces. Hence, extra charging points for employees’ EVs could be installed as well.

3.3.3 Public charging points

It is expected that the majority of recharging is likely to take place at home and at work, and thus extensive public recharging infrastructure would be underutilised and uneconomic. However, there will still be need for public charging points that should be targeted at key destinations such as supermarkets, retail centres and car parks, with a focused amount of on-street infrastructure, particularly for residents without off-street parking. Moreover, public charging points are needed to enable longer journeys. In an attempt to meet that need, Tesla for example is developing its rapid public charging points all around the world to enable long journeys.

Box 2: New York City requiring 20% of all parking spaces to be EV ‘charger ready

NYC has mandated that owners of parking lots, parking garages and other off-street parking areas to supply a fifth of the spaces with charging stations. That means that the number of off-street spaces reachable to plug-in chargers in the Big Apple should surge from fewer than 200 today to about 5,000 spaces by the end of the decade and, eventually, to 10,000. Parking lots need to be able to supply “3.1 kW of electrical capacity to at least 20 percent of the parking spaces of the garage.”

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3.4 Temporal distribution of electricity demand

The charging of the EVs is likely to depend on the type of use and the behavioural characteristics of the EV user.

3.4.1 Type of use for EVs

EV owners prefer to use their EV mostly for personal errands and shopping followed by work commute and leisure as shown in Figure 9. On the other hand EV owners tend not to use the EV for their holidays and business travelling. Issues around the range of EVs are likely to be the main reason for such behaviour.

Figure 9: EV owners prefer to use their EV mostly for personal errands and shopping

Two different types of EV owners have also emerged: the Urban Commuters and the Enthusiasts

Urban Commuters

Increasing availability of public charging infrastructure and/or a charging infrastructure at workplaces has and is likely to increasingly encourage urban commuters with off-street parking (who can also plug in at home) to take-up EV’s. It is these characteristic that have made urban areas an ideal location for early adaptors. Also, the provision of financial incentives to encourage EV ownership has been a key driver. These incentive schemes also tend to focus on urban areas, where need to improve air quality is higher e.g. derogation of congestion charging in London.

Enthusiasts

These customers are driven by innovativeness and are prepared to pay a premium for EV’s. They represent a very small segment of overall car buyers but tend to form a higher proportion of early adaptors. These enthusiasts are more willing to adjust their driving and parking habits to own an electric car and as such are likely, for example, to be less concerned about a comprehensive charging
infrastructure. However, as EV's migrate to the mass adoption in urban areas the appropriate infrastructure will become increasingly important.

These different types of uses are likely to lead to different temporal needs for charging that can take place also in different places. For example, an EV owner who uses her car mainly for shopping or an EV enthusiast may use more public charging points than somebody who primarily uses her car for work commute.

Apart from the domestic EV owners there are expected also to be owners of fleets of EVs that may be used by the public or private sector to cover certain needs. These fleets will also have different temporal energy demand needs depending on the type, duration and period of the day they are used.

**Fleet**

**Public sector procurement.** Government, local authorities and other public sector organisations have supported a switch to EV's. For example, the government has committed to invest £5 million to introduce electric vehicles across government and wider public sector fleets this year.

**Private sector procurement.** Fleet or business users in urban and suburban locations are better placed to exploit the full environment and cost of ownership benefits from EV's, which include:

- Lower running costs ie. cheaper than petrol
- Lower servicing costs for pure electric vehicles due to fewer moving parts i.e. less frequent servicing
- Current tax perks – lower company car tax than petrol cars and lower Vehicle Excise Duty
- Other Government initiatives also lower the cost of EV ownership, such as grants towards the cost of a new EV (e.g. 25% off the cost of a car, up to a maximum of £5,000, 20% off the cost of a van up to a maximum of £8,000)

**Box 3: The development of fleets of EVs can improve the public perceptions of EVs**

Nissan is getting into the taxi market in New York, London, Barcelona, Hong Kong and Tokyo, and the reason is the same: electric. By 2015, they aim to put electric taxis onto the streets of these cities in order to improve air quality but also to showcase the appeal of electric cars. Moreover, British Gas has recently completed a trial of 28 Nissan e-NV200 electric vans, running on its home-brewed energy, that joined the firm’s 13,000 home service fleet. The trial was quite successful and British Gas is to buy 100 more all-electric e-NV200 vans. The company intends to switch 10% of its fleet to electric power by 2017. As thousands of people will use cabs and see the electric vans they could transform their vision of what electric cars can do.
3.5 Commercial models and new technologies

As the EV market is still at its infancy, new business models and technologies are likely to have a significant impact on the previously discussed aspects leading to potentially different impacts on the distribution network.

Repurposing electric car batteries for grid storage can drive EV prices down and lead to a higher uptake of EVs

Currently lithium ion batteries make up roughly half the cost of an all-electric vehicle and thus keep the prices of EVs quite high compared to conventional vehicles. However, the introduction of a new business model that allows the repurposing of auto batteries for grid storage could significantly cut down the cost of EVs for consumers. Lithium ion batteries lose a significant percentage of their charging capacity after thousands of charging cycles, but still the remaining capacity is good enough for grid storage. A potential business model that is being explored is that utilities would own and lease the batteries to consumers and then recoup them after a certain time\textsuperscript{24,25}. Lower prices of EVs will boost their sales and allow their development more quickly without a technology breakthrough in batteries. However, the success of such a business model will depend on the actual value that storage can extract from the electricity system.

Mobility as a service for cities can allow the development of optimal infrastructure for EVs\textsuperscript{26}

Car sharing has seen significant growth over the last years in major cities worldwide. Companies such as Zipcar and Hertz 24/7 have cars parked in different locations within a city and hire them by hour. This allows the same car to be used by many different customers. Both companies experimented with EVs to better understand how they can adapt their business model to allow their integration. Wider behavioural change of the way people use their cars might be needed for the further growth of such schemes. If this happens, the infrastructure needed for EVs in cities is likely to be very different, as fewer charging points will be needed and different charging profiles will be applicable. Such a business model will increase vehicle utilisation and reduce the system-wide capital costs required for the transition from conventional cars to EVs.

Driving subscription plans could determine the development of charging points and the form of charging profiles

Companies such as NRG EV Services (division of utility NRG)\textsuperscript{27}, and Charge Your Car (CYC)\textsuperscript{28} in UK have developed a business model around offering monthly plans for charging EVs. They develop their own privately funded charging stations ecosystem. Customers pay a monthly fee and they have access to charging points at home and in public places and can also have a home charger installed for free. This type of offer can also remove the electricity price volatility risk by offering fixed prices for longer periods that can be appealing to customers. This business model is like a mobile plan where
customer has to pay a monthly fee for a service. Besides, some EV manufactures have also introduced schemes to offer free charging at main fast charging stations (e.g. Tesla) which can also have an impact on charging profiles.

**Development of Vehicle to the Grid (V2G) services can have a significant impact on charging profiles**

Vehicle-to-grid (V2G) services refer to services in which EVs can be used to deliver electricity back to the grid when it is needed. Services such as system balancing could be offered through the utilisation of EVs. Development of such services could have significant impact on charging profiles as the battery of the EV would be also used as a storage device to offer services to the grid. However, such services are still not very efficient and raise battery life degradation issues.

**New IT added value services for the user (charging points, charging management) can influence charging profiles**

New IT enable technologies that are likely to use the mobile as core for customer interface can have a significant impact in several aspects of an EV car use. There are already applications available that can allow EV drivers to find public charging points or even book a time slot at those (e.g. Ecotality and Coulomb Technologies, Zapmap). Such applications can allow higher flexibility to use public charging points and thus reduce the potential use of home charging points. Moreover, other applications allow customers to choose when to charge their EVs (e.g. BMW application) in order to potentially take advantage of lower electricity prices during certain periods of the day.

**Driverless cars can improve energy efficiency and potentially change the way EVs are charged leading to different charging profiles and charging point needs**

Driverless technologies are developing quickly and UK Government has announced pilot schemes to get cars without drivers on the road by 2015. From an energy perspective, driverless cars can improve the energy efficiency of a car due to much smoother driving speeds and reduced drag through concepts such as car trains. This could directly influence the charging profile of EVs as less electricity would be consumed for the same itinerary. Moreover, driverless cars might not require to be charged at home as they will be able to drive to a local fast-charge point on their own when owners not using them. This could completely alter the current thinking that most of the charging of the EVs will happen at home.
The potential introduction of supercapacitors instead of lithium-ion batteries for EVs could impact the charging profiles

Supercapacitors store energy physically, on the electrodes’ surfaces instead of chemically in the material of their electrodes and their technology has been improved significantly the last years. There are applications on supercars such as Toyota TS040 hybrid that allow a kick of an additional 480 horsepower to be available from two electric motors connected to this supercapacitor. A new device, the hybrid supercapacitor, has recently reached 30-40% of a lithium-ion battery’s energy-density, and is likely to increase energy-densities still further in the near future. Supercapacitors can also last longer than batteries\textsuperscript{32}. If supercapacitors become mainstream in the future they could have an impact on the charging profiles of EVs.
4 Impacts of EVs on the network

The significant growth of EV’s is likely to increase network load and result in varying load patterns going forward. The specific impact on the distribution network will depend on the technical characteristics of the network itself and the type, location and time of vehicle charging. These factors will impact the DNO’s management of the network and exacerbate network management challenges in a number of ways. A few case studies were conducted over the last decade concluding that uncontrolled EV charging could lead to a significant increase in peak demand, power losses and voltage problems. Based on an extensive literature review the impacts of EVs on the distribution network and metrics used for quantifying those are; voltage levels, thermal loading, power losses, unbalance, harmonic distortion levels and transformer’s Loss of Life (LOL).

4.1 Thermal loading issues

EV charging will increase network load and power flows on the network, which will push network transformers and network line assets (e.g. underground cables) to operate at or closer to their maximum thermal rating. The thermal rating is determined by the asset’s maximum current-carrying capacity, so networks already operating close to capacity are likely to be particularly affected.

Some components of the distribution network, such as transformers, have normal and emergency ratings for their function. Critical parameters for the evaluation of thermal loading are the type of assets that are affected, the number of times that ratings are exceeded and their duration and magnitude. The shorter time scale of sampling during the load flow analysis can increase the accuracy of these results.

According to the results of another study transformers and three phase primary lines are the most sensitive assets. Transformers in particular are more likely to experience overload conditions if the connected EV chargers have an onerous load profile (large rating). The timing of the charging and its coincidence with existing peak network loading appears to have less overall impact on the likelihood of a transformer overload. Moreover the number of overloaded elements increases with EV penetration as expected.

4.2 Voltage control issues

The growth of EV’s will be customer driven and not centrally planned by DNO’s which increase the risk of unbalanced voltages. DNO’s are required to supply voltage within specified limits (230/400V +10/-6% for low voltage distribution networks). Potential concentration of EVs closer to the end of the LV feeders could create significant voltage drop issues. Research conducted on a typical UK and a Belgian distribution grid showed that a significant voltage deviation could be recorded in high EVs’ penetration levels.
Whilst in the urban areas more reinforcements are expected in medium and low voltage transformers than in feeders due to thermal loading issues, in the rural areas more reinforcements are required in feeders due to voltage control issues\textsuperscript{40}.

### 4.3 Network load losses

System load losses will be impacted by EVs due to changes of the power flows on distribution networks. If EVs are charged during the network peak demand times, this will increase the current levels and subsequently the network losses as these are proportionate to the square of the current value. A study\textsuperscript{41} showed that based on their simulation results, uncoordinated charging of EVs increases peaks and active power loss of power grid, which is caused by the charging load of EVs. Other studies also identified that the increased EVs’ penetration would also increase power losses\textsuperscript{38,39}.

### 4.4 Unbalance

EVs’ integration in the grid may lead to their disproportionate penetration on a particular phase of the electric system which adds to the unbalance of the system\textsuperscript{36}. A study\textsuperscript{42} focused on exploring the impact of electric vehicles on voltage stability and the results they acquired show that location and phase allocations of the EVs in network have a very significant impact on network stability.

### 4.5 Harmonic distortion levels

Converters AC to DC used in EVs for battery charging produce harmonics and affect the network\textsuperscript{43}. High harmonic distortion levels could have significant impacts on the distribution network\textsuperscript{44}, but a report for the California Energy Commission concluded that battery EV chargers complying with international guidelines at the time should not cause concern\textsuperscript{45}. Besides new power electronics for EVs allow the significant reduction of harmonics and as their cost is likely to reduce, it is expected that harmonics distortion levels will be minimal in the future not leading to any technical issues for the distribution network\textsuperscript{10}.

### 4.6 Transformer loss-of-life (LOL)

EV uptake could affect both positively or negatively the transformers’ life expectancy depending on whether EV charging coincides with network peak demand. The potential increased demand during network peak due to EVs can increase transformers’ temperature and subsequently it may decrease the life expectancy of the transformer. However, there may be a decrease of the probability of transformer’s failure due to load levelling resulting from off-peak EVs’ charging\textsuperscript{44}. It is also important that the combined effect of the ambient temperature and the rest of the factors that affect transformers’ LOL is understood as it can prove very crucial especially for geographical regions with high average temperatures.
A study\textsuperscript{46} showed that transformers’ LOL is exponentially dependent on transformer temperature and thus it is affected significantly by the deployment of EVs and ambient temperature. The losses increase when the number of PHEVs connected to the transformer increases as well as when the ambient temperature increases. However, the authors conclude that the results of their case study are extremely system specific.
5 Modelling network impacts

In order to better understand the potential impacts of EVs on the network through the Network Modelling Environment (NME) that has been established for the NTVV project47, a model that forecasts future electricity demand is required. The analysis undertaken in Sections 3 and 4 has been used to influence the development of the forecasting methodology to some extent. A simplified version of the overall modelling approach adopted is presented in Figure 10.

Figure 10: The overall modelling approach incorporates temporal and spatial considerations on EV charging

For the purposes of this study University of Reading (UoR) has created a forecasting model that allocates the distribution of EVs to the households of Bracknell area and the calculation of the demand profiles for households with and without EVs. The study has focused only on households and not SMEs as very limited or no data are available regarding the uptake of EVs and the charging profiles in this sector.

5.1 Overall scope of the UoR model

There are various projections as to the rate of EV uptake, but all predict an increase over the next ten years. Charging these EVs will produce one of the biggest loads on the low voltage network. Our primary goal is to understand the impact of EVs on the LV distribution network looking up to 8 years ahead to reflect the DNO price control period (RIIO ED1 price control review). To simulate the impact on the network under different EV uptake scenarios looking up to 10 years ahead (towards 2023) UoR developed an agent-based model for approximately 32,000 households, that includes 570 substations.
in Bracknell area using as input buddied medium term forecasts in half hourly resolution and real life charging patterns from an EV trial. At this stage the simulations are run for 379 households, 3 substations only (Grange Road, Horsenile Lane, and Ollerton) that are representative of the three different network sizes (small, medium, large in terms of customers connected). UoR initialises the model to assign an EV to a household based on either random distribution or clustered (based on social influence) distribution. Taking as input MPANs, postcodes, income information, existence of PV, street names and IDs of circuits the model outputs results in a csv file which will be then used as input for NME environment. The file encompasses recorded electric load demand data for all households in Bracknell area at half hourly resolution for the 5 chosen days (these that represent a mix of summer and winter weekend and weekdays and one Bank Holiday) in a year for 8 years ahead for given scenario and EV distribution. UoR demonstrates that the combination of agent-based modelling and simulation comprises a useful methodological approach to forecasting long term electric load demand, taking into account the factors such as timely and spatial characteristics of adoption of renewables (e.g. EV). The result is a flexible computational environment that enables simulating and comparing various future energy scenarios.

5.2 Methodology

Modelling complex systems, especially ones that include human behaviour such as energy demand and generation raise significant challenges based on complex interactions between different parts of the system, lack of knowledge of governing mechanisms and the limited predictability of human behaviour. With the long-term forecasts it is difficult to know what the global characteristics of a system will be in future. Also as we are looking into very fine resolution (individual households) it seems that ignoring heterogeneity would not be a realistic assumption, and therefore in order to model long term individual loads influenced by EVs under different uptake scenarios we adopt an agent-based modelling (ABM) approach. Use of ABM for load forecasting purposes is a relatively novel approach, but it is increasingly popular in this field. In a couple of articles 48, 49 the authors define an agent-based simulation as “a collection of heterogeneous, intelligent and interacting agents, which operate and exist in an environment, which in turn is made up of agents”.

ABM approach uses a computer simulation to track the model through time and/or space. It enables insights about complex systems on different scales: on an individual scale where individual agents are followed (micro-scale); on a meso-scale where groups are followed; and on a macro scale which can find steady states of the system. This flexibility arises from modelling (behaviourally) irreducible parts of the system as agents with simple rules of behaviour and interaction. ABMs can show “what could be” under different scenarios across uncertain futures (see 50 and 51). As previous research suggests ABMs can be used for exploring different scenarios of long term individual energy load. The main advantages are that a model can comprise many heterogeneous components that could interact
between themselves and nonlinear dynamics could be captured\textsuperscript{52}. Additionally, ABM structure would allow for inclusion of many different scenarios into the same model.

The more detailed description of the long term forecasting ABM, its rules and constraints set, is given below.

5.2.1 Long Term Forecast Model Description

As our main concern is an individual electrical load, we consider a household to be an agent - the irreducible part of a system. Our model predicts an agent behaviour in future 10 years on half-hourly basis, and aggregates agents behaviours on street/feeder and substation/neighbourhood levels. Calibrating a model with data, assigning simple constraints/rules to households, and using a computer simulation, we track the model through a number of future years.

The model is implemented in Java using open source Repast agent-based simulation libraries\textsuperscript{53}, which enable separation between model specification, model execution, model visualisation, and data storage. It comprises of ‘household’ agents with addresses corresponding to the Bracknell area provided by SSEPD (Scottish and Southern Energy Power Distribution). Currently our model is static i.e. the agents do not change location and do not interact but do observe each other.

The distribution of electrical vehicles between agents is implemented to be random or clustered. In a clustered distribution an EV is assigned to a household based on a social influence i.e. the neighbour of an EV owner is more likely to also purchase an EV. For EV distribution UoR uses so called Roulette Wheel or fitness proportionate selection method where fitness of a given household will depend on the number of its neighbours already owning an EV. The list of its neighbours is obtained from data file from the Bracknell area network. It is assumed that two households are neighbours if they are located on the same street and are on the same feeder (information extracted from circuit ID).

5.2.1.1 Creation and initialisation of household agent

In the model, we initialise all agent households with historical buddied medium forecast load profiles data sampled for previously chosen 5 days (August 10, 2013; August 14, 2013; January 3, 2014; January 7, 2014 and April 20, 2014) that represent a mix of summer and winter weekend and weekdays and one Bank Holiday (Easter Sunday). We use the same sample for all simulations, assigning randomly households to load profiles (see Figure 11).
The buddied medium forecast data was provided by our colleagues from University of Oxford as part of the Thames Valley Vision project. We use another data-set gathered by SSEPD as part of its research into electric vehicles which contains 19 electrical vehicles charging patterns through one year period. We select and sample charging patterns for each day of the week during one month in summer, one month in winter and bank holidays. Other parameters needed for the initialisation are EV distribution type (clustered or random), and EV uptake scenario (high, medium or low EV uptake).

Figure 11: Agent ‘Household’ is initialised with a buddied medium forecast load profiles. If it obtains EV, its charging will be added to its profile.

5.2.1.2 Running the simulations and output

At every time-step (1 year), a given number of EVs (decided by the given scenario) is distributed between household agents such that parameters and constraints of the model are satisfied (see Figure 12); some of the properties of household agents are updated; and the change of load demand for every agent is recorded. The output is the updated half-hourly daily profile for each household for each year. If a household acquired an EV, the corresponding average EV charging pattern will be added on a top of its base-load on each of 5 selected days. The output therefore contains updated half hourly loads for all households on the five selected days.

When a particular scenario (high, medium or low uptake of EVs) is chosen, this defines the number of EVs that will be distributed in the neighbourhood each year. If Random Distribution is then chosen, EVs will be distributed uniformly at random to the eligible households, i.e. ones that do not already own an EV; if Clustered distribution is chosen, EVs will be distributed to the eligible households using

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3 SSEPD’s MINI E Trial Phase 1 where participants were incentivised to charge their EVs after 23:00.
so called Roulette Wheel or fitness proportionate selection method where fitness will depend on the number of neighbours already owning EV.

**Figure 12: 3 EV uptake scenarios and two spatial distribution approaches are used**

5.3 Assumptions

In this subsection we present the list of assumptions we adopted for our long term forecast model. See below the list of key assumptions:

- It is assumed different rates of adoption of low carbon technologies (LCT) as suggested in DECC future energy scenarios. DECC scenarios give nationwide predictions, thus for this project UoR scaled down the numbers to ~30000 households.
- It is assumed that at 2013 (which is the year we start our simulations) there are no EVs in Bracknell area.
- In our long term forecast model we look at household level electricity demand only. At this stage we do not take into account any commercial customers.
- It is assumed that a household can take charge of one EV only throughout 10 years interval.
- Households with no private parking spaces could potentially be assigned an EV.
- It is assumed property type does not have any impact on adoption of EVs.
- UoR analyses the impact of fast charging EVs (the cars observed in MINI E Trial Phase 1 have 7kw chargers) since currently this is the only data available containing EV uptakes in 48 half hours resolution for 1 year period of time. Despite the fact that the participants in the trial were incentivised to charge their EV after 23:00 there is some evidence from other trials that...
such behavior may be adopted even without incentives. People may find it more convenient to do the charging of their EV just before they go to bed in a similar way they charge their mobile phones.

- It is assumed that every household that acquires an EV has got one charging point for slow charging EV.
- No public EV charging points are taken into account.
- It is assumed that two households are neighbours if they are located on the same street and are on the same feeder (information extracted from circuit ID).
- All new EVs that are allocated in each year are distributed to the customers on the first day of the year.

5.3.1 EV uptake in Bracknell area

The uptake of low LCT is modelled according to future energy scenarios (DECC works-stream 3)\(^4\), which propose different rates of adoption for different global future trends. LCTs are distributed between agents and the change of load demand for every agent is recorded. In our model the experiments are implemented for 3 scenarios (DECC work stream scenarios 1, 3 and 4 on slow-charged EVs uptake, adapted for SHEPD by Element Energy). Scenarios for the south east UK are available but not in the public domain.

<table>
<thead>
<tr>
<th>DECC Scenarios*</th>
<th>EVs Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low - Purchase of international</td>
<td>4 Low</td>
</tr>
<tr>
<td>Medium - High abatement in low carbon heat</td>
<td>1 Medium</td>
</tr>
<tr>
<td>Medium - High abatement in transport and bio-energy</td>
<td>2 Medium</td>
</tr>
<tr>
<td>High - Focus on high electrification</td>
<td>3 High</td>
</tr>
</tbody>
</table>

Figure 13 plots total number of EVs for ~30000 households in Bracknell area (see Fig. 11) per year in Scenario 1, 3 and 4 correspondingly.

*Note: Number of years is limited to 18. According to DECC scenarios after 2024 fast charging EVs will take over the market. Thus the number of slow charging EVs starts decreasing. For this phase of the project we assume all purchased EVs are slow charging.

\(^4\) Note we skip scenario 2 since it is identical to scenario 3 for EVs.
To put these numbers in perspective, the sales of PEVs in the Bracknell area (Bracknell Forest Council) during the last 4 years are quite low and lower than the UK average. In 2013, 0.17% of new car sales in UK were PEVs but in Bracknell Forest Council only 0.01%.

Figure 14: EV sales in Bracknell area are very low compared to the total car sales
5.4 Overall scope of the NME model

The NME model is able to analyse load flow and nodal voltages of the distribution network in the Bracknell area including the three substations that are simulated for the purposes of this report.

5.5 Results and Analysis

There are three substations simulated for the purposes of this study in the Bracknell area: Grange Rad, Horsneile Lane and Ollerton. Simulations have been undertaken with NME to understand the network impacts for year 2021-2022 (at the end of RIIO ED1) price control review for DNOs). In order to evaluate the impact of EVs, it was necessary to run the study with forecast house hold load separately with and without EV loads added.

The results from the NME include the load flow analysis and voltage nodal analysis. Thematic maps of the network are produced as a result of the base case and confidence case power flow analyses. These show the loading (calculated current compared to rated current) levels of the equipment in three colours: Red (base case above 100% loading), Amber (base case below 100% loading, but above 100% for at least one confidence case) and Green (all base and confidence cases below 100% loading).

5.5.1 Clustered High EV uptake scenario

The first simulation run is the one with the clustered allocation and high EV uptake scenario (Clustered High EV uptake scenario) in order to analyse the worst case scenario for the network for the time period considered. This scenario is expected to have the most severe impact on the network due to the highest number of EVs and their relatively high concentration in particular areas of the network.

Network issues identified

Taking into account all the assumptions laid out in the previous sections, the analysis of the results showed:

No voltage related issues

The voltage nodal analysis of the NME simulations for all days revealed that there are no voltage drop related issues. The network operates within the voltage variation limits during all times. Thus the analysis below will focus on the power flow issues.

5 For further information on the NME functionality please see GE (2013) Network Modelling Environment, P11797-SSEPD-LCNF-NTVV, Detail Design
No parts of the network are overloaded due to EVs (no “Red” parts)
The power flow analysis from the NME indicates that the EVs do not cause severe overloading of any parts of the network (no additional “Red” sections). However, on some occasions the EVs increased the number of sections of the network that may become partially overloaded (some additional “Amber” parts).

Parts that may become overloaded due to EVs are mostly located closer to the substations
The impacts of increased EV loads becomes more apparent in main cables 3-phase feeders closer to substations where some parts of the network may become overloaded (some additional “Amber” sections).

Smaller low voltage networks with fewer customers may face less impacts from EV uptake
Initial evidence suggests that smaller networks will be less impacted by EV uptake as they are likely to have more headroom available in their feeders.

Impacts from EVs during summer may be more severe compared to winter
During summer feeders operate with reduced ratings (thermal capacity is less due to higher air temperature) and thus can serve reduced power flows. As a result the impacts from EVs could be higher during summer.

Summary of results
A summary of both the power flow and voltage nodal analysis in presented in Table 1. The power flow analysis includes the percentage of the length of the network that corresponds to the three categories “Red”, “Amber”, “Green” as well as the total length of the feeders that are at risk (“Red” and “Amber”). The voltage nodal analysis presents the percentage and number of customers services that subject to voltage limit violations.
### Table 1: Summary of results

| Substation   | Feeders length (m) | Customers served | Number of EVs | Red | Amber | Green | Risk length (m) | Customers in risk | Red | Amber | Green | Risk length (m) | Customers in risk | Red | Amber | Green | Risk length (m) | Customers in risk | Red | Amber | Green | Risk length (m) | Customers in risk | Red | Amber | Green | Risk length (m) | Customers in risk |
|--------------|-------------------|------------------|---------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|-----|-------|-------|----------------|------------------|
| **Baseline** |                   |                  |               |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |
| GRANGE ROAD  | 1452              | 43               | 6             | 0.00%| 0.00%| 100.00%| 0              | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                |
| HORSNEILE LANE | 4778             | 199              | 27            | 0.54%| 0.00%| 99.46% | 26             | 0                | 0   | 0.00%| 0.54%| 99.46%       | 26               | 0   | 0.00%| 0.54%| 99.46%       | 26               | 0   | 0.00%| 0.54%| 99.46%       | 26               | 0   | 0.00%| 0.54%| 99.46%       | 26               |
| OLLERTON     | 2695              | 137              | 21            | 0.86%| 0.17%| 98.98% | 28             | 0                | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               |
| **Clustered**|                   |                  |               |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |
| GRANGE ROAD  | 1452              | 43               | 6             | 0.00%| 0.00%| 100.00%| 0              | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                |
| HORSNEILE LANE | 4778             | 199              | 27            | 0.54%| 1.30%| 98.16% | 88             | 0                | 0   | 0.54%| 1.30%| 98.16%       | 88               | 0   | 0.54%| 1.30%| 98.16%       | 88               | 0   | 0.54%| 1.30%| 98.16%       | 88               | 0   | 0.54%| 1.30%| 98.16%       | 88               |
| OLLERTON     | 2695              | 137              | 21            | 0.86%| 0.17%| 98.98% | 28             | 0                | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               | 0   | 0.86%| 0.17%| 98.98%       | 28               |
| **High uptake** |               |                  |               |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |     |       |       |                |                   |
| GRANGE ROAD  | 1452              | 43               | 6             | 0.00%| 0.00%| 100.00%| 0              | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                | 0   | 0.00%| 0.00%| 100.00%       | 0                |
| HORSNEILE LANE | 4778             | 199              | 27            | 0.54%| 0.54%| 99.46% | 26             | 0                | 0   | 0.54%| 0.54%| 99.46%       | 26               | 0   | 0.54%| 0.54%| 99.46%       | 26               | 0   | 0.54%| 0.54%| 99.46%       | 26               | 0   | 0.54%| 0.54%| 99.46%       | 26               |
| OLLERTON     | 2695              | 137              | 21            | 0.86%| 1.02%| 98.98% | 28             | 0                | 0   | 0.86%| 1.02%| 98.98%       | 28               | 0   | 0.86%| 1.02%| 98.98%       | 28               | 0   | 0.86%| 1.02%| 98.98%       | 28               | 0   | 0.86%| 1.02%| 98.98%       | 28               |

**Notes:**
- **Baseload** represents typical load conditions.
- **Clustered** represents increased load conditions.
- **High uptake** represents peak load conditions.
- The table includes columns for **Temperature** node, **Voltage nodal**, **Thermal flow**,
- **Clustered**, **High uptake**, and **Baseline** load conditions.
- Each substation is listed with its associated feeders, length, customers served, and number of EVs.
- Risk length and customers in risk are calculated for each scenario.
- Each substation is assessed for Red, Amber, and Green zones.

**Abbreviations:**
- **Red**: Red zone indicates high risk.
- **Amber**: Amber zone indicates moderate risk.
- **Green**: Green zone indicates low risk.

**Further Analysis:**
- The table provides a comprehensive summary of the results for different load conditions, enabling a detailed comparison of performance under various scenarios.

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**Further Reading:**
- For a detailed analysis of the data, refer to the full report on the New Thames Valley Vision project.
**Detailed presentation of results**

As shown in Table 1 there are no voltage related issues in any of the substations and days analysed. Also in the **Grange road** substation’s network which represents the substation with the fewer customers there are no issues identified both without EV load added (Base load) and Clustered high EV uptake scenario during any of the days analysed. Thus the analysis below will focus on the power flow analysis of the Horsneile Lane and Ollerton substations. Also in some cases the results between the Base load and the Clustered High EV uptake scenario are the same indicating that no additional network impact is caused by the EVs\(^6\). Therefore an analysis takes place only on the occasions when an impact associated to EVs is identified.

**Horsneile Lane substation**

In all the five days explored the deployment of EVs caused a small proportion of the network (less than 2%) to turn amber from green implying the increased risk of potential failure as shown in Figures 15-18 (marked with a red X are the locations of the EVs). During summer and on Easter day there are a larger number of network parts that face an impact. In the case of summer this is explained due to the reduced thermal capacity ratings of the feeders because of the higher air temperature. During Easter the base loads are higher and thus the additional impact of EVs is also bigger. Moreover, the network issues appear to be closer to the substation where the load is higher on all occasions.

\(^6\) Please note that in some occasions there are overloaded sections of the network in the Base load simulations.
Figure 15: HORSNEILE LANE - Saturday Aug 2021
HORSNEILE LANE Base Load  
Saturday Aug 2021

HORSNEILE LANE Clustered High uptake  
Saturday Aug 2021

Figure 16: HORSNEILE LANE - Thursday Aug 2021
HORSNEILE LANE Base Load  
Thursday Aug 2021

HORSNEILE LANE Clustered High uptake  
Thursday Aug 2021
Figure 17: HORSNEILE LANE - Friday Jan 2022 & Tuesday Jan 2022

HORSNEILE LANE Base Load Friday Jan 2022 & Tuesday Jan 2022

HORSNEILE LANE Clustered High uptake Friday Jan 2022 & Tuesday Jan 2022

Figure 18: HORSNEILE LANE - Easter April 2022

HORSNEILE LANE Base Load Easter April 2022

HORSNEILE LANE Clustered High uptake Easter April 2022
**Ollerton substation**

There is only one out of the five days analysed when there is a difference between the impacts of base load and the clustered high EV uptake. This is on a weekday in January 2022 and only involves a short part of a feeder close to the substation that becomes amber revealing the increased risk of failure for this part of network.

**Figure 19: OLLERTON - Friday Jan 2022**

- **OLLERTON Base Load**
  - Friday Jan 2022

- **OLLERTON Clustered High uptake**
  - Friday Jan 2022
5.6 Model limitations

5.6.1 UoR model

The long term forecasting model has the following limitations:

- It is constrained by the assumptions listed in subsection 5.3
- Data obtained from EV uptake trial is limited. The trial contains observations for 19 customers only that were incentivised to charge their EVs from 23:00 onwards.
- It only takes into account five days around the year and doesn’t necessarily focus on the period when the actual network peak demand from base load perspective is expected
- The model validation can be difficult due to the long term time scale and probabilistic approach used in EV clustered distribution mode. This can be overcome by running multiple simulations and testing the accuracy of the long term forecasts using both for clustered and random EV uptake distributions and comparing the results in the context of half hour electricity uptake and mean and standard deviation of end-user demands.

5.6.2 NME model

The NME model has the following limitations:

- The NME is at an early stage of development and is configured for project use. Significant time is needed in order to conduct the full network analysis due to the relatively slow computational speed. Several hours were needed in order to get the NME results for 3 substations that serve 379 customers for 5 days for each iteration of the simulations.
- Disaggregated results from power flow and voltage nodal analysis
- Lack of high level summary of network analysis

5.7 Recommendations for future refinement of the model

Conduct simulations for a wider network area and incorporate criteria such as income and PV ownership to determine the EV ownership

Modelling the uptake of EVs in the wider Bracknell area will allow the adoption of further criteria such as income and PV ownership to determine the EV ownership. This approach will allow the identification of the network areas that have more EVs adopted and thus conduct subsequent detailed network analysis to the areas that have the larger rate of EV adoption.

Simulate more days of the year and look further in the future

Simulation of more days around the different seasons of the year could allow a better understanding of when the EVs can cause the biggest impact around the year. Also simulations that look further into the future could provide an indication of when and at what EV penetration levels major network
reinforcements will be needed.

**Determine neighbours based on their actual physical locations**

The use of actual GIS data to determine the “neighbour” relationship could allow a more realistic representation of the clustering effect. Such an approach will allow customers that are actually neighbours but live in different streets and are connected to different feeders will be considered as neighbours for the modelling purposes.

**Inclusion of all metrics to assess EV impacts**

All the metrics presented and analysed in Section 4 should be used in order to exhaustively evaluate possible technical barriers. This study has looked into the analysis of power flows at the feeder level but not at the substation level (transformer level). Therefore, further research is needed to fully understand the impacts at a substation level and especially to be able to calculate and evaluate the harmonics distortion levels, the unbalance of the system, the network losses and the transformer loss of life.

**Use of different charging profiles for different customer categories**

As more EV trials are conducted in UK and especially in the LCNF framework there is scope to use the outputs from these projects (e.g. My Electric Avenue project) in order to use more realistic EV charging profiles that can be assigned to different customer categories. Such a strategy would allow the better representation of the behavioural aspect of EV charging and its impact on different parts of the network.

**Simulate the impact of the implementation of potential remedial measures (see Section 6)**

Specific case studies could be conducted to evaluate the impact of the implementation of potential remedial measures to better understand which could work better taking into account the particular characteristics of the local network.

**V2G services to be included**

Future studies, depending on the development of the technology, should explore the V2G technologies and their potential impact on the distribution grips (creation of network peaks if they participate in the spot market)
6 Potential remedial actions for EV impacts on the distribution network

The literature review and modelling work revealed that grid restrictions may limit the growth of EVs penetration, if no additional measures are adopted. Since EVs’ popularity depends also on the readiness of the electrical system to integrate them, it is important that DNOs are well prepared to alleviate these impacts using different remedial actions. These potential actions have been grouped in three main categories depending on the type of approach that the DNO may choose: a) Reactive approach to charging point deployment, b) Proactive approach to influence charging point deployment without smart control charging and c) Proactive approach to charging point deployment with smart control charging. There are two main considerations for DNOs when it comes to selecting an approach: the level of complexity in its implementation and the potential benefits for the DNO. Figure 20 presents conceptually how these approaches compare against these two key aspects.

Figure 20: Increased potential benefits from remedial actions for EVs are likely to come with higher levels of complexity

A discussion around the different approaches and potential actions follows.

6.1 Reactive approach to charging point deployment

DNOs have the option to just react on whatever happens regarding the deployment of the charging points in their network. On this occasion they need only to be able to identify in which points of the network traditional reinforcements are required to ensure the normal operation of the network.

Identification system/licence for domestic charging point installation – regulatory intervention
needed
Currently DNOs have no visibility of EVs charged at customers premises via the existing service connection. However, in order to avoid potential local blackouts DNOs need to become aware or these installations. It is likely that a regulatory requirement will be needed to announce the installation of the charging point to the DNO (potentially through the car distributor) or through the connection of an Auxiliary Load Control Switch (ALCS) in household’s HAN of the smart metering infrastructure. ENA has already developed a notification form that could be used in the future. This would be similar to the G59 Generation Connection Guide requirement.

6.2 Proactive approach to charging point deployment without smart control charging
Conducting research and following EV market trends could allow DNOs to develop a more proactive approach in order to influence the point and voltage level of connection to the their network by informing other stakeholders that are interested in deploying charging points. This way DNOs in collaboration with other stakeholders would be able to deliver more cost efficient traditional network reinforcements.

Aggregated charging points at a high voltage level located near the existing high voltage network can be more cost effective than charging points in the low voltage network in studies else where it has been suggested that aggregated recharging in the high voltage network is less costly, except when the new high voltage recharging points are located far from the existing high voltage network. In the latter case, charging at low voltage would be a cheaper approach. Therefore, if aggregated charging points are deployed at a high voltage level, they should be located near the existing higher voltage network in order to reduce the connection cost.

On those occasions that connecting charging points at higher voltage network makes sense and there are available parking spaces, DNOs could promote/encourage other stakeholders to develop aggregated charging points to ensure lower network investment costs. It may be worth to further explore whether such an approach would be appropriate for the UK distribution networks.
6.3 Proactive approach to charging point deployment with smart control charging

DNOs have the opportunity to implement a proactive approach to the deployment of charging points through the use of smart control charging strategies that can be implemented either by direct EV load control or by a market-based approach for the EV charging. The complexity of the implementation mechanisms depends on which and how many markets the EVs participate in, as network congestions can be further enlarged due to the clustering effect and thus smart charging solutions are needed to alleviate these effects.

The following sections present the strategies that the DNOs can adopt to mitigate the network impacts from EVs, what different implementation mechanisms are available and what may be the associated technical and technical issues (see Figure 21).

Figure 21: A set of strategies and implementation mechanisms are available to mitigate network issues through smart charging but there may be some technical and regulatory issues

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Implementation Mechanisms</th>
<th>Technical and regulatory issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Minimise contribution to network peak</td>
<td>1. Market based</td>
<td></td>
</tr>
<tr>
<td>2. Match local demand with local generation</td>
<td>2. Direct control</td>
<td></td>
</tr>
</tbody>
</table>

6.3.1 Strategies that help alleviate EV uptake issues

There are two main groups of strategies that can help alleviate EV uptake issues: minimise contribution to network peak and match local demand with local generation. Both of these strategies can reduce the thermal constraint and voltage drop issues depending on the network conditions.

6.3.1.1 Minimise contribution to network peak

DNOs can alleviate network issues by reducing the network peak load in order to maintain the operation of the network within approved limits. This can be done either by avoiding EV charging during network peak or by reducing the actual EV charging load.

Introduce charging points that can operate both as slow and fast chargers to allow higher flexibility

According to DECC scenarios fast charging will prevail in the future as it will allow reduced charging times. However, the load that is added to the network with fast charging is approx. double of that of slow charging, reinforcing the issues that networks are facing. To alleviate these issues, instead of deferring or stopping a charging cycle for the EV, the introduction of a dual charging system (both slow and fast) that can be used interchangeable depending the network condition. The fast charger will be
used when the network is not facing any issues, and will be substituted by a slow charger when network needs capacity to be freed. Such strategy allows the continuing charging of the EV but with a lower charging rate. Automated dual charging systems could be part of a solution to better manage continuous EV charging that could be more accepted by customers compared to controlled interrupted charging.

**Deployment of distributed storage in the low voltage network can be used to cover part of the EV demand and thus reduce network peak demand**

Distributed storage has the opportunity to alleviate problems from EVs as it can be used to cover part of the additional EV demand when needed in order to reduce the network peak at local level. V2G services also explore the opportunity to use EVs as practically distributed energy storage resources that can be utilised when required. However, the potential impact of V2G services to the deterioration of the life of EV batteries may act as a barrier for the uptake of this technology if not resolved.

**6.3.1.2 Match local demand with local generation**

Matching local demand with local generation offers the opportunity to avoid exporting electricity to a higher voltage level network creating reverse power flows that can trigger network investments. EVs could absorb the electricity generated locally to alleviate this issue.

**Take advantage of synergies between DG and EVs to alleviate DNOs issues**

EV charging offers an opportunity to better manage DG integration and operation in the low voltage network. Technologies such as PVs and micro-CHPs are expected to be connected in the LV network and EV charging in the same feeder could be incentivised to take place when there is significant output from these.

**Promote charging of EVs during daytime for households with PVs**

Latest studies have revealed that there is a correlation between the ownership of PVs and EVs (see Section 3.3.1) and thus there is an opportunity for the DNO to promote EV charging during the daytime when there is significant PV electricity output. By doing this it is likely that EV charging could avoid the evening network peak and also reduce potential reverse power flows due to PV outputs. Such strategy could work well with EV and PV owners that do not always use their EVs during daytime (e.g. people working from home) but wouldn't be necessarily widely applicable.

**6.3.2 Implementation mechanisms**

Broadly there are two mechanisms that the DNOs can use to promote the two strategies mentioned previously. Whilst the market based mechanisms take advantage of market powers to incentivise
customers to adopt certain EV charging habits without offering any certainty to the DNO regarding the implementation of a strategy, direct control based mechanisms that allow the DNO to directly control EV loads offer certainty to the DNO.

6.3.2.1 Market based

ToU Charging (Energy)
The introduction of ToU tariffs combined with a simple timer, to allow customers to select the starting or finishing charging hour of their EV charging can encourage customers to recharge at off peak hours. The deployment of smart meters in UK will enable the development of these ToU tariffs. However, with a simple ToU scheme, probably most customers would simultaneously start charging at the start of the off peak tariff. Therefore, a somewhat more complex multi-tariff scheme should be established so that customer recharging is better spread through the off peak hours\textsuperscript{20,40}.

Moreover, a simple nationwide ToU scheme might not work well from a network perspective as local network issues may not coincide with the times that the national system is under stress. On the contrary a ToU scheme could even make network issues worse by incentivising people to consume more energy during a time of local network peak demand.

ToU Charging (Power)
To deal with such potential issue, customers could endure distribution costs for the subscribed kW rather than only purchased kWh. Charging subscribed kW rather than only purchased kWh has the advantage of better reflecting the cost incurred by DNOs\textsuperscript{57}. There could even be a variation of the cost of the subscribed kW depending on the time of day or the year. Price signals could be either constant for a relatively long period (e.g. 6 months – 1 year) or can be very dynamic varying based on the system and network conditions.

Congestion market
Another way to control the network peak demand (power) is the introduction of a congestion market. The congestion market introduces limits to the overall maximum power, and thus the high peaks resulting from charging EVs in the hour with the low ToU tariff must be spread out over some hours\textsuperscript{57}.

6.3.2.2 Direct control (Automated Demand Response- ADR)
An alternative to market based solutions in order to achieve the necessary network strategies is by introducing direct control of EV loads from the DNO. Special control equipment will be required as well as the customers acceptance of the installation and operation of such a form of control, potentially
seen as intrusive by the customers. The formation of Virtual Power Plants (VPPs) can allow the direct control of large numbers of EVs.

Box 4: Centralised VS decentralised direct control
There are two main architectures of smart charging control the centralised and decentralised. At low penetrations of EVs decentralised architectures seem to be a more cost effective solution as it requires less communication infrastructure to be in place. However, for high penetrations of EVs the centralised architecture is more favourable as it allows the full exploitation of the network capacity. For the simulation of these architecture to implement smart charging control, optimisation and heuristic methods have been used. Whilst optimisation methods are better to minimise/maximise costs/benefits, the heuristic methods are more suitable to ensure that distribution network runs within its operational limits. Besides, optimisation methods require high computational power and thus are not suitable for real time applications.

6.3.3 Technical and regulatory issues
All the above approaches and strategies may come along with technical and regulatory issues that will need to be resolved. Some of those are discussed below.

A charging point must be able to communicate with the “power system” and standardisation is crucial
To allow the development of smart charging techniques, both market and direct control based, the charging points need to be able to communicate with the “power system”. In that regard, standardisation of the communication between the EV and the “power system” is crucial in order to ensure the possibility of implementing smart charging solutions. In the UK there is an opportunity for DNOs to use the smart metering that is about to be deployed to control EV charging potentially through the Auxiliary Load Control Switch (ALCS) that allows control of loads such as EVs.

Enhanced monitoring system of the network is needed
All methods for smart charging require more knowledge of the distribution network than the one available today. Investments in monitoring equipment will be required to better understand the areas of the network that are experiencing any issues.

Review of regulatory targets for losses
Smart charging methods will allow the delivery of more energy with the same infrastructure. Whilst this enables the more efficient use of existing infrastructure, it can lead proportionally to higher losses.
Higher losses can lead to reduced revenue for DNOs as they may not be able to meet their regulatory targets\(^5\). Hence, a review of DNOs' losses target might be needed.

A summary of the potential remedial actions based on the previous analysis is presented in Figure 22.

**Figure 22: Summary of potential remedial actions**

- **Strategies**
  1. Minimise contribution to network peak
  2. Match local demand with local generation

- **Implementation Mechanisms**
  1. Market based
  2. Direct control

- **Technical and regulatory issues**

  - **Proactive approach to charging point deployment with smart control charging**
    - Aggregated charging points at high voltage located near the existing high voltage network can be more cost effective than charging points in the LV network.

  - **Reactive approach to charging point deployment**
    - Identification system/licence for domestic charging point installation – regulatory intervention needed
7 Conclusions and recommendations

7.1 Conclusions

Evidence to date reveals that EV sales are slowly increasing. Whilst there is some data already available on the characteristics of the early EV adopters, still little is known on how people might be using and charging their EVs in the future and what the electricity requirements for these will be. Besides, the development of new business models and technologies are likely also to influence aspects of the impacts of EVs on the distribution network.

The initial results from the modelling work, taking into account all the assumptions used, reveal that even under the Clustered high EV uptake scenario by 2022 the impacts on the low voltage distribution network are relatively small.

There are no voltage issues identified and there are only small scale thermal capacity issues that cause concern (amber) rather than areas that would definitely need some reinforcements. The pattern that thermal capacity related issues come before the voltage related issues confirms the same finding from Low Voltage Network Solutions another LCNF project. Also it is found that parts of the feeders that may become overloaded due to EVs are mostly located closer to the substations, as expected.

Initial results indicate that smaller voltage networks with fewer customers may face less impacts from EV uptake. Moreover, they show that impacts from EVs during summer may be more severe compared to winter due to the reduced thermal capacity of the feeders. All the above results should be interpreted, taking into account that EVs are charged primarily during night with fast chargers (7kW).

The DNOs have a set of potential remedial actions that could undertake to alleviate the impacts of electric vehicles. Based on the modelling results, it is expected that in the medium term up to the end RIIO ED1 price control review there is only need for a more reactive approach, as described previously, from the DNOs that will allow them to better understand the locations on the network that may face a need to undertake minor traditional reinforcements when needed. However, further in the future when more EVs might be charging in the network more proactive approaches will be needed to ensure the cost efficient deployment of traditional reinforcements or the deferral of those with the use of smart charging strategies.

7.2 Short term recommendations

Drawing on the wider conclusions of this project, there are some short term recommendations that
DNOs could adopt in order to be better prepared for a potential high EV uptake in the future. A discussion around those follows.

**Market Monitoring**

For DNOs to be better prepared, they need to follow and understand the market developments around new technologies and commercial models, as they are likely to influence the impact of EVs (see Section 3). Gaining insights from these developments and simulating their impacts on networks can provide a better understanding on how and whether their businesses will be affected.

**Industry partnerships**

EV producers have a vested interest to ensure that their clients will be able to have their EV charged when they need it, making sure that there are no blackouts that can damage customers perception about EVs. Therefore, there is an opportunity for DNOs to form an industry partnership with EV industry leaders to allow them to communicate the importance of sound regulatory policies if needed, while maintaining a level playing field in the marketplace. Besides, such partnerships would allow the active participation of DNOs in policy development\(^5\).

**High level forecasting tool for the wider DNOs’ regions to predict specific areas with higher concentration of early EV adopters**

A high level forecasting tool could be used by DNOs to better identify the specific geographical areas of their region with the higher concentration of potential early EV adopters, based on their demographic and other characteristics. This model can be constantly updated according to the market developments that can influence significantly the EV uptake. Using that analysis DNOs can then further look into the network conditions of the areas with the high EV uptake and conduct more detailed analysis (like the one undertaken for this study) to identify these areas that are likely to have network issues. Anticipating where the issues in the network may arise, DNOs can be better prepared to deal with the initial EV uptake.

**Market Education and Outreach**

\(^7\) Such a tool could be developed by a third party (e.g. DECC, Industry, Academia) and be either managed by the same third party or the DNOs.
EVs could become very popular in relatively short period of time, if they become directly competitive to the conventional vehicles. On this occasion people need to be aware of the challenges to the network that may affect their customer experience and the potential solutions that can be implemented. This needs to be communicated to the customers to ensure they are better prepared to adopt technologies or commercial arrangements that may be needed.
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