Opportunities for smart optimisation of new heat and transport loads

By UK Power Networks
Modelling data from our trials shows that, in a future with significant penetration levels of low carbon technologies, while Heat Pumps are less suitable for smart optimisation, active control of Electric Vehicles could have benefits for distribution networks.
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This report is a contracted deliverable from the Low Carbon London project as set out in the Successful Delivery Reward Criteria (SDRC) section “Enabling Electrification of Heat and Transport”.
Executive Summary

This learning report examines the opportunities for smart management of new transport and heating loads. With the anticipated proliferation of Electric Vehicles (EVs) and Heat Pumps (HPs), Low Carbon London (LCL) has investigated mechanisms and identified consumer groups that can support smart management of these new loads. Smart management will release capacity on constrained networks and enable the increasing demand at minimum additional cost to consumers. The report builds on understanding from Report B2, which examines the impact of EVs and HPs on network peaks.

Two EV charge regulating trials were carried out as part of the LCL project. The first trial investigated the impact of Time of Use tariffs on domestic customers’ recharging behaviour at home, whilst the second trial looked at the control that could be achieved on public charging points by cyclic switching at times of high demand. The evidence from the LCL EV trials demonstrate that load shifting can be achieved by both methods.

To understand the value of smart management mechanisms to the DNO, consideration was given to different EV consumer groups and the flexibility in their charging requirements. The different behaviours and charging requirements of individual consumer groups make them more or less responsive to load shifting and load reduction.
There is potential benefit for DNOs to develop opportunities for smart optimisation of new transport loads.

**New Transport Loads**

Demand shifting can be achieved in two distinct ways:

- Encouraging behavioural changes consisting of financial incentives aimed at influencing customer behaviour; and
- Technical mechanisms, such as cyclic switching of specific loads at peak times.

Key consumer groups were identified which have charging behaviours and requirements that make them suitable for smart control. The three groups were: domestic, fleet and public transport.

**Time of Use EV trial**

The trial showed that 70% of domestic EV users modified their charging behaviours to predominately charge their vehicle at off-peak times, despite the monetary incentive being small. There is some suggestion that this may have been down to users being monitored by the project, but the consistent manner in which participants charged off-peak indicates that the time of use tariff acted as a useful mechanism to shift load from time of peak demand.

**Active Network Management (ANM) EV trial**

The trial demonstrated that a combination of ANM and an EV controller can provide an automated, real time distribution network load management solution for public access charge points, with minimum impact on EV drivers. Crucially, the availability (the volume of EVs charging in the licence area) and the reliability (the operational efficiency of this solution), will underpin the decision of a DNO to pursue its use as a suitable mechanism to control loads. Public charge posts are currently under-utilised, hence load management will not be required for some years to come.

**New Heating Loads**

The operation of HPs observed on the LCL trials shows that the loads are irregular, making them less suitable to smart optimised control. Further considerations about HP demand during times of network peak loads, which in the colder months would be times when the HP would be required to bring increase indoor temperatures, suggests a more complex dynamic to controlling this load. This suggests a need to understand how external temperatures and peak time loading coincide to assess the opportunity for regulating demand.

**Key Recommendations**

The improved visibility of distribution network-located Low Carbon Technologies (LCTs) that replace or are a substitute for hydro-carbon based technologies, such as EV charging points and heat pumps, will greatly assist the DNO in the efficient planning and management of LCT growth on the distribution network. Consideration needs to be given to utilising existing mechanisms (e.g. DVLA and the RHI scheme) or by establishing new national frameworks, to enable significantly improved visibility of LCT installations for the DNO.
### Proactive Load Monitoring

It is good practice for the DNO to understand the current state of the network, any critical capacity issues and transformer states where there is significant clustering of EVs or HPs. The DNO should implement appropriate monitoring and diagnostic activities similar to the Distribution Network Visibility tool used in UK Power Networks.

### Communications and Integration Standards between DNO and 3rd parties

Currently any integration between the DNO control system and another third party requires complex integration. It is recommended that an appropriate standard should be developed and adopted for a common communications channel to enable load management. This will enable interoperability and encourage integration of multiple third parties such as Charge Network Operators (CNOs) and Demand Side Management (DSM) Aggregators with the incumbent DNOs.

The IEC 61850 CIM standards could be updated to include this communications channel.

### Lobby Against Removal of ALCS Functionality from SMETS

There is a possibility that as the Smart Metering Equipment Technical Specification (SMETS) is refined, the standards will drop Auxiliary Load Control Switches (ALCS), the result of this will make the control of EV and HP in the home more complex and increase costs. It is important that the DNOs continue to lobby the Department of Energy and Climate Change (DECC) to ensure that this functionality is maintained in the specification to ensure the monitoring and diagnostics of household loads.

### Need for accurate uptake forecasts underpinned by real growth numbers

Correctly predicting the potential EV and HP uptake is crucial to DNO plans. Growth is being driven by many influences, and there is significant commitment from the UK Government to move to Ultra-Low Emissions Vehicles (ULEVs) and to move household heating from gas to alternative technologies.

### Deploying ToU tariffs or ANM technologies widely to mitigate primary reinforcement requirements is unlikely to be cost effective

Mandatory application of ToU tariffs to domestic EV charging could reduce reinforcement costs by an NPV of £5.5m across LPN. However, this would then need to cover the costs required to implement such a mandate, including changes in DNO and supplier settlement systems.

Mandatory application of ANM for regulated charging of domestic EVs would be very expensive, based upon current cost assumptions with the benefits of regulating domestic EV charging being significantly outweighed by the cost incurred.

### Executive Summary

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Based on current equipment costs for ANM, the benefit of the reduced connection size required for a fleet of commercial EVs when ANM is used is likely to start outweighing the costs of installing the ANM equipment for fleets over 131 vehicles.
Overall Conclusion

The implementation of intelligent systems can avoid costly reinforcement, provided a holistic view of a number of primary factors is understood:

- The ability of the various stakeholders to encourage consumer response to the behavioural and technological interventions required;
- The uptake of EVs and HPs in a given area and the potential for clustering effects driven by consumer incentives from DNOs, retailers or local authorities; and
- Analysis of network data to identify current peak demand on transformers.

There is no single mitigating action against the impact on the network, and the DNO may deploy different interventions to different consumer groups.

In the long-term, the DNO position may be to manage a vendor-agnostic interface, with any number of technical solutions, to manage aggregate demand (similar to that currently offered in the demand side response market). This will require the development of a standard communications protocol for communications between the DNO and a vendor, in addition to new contractual arrangements.
Introduction

1.1 Background

This report describes the effects of EVs and HPs on the network and the opportunities for regulating EV behaviour. It addresses questions such as:

- The opportunities for regulating the behaviour of LCTs;
- Where investment is likely to be required; and
- How a proactive approach can mitigate or defer these investments.

Report B2 [Ref.1], describes the LCL EV and HP trials, and details the learning from the LCL EV trials in terms relevant to the DNO. This report builds on the LCL trial results to examine opportunities for controlling EV and HP load using behavioural and technical interventions.

The existing consensus is that EVs and HPs will not have adverse impacts on the network in the near-term, but will have localised impacts where clustering EV charging occurs, or where a single load supporting a heating network is significant.

The relative size of new EV and HP loads and the lack of clarity as to how this new market will develop add additional uncertainty to the issue of load growth management. However, there are a number of key considerations for the DNO to be aware of, to enable issues to be addressed as they arise.
1.2 Problem / Opportunity Statement

This report has been developed to answer one key question with regards to the implementation of LCTs in the distribution network:

“What are the effects of EV and HP usage on the distribution network, and what are the opportunities and potential mechanisms for regulating their demand?”

To provide a robust response to this question, a number of more focused questions need to be answered. This report is divided into discrete sections in an effort to provide an answer to the below questions:

- Identifying EV and HP consumers and what are their behaviours;
- Identifying EV and HP service providers that are impacted by consumer usage;
- How the service providers influence or constrain consumer behaviour;
- Determining the current up-take and projected growth of EV’s in the UK based on industry prescribed scenarios;
- Developing a future business scenario of EV up-take for each consumer type;
- Investigating the point at which within each business scenario it becomes necessary to apply an intervention;
- Determining the most suitable interventions for each of the different consumer types;
- Identifying enhancements required to the existing constraints to increase their effectiveness;
- Investigating how evidence from the LCL and other trials can inform the effectiveness of Time of Use (ToU) and Active Network Management (ANM) interventions;
- Developing the value chain and value proposition for each different business scenario from a consumer and service provider perspective, and
- Determining the recommended steps to be taken by the service providers to manage the impact of EV and HP on the network.
2.1 Electric Vehicles

There are multiple stakeholders involved in the EV landscape. In the context of this report, the DNO is the primary stakeholder, with two secondary groups, the consumers and service providers.

Service providers represent parties or technologies that can influence or are influenced by the EV landscape. Figure 1 illustrates the EV landscape and relationships between various stakeholders.

Figure 1 – EV Stakeholder Relationships
This chapter introduces stakeholders, providing a brief description of each, their requirements and key behaviours.

2.1.1 DNO

Report B1 [Ref. 2] has demonstrated that whilst EV charging has the potential to add significant additional load to the network, it varies by consumer group and does not always coincide with peak systems demands. It is critical for the DNO to understand how the load profile of these consumer groups may cause issues relating to both the thermal capacity of network components and voltage stability at customers’ terminals within statutory limits.

There are currently no mandatory requirements for the consumer to notify the DNO when a charge point is connected to the network. The Institution of Engineering and Technology (IET) operates a best practice scheme for EVs, but these guidelines are often ignored, with the DNO only aware of around 3% of connected charge posts. In order to proactively manage the network and its assets as LCT loads increase, the DNO will require an increased awareness of EVs connected to the network.

Excessive electricity consumption can cause a number of problems, particularly for assets such as local distribution transformers. The life expectancy of a transformer, for example, can be reduced significantly by sustained overloading, which can result in a burnout before a problem is noticed.

In addition to the consideration of failure, it is also necessary to understand how new or upgraded equipment may be required to ensure sufficient capability to cope with the new types of load considered in this report. Traditionally, when the level of consumption starts to approach 85% of the transformer nameplate rating for extended periods of time, it is necessary for the DNO to consider taking network reinforcement action to upgrade or introduce new equipment to cope with the additional requirements.

This report looks to explore and validate methods of both behavioural and technical interventions that can be deployed in order to control load and/or to delay reinforcement. This will address whether demand can be shifted from peak times to off-peak times, through behavioural changes or through technological control.

2.1.2 Consumers

The consumers’ ultimate requirement is an accessible, reliable supply of electricity at a reasonable price.

There are a number of different types of consumer, operating in varying ways and impacting the network at different times and extents. These consumers can be categorised into three distinct groups based on both their requirements and behaviour:

- **Domestic** – including both private and public/commuter charging;
- **Fleet** – i.e. light goods, and
- **Public Transport** – i.e. buses.

The next sections characterise each of these groups and reviews the primary factors that influence their behaviour and their responsiveness to external influences. Subsequently the report looks in more detail at how each of these consumers could impact the network based on real-world scenarios and what interventions a consumer might respond to in order to assist the DNO to protect and manage their assets.

2.1.2.1 Domestic

Domestic consumers have privately purchased their EV, commute to a place of work in a company-owned vehicle, or are small businesses with small vans. As evidenced in Section 4.1, this consumer group will charge their vehicles predominantly at home in the evening, or make day-time use of the public charging infrastructure.

**Requirements**

Domestic consumers have a simple requirement, that the vehicle is sufficiently charged for their respective journey.

Individually, the demand created by charging a domestic vehicle is low, 3kW – 7kW. This indicates that the impact of this consumer group would only be felt by the DNO through clustering of EVs in a small area.

**Behaviour**

The behaviours listed below characterise the energy demand of domestic EV consumers. The choice from the consumer has implications on the level of control a DNO can make on EV charging. As described above, one major factor that compels these behaviours is the requirement for the EV to be sufficiently charged for the next trip.
As seen in Section 4.1.1, domestic consumers have a tendency to only use EVs for short to medium trips, plugging their vehicle in as soon as they return home, regardless of the remaining charge;

- Consumers charge at every opportunity, to avoid running out of range when they next use the vehicle; and
- The consumer is free to purchase or source a charging point for private charging, typically in the 3 to 7kW range, from any vendor if they wish; the IET also recommend that a dedicated charge point is used for home charging of EVs. Alternatively, domestic users can charge their EVs using an existing mains socket. The consumer group does not always inform the DNO or Supplier of the charge point installation in the home. Under IET guidelines, an electrician fitting a 32A breaker for a 7kW has to inform the DNO; however, 3.5kW units do not need to be declared.

The above behaviours typically result in, and have been highlighted in the conclusions of LCL B1. [Ref. 2]

- Top-up charging, with an average of 2.5 hours or less to complete;
- Charging taking place predominantly in the evening, coinciding with early evening peak demand;
- Use of public or work charging infrastructure during the day to top-up. Consequently, consumers expect the charge speed to be as high as possible and available anytime they use a public charging point;
- The DNO and Supplier are not aware of the additional load which causes problems for forecasting, balancing and settlements; and
- A mixed population of charging points in the home from different vendors on the same transformer.

This results in a variation in the demand for energy for private and public charging as indicated in Figures 2 and 3 below (see [B1]):

**Figure 2: Domestic Consumer Private Charging Profile [ICL3]**

- Typical private charging profile indicates demand coincides with peak residential demand, as the consumer charges in the evening, reducing overnight.

Given the nature of charging observed, i.e. overnight charging for a short duration relative to parked time, this highlights an opportunity for load shifting with the consumers’ energy requirement still met.

**Figure 3: Domestic Consumer Public Charging Profile [ICL3]**

- Typical public charging profile indicates demand coincides with peak commercial demand, as the consumers get opportunistic charges.

Although Figure 3 above shows that there are times when energy demand can be shifted to favour network utilisation, the consumer behaviours highlighted above suggest that load shifting using public charge points, unless in an emergency, can be difficult to enforce.

Furthermore, the volumes of public charging are currently low, such that they do not present an ample amount of demand for shifting. DNO-led public charge point control is discussed further in Section 4.1.1.2.
2.1.2.2 Fleet
EV fleet vehicles are considered here to be medium size vans to freight vehicles, which will be charged at depots or equivalent. This distinction is made because the nature and location of the demand from cars and small vans fits closer with the domestic EV user group, Section 2.1.2. Similarly, the volume of demand from a depot with fleet EV charging is different from the demand in a domestic context, as highlighted in the LCL trial.

Requirements
Fleet consumers will have differing requirements depending on the size and type of operation:
- They will be driven by a strict schedule and will require a fairly consistent amount of charge;
- Similarly, the charge needs to be completed within the scheduled time and the vehicle must have sufficient range, e.g. for a delivery schedule; and
- Individually, the demand created by charging a fleet vehicle is low, 3kW-22kW to ensure the vehicle is fully charged in the time it is idle.

Behaviours
Fleet consumers will typically follow the behaviours indicated below:
- The EV fleet will be plugged in for charging at the end of a schedule;
- They will charge at every opportunity and may use public infrastructure in addition to the infrastructure deployed at the depot;
- Charging will be predominantly overnight (in a small number of cases this could be daytime); and
- EV usage during the shift can vary significantly from fleet to fleet. For example, a delivery vehicle could be used continuously, or a maintenance worker could only travel a few miles per day.

Figure 4 – Fleet Consumer Charging Profile from the LCL commercial EV trials [ICL3]

Based on the observation from the LCL commercial EV trials, fleet operators with a fairly regular schedule of operation from a depot are expected to follow a “brick wall” pattern for charging, with common start and end times for each vehicle. This means that charging volumes tend to be high and at fairly regular periods. Although this is one example, in Figure 4 (see [B1]), the timeline could be any start or end time during the day or night, depending on the nature of the fleet (e.g. milk floats are likely to charge in the afternoon, parcel delivery fleets are likely to charge in the evening).

The size of fleets can vary significantly, from 1 or 2 to 60 or more vehicles. The larger the fleet and the clustering of charging on a local power distribution network, the greater the impact. Section 3.4.3 illustrates an example and the potential impact on the network.

As fleet vehicles generally cover greater distances and have schedules to maintain, they are more likely to need a full charge every day in order to be ready for the next day. This can make fleet operators less responsive to behavioural incentives so, as will be seen in Section 5.1.3, it will be the technical interventions that will be considered to manage the load.
2.1.2.3 Public Transport

Whilst all-electric buses have been available for a few years, uptake has been very slow in the UK. Hybrid electric vehicle (HEV) buses have trialled in city centres such as Birmingham, Oxford and Aberdeen. However, these do not impact the electricity network, as they generate their own power from the on-board diesel engine. The newer plug-in hybrid electric vehicles (PHEVs) are still to make an appearance, at the time of writing only one example could be found:

- The United States Department of Energy (USDOE) has announced a cost-shared award of up to $10 million to develop, test, and deploy PHEV school buses. These buses have a goal of being able to achieve a 40-mile driving range on one charge.5

Requirements

Public transport has a number of simple requirements that must be met:

- They will be driven by a strict schedule and will require a fairly consistent amount of charge;
- Similarly, the charge needs to be completed within the scheduled time and the vehicle must be fully charged for the next schedule/trip; and
- Consequently, the demand created by charging the bus is likely to very high, 60kW-100kW to ensure the vehicle is fully charged in the time it is idle.

Behaviour

Public transport consumers exhibit the following behaviours:

- The EV fleet will be plugged in for charging at the end of a schedule;
- Charging occurs predominantly overnight. Night buses would charge during the day, but there are expected to be fewer of these;
- The vehicle will be used continually throughout the day to be able to meet the schedule. Where possible, taking advantage of intermittent returns to perform short top up charges; and
- The range of a single leg of a route may be short; however, the total distance travelled between charges may be quite long.

Given the behaviours outlined above, it is anticipated that the majority of the charging occurs overnight, dropping down to very little through the day, accommodating top-ups and night buses. Given that current electric alternatives to Internal Combustion Engine (ICE) buses do not offer a like-for-like substitution, data on the current routes performance is not enough to adequately inform an illustration of the charging demands.

Finally, a bus garage is unlikely to have a 3-phase connection, so will not support the 60kW – 100kW charger required for a single bus. Therefore, it is anticipated that any interaction with this consumer group would be in the form of new connections requests, thus giving the DNO visibility of that connection.
2.2 Heat Pumps

There are multiple stakeholders involved in the HP landscape. In the context of this report, the DNO is the primary stakeholder, with two secondary groups, the consumers and service providers. Service providers represent parties or technologies that can influence or are influenced by the HP landscape. Figure 5 below describes typical HP stakeholder relationships.

Figure 5 – HP Stakeholder Relationships

The following sections introduce each stakeholder, providing a brief description of each, their requirements and key behaviours.

2.2.1 DNO

LCL Report B3 [Ref. 3] has demonstrated that HP load profiles are diverse and do not always coincide with peak systems demands. Given this variation, it is critical for the DNO to understand whether a typical load profile can be derived for each consumer group, so that adequate planning can be undertaken, and to avoid issues relating to both the thermal capacity of network components, and its ability to maintain the voltage at customers’ terminals within statutory limits.

Currently, the installation of heat pumps in the UK is administered by the Micro-generation Certification Scheme. Earlier this year a DNO notification process was introduced by the Energy Networks Association (ENA) and its DNO members which should begin to afford DNOs visibility of the installation of HPs on the network. This information can be used by DNOs to inform load forecasts and network reinforcement plans.

It is important to note that, unlike EVs, the scope of possible control of a HP is more limited as the demand from the HPs is irregular and not constant, and as they are heating homes there is limited scope to shift load. This is owing to several factors that include external temperature, internal temperature, heating control system settings, consumer comfort levels and so on. Variables which are beyond the scope of this report to consider and conclude on how HPs lend themselves to the control mechanisms considered. Notwithstanding, this report looks to explore and validate possible methods of technical interventions that could be deployed in order to control load and/or to delay reinforcement.
2.2.2 Consumers

The consumers’ ultimate requirement is for their heat load to be affordable. There are two types of consumer that can be identified; these groups are indicated below:

- **Domestic** – Including both private and rented properties heated via localised heat pumps, and
- **Communal and Commercial** – Several properties heated via a Heating Network from a centralised source, e.g. Social housing, Shops, heated via a heating network or a localised heat pump.

In the next sections each of these consumer groups will be outlined and the primary factors that influence their behaviour, as well as their responsiveness to external stimulation reviewed.

2.2.2.1 Domestic

Domestic consumers will have a localised heat pump installed, or run a hybrid system that blends gas and HP for their heating purposes. As evidenced in Report B3 [Ref. 3], domestic load is unpredictable which reflects the personal nature of heating.

**Requirements**

Domestic consumers have a simple requirement; that they may heat their home in the manner in which they desire. On average, the demand created by residential HPs is low, less than 3kW, and as the demand fluctuates, rather than being a constant load, it is unlikely that the impact of this consumer group to the DNO will be significant, unless there is a significant cluster in a local network area.

**Behaviour**

There are variables which have not been monitored in the trials that characterise the demand from this consumer group. These variables include factors such as external temperature, internal temperature, heating control system settings and consumer comfort levels, which means consumers heat their home as they require. As illustrated in LCL Report B3, domestic heating profiles vary case by case, two examples are shown in Figure 6.

In addition to the unpredictable nature of the load, HPs take time to extract heat from the source so there is no scope to constrain off the HPs as this would have a significant impact on the ability to heat the home and thus are unsuitable for load control. This limited flexibility in the demand from domestic HPs means they are an unlikely load for the DNO to consider for smart optimised control.
2.2.2.2 Communal and Commercial Heating

New developments could take advantage of HPs to provide communal and commercial heating using a local heating network. These larger HP deployments will be 3-phase and will be installed on a single feeder, therefore there is the potential for these HPs to cause a constraint.

Requirements

Heating networks for communal housing should have a more predictable load on the network, due to the need to provide for a larger number of properties and hence any spikes or troughs in demand should average out over the day. The list below provides the types of requirements that will need to be met:

- They will be driven by unpredictable consumer demand; and
- Heat must be available on demand and be fairly instant.

Behaviours

This consumer group is more predictable and will heat their home as they require. As illustrated in Report B3 [Ref. 3], communal heating profiles are more linear, an example is shown below:

**Figure 7 – Example Communal Heating Load Profile**

Communal heating is expected to follow a fairly flat pattern, with communal and commercial demand averaging out heating requirements over the day. This potentially makes this consumer group a possible candidate for including in a Demand Side Aggregators portfolio of curtailment.

2.3 Service Providers

In addition to the DNO and consumer groups, there are a number of other parties that are influenced by, or influence, EVs and HPs. A detailed analysis of these parties is not in scope of this report; however, a high-level view of the impact and their influence is included below.

2.3.1 Supplier

Suppliers need to be able to forecast and model their customers’ demand at half-hourly intervals, so they can contract to purchase appropriate amounts of electricity in the wholesale markets. Where Suppliers are under or over contract, they will be “out of balance” and will be required, under the Balancing and Settlement Code (BSC), to pay imbalance costs to make good the difference. Therefore, to reduce exposure to imbalance costs, Suppliers need to have good knowledge of their customers’ consumption patterns and, ideally, prior knowledge of the installation of an EV charging point or HP.

The Supplier also has a key role to play in the implementation of Time of Use (ToU) tariffs. If EV consumers can be influenced to respond to the benefits of ToU tariffs, this presents an opportunity for the load control of EV at peak times.

2.3.2 Charging Network Operator (CNO)

As owner of the public charging points, the CNO is responsible for their control, management and maintenance. In London there are four suppliers - ChargeMaster, PodPoint, Elektromotive and CPMS. The CNOs currently operate the only IT system that has direct access and control of the public charge points via an EV Controller, as detailed in Section 2.3.6. Therefore, if any other parties wish to apply load management with the charge points managed by the CNOs, it will require interaction and agreement.

2.3.3 Demand Side Management Aggregator

The role of the DSMA is to offer a commercial proposition to the DNO, where curtailment at constraint points is offered in return for financial payment. As direct control over HP installations will have little benefit to the DNO, it is entirely possible that flexible HP loads could be aggregated to form part of a portfolio of curtailment that the DSM Aggregator may offer to the DNO, and which they will manage. Controlling commercial or communal HP installations via the property’s Building Management System (BMS) or directly through their own control equipment, might make these HPs an attractive option for Aggregator’s.
2.3.4 External Groups
A number of external bodies are involved in shaping the future of EVs in the UK, these include the following:

- **Office for Low Emission Vehicles (OLEV)**
  OLEV is a subgroup of Department for Transport (DfT) which supports the early market for ultra-low emission vehicles (ULEV). £900 million is being made available to ensure that the UK is at the global forefront of ULEV development, manufacturing and use. This benefits both the economy and the environment as it promotes economic growth and CO₂ emissions reduction. OLEV offers:
  - Domestic recharging grants
  - The Low Carbon Vehicle Public Procurement Programme (LCVPP) scheme to promote the use of EVs.

- **Energy Savings Trust (EST)**
  The EST work with the Government to ensure that the most effective and efficient technology is used e.g. EVs and HPs. Their role is to promote the use of LCTs through the use of Government grants such as:
  - Plugged-in fleet Initiative 100 and Plug-in vehicles grant
  - The Government are offering subsidies of:
    - 25%, up to £5,000, towards the cost of an electric car
    - 20%, up to £8,000, towards the cost of an electric van.
  - Renewable Heat Incentive is currently offering subsidies of:
    - **Domestic**:
      - ASHP – 7.3p per kWh of renewable heat generated
      - GSHP – 18.8p per kWh of renewable heat generated
    - **Non-Domestic**:
      - ASHP – 2.5p per kWh of renewable heat generated
      - GSHP – 8.7p per kWh of renewable heat generated

- **Institution of Engineering and Technology (IET)**
  The IET are an Institution that provide expert guidance for EV charging equipment installation and maintenance. They are responsible for the code of practice for EV charging equipment installation, which has been developed by a committee of experts representing the key players across the EV industry. The code is applicable to administrators and managers specifying and procuring EV charging equipment and contractors.

The incentive schemes for domestic and fleet operators being run by OLEV do not currently incentivise one consumer group over the other. However, given the additional benefits ULEV offer to commercial operators operating in London, such as exemption from the congestion charge and travel distances that fit the range of commercially available EVs, it is likely that more commercial operators will move to EVs than domestic consumers. For fleet operators, these are likely to be clustered on a site, which will result in a demand for new load connections and this will offer the DNO an opportunity to consider control mechanisms when these sites are in areas where there is a network constraint.

2.3.5 Standards and Policy
There are many standards for the physical aspects of EVs, including connectors, batteries, engines etc., such as the J-numbered standards from SAE International. However, there are few to support the communication and interoperability between providers within the EV landscape.

- **Open Charge Post Protocol (OCP)**
  The most mature of the protocols is OCPP, which is currently at version 2.0, introduced in 2013. This European protocol provides control and messaging between the EV Controller and the charge point.

- **ISO 15118 Road Vehicles**
  Vehicle to Grid Communication Interface – International Standard ISO 15118 consists of a suite of protocols specific to the communication between the vehicle and the charging point. The list below details the standard composition, however it should be noted that not all have been released:
  - **Part 1**: General information and use-case definition
  - **Part 2**: 2014 Technical protocol description and Open Systems Interconnections (OSI) requirements
  - **Part 3**: Physical and data link layer requirements
  - **Part 4**: Network and application protocol conformance test.
These standards are expected to allow essential information to be read from the vehicle, such as distance travelled and current state of the battery.

- **SMETS with ZigBee SEP [Ref. 9]**
  Department of Environment and Climate Change (DECC) released details in 2013 of how they will allow Demand Side Response (DSR) to work with the Data Communications Company (DCC). The suggestion is that Smart Metering Equipment Technical Specification Version 2 (SMETS2) will support a set of separate control switches available through the home area network (HAN), using the ZigBee SEP 1.2 protocols to allow the auxiliary load to be switched on or off:

  "... analysis suggesting a need for up to five HAN-connected Auxiliary Load Control Switches (ALCS), for example one control for hot water, two for space heating circuits, one for an EV and a spare. Provision for five ALCS will provide future flexibility" [Ref. 10]

  "SMETS 2 requires as a minimum that an electricity meter must support at least five HAN-connected Auxiliary Load Control Switches – with manufacturers able to support more at their own discretion. This decision was based on discussion with industry representatives who demonstrated this would provide flexibility to cover existing uses as set out here, and additional capacity for future uses. In addition, one HAN-connected ALCS may connect to multiple devices responding at the same time, for example two EV charging points. In parallel, we are also supporting the use of CADs. Allowing the consumer to control devices based on price signals and other triggers should also provide another route for the future flexible use of energy."

This will provide the mechanism for price triggers, DSR and demand side management, and should allow the DNO access to control the charger in the home.

The ISO 15118 and OCPP standards do not directly affect the DNO as these are the responsibility of the CNO and charging point and vehicle manufacturers. The advantage to the DNO is potentially being able to support load management, load curtailment and being able to predict the requirement through reading the charge the vehicle already has. Without these capabilities to effectively manage the load it can be difficult to perform any form of load management.

**Figure 8 – EV Communication Standards**

In order for the ANM or forecasting systems to communicate with the EV charging points it is necessary to integrate them with the EV Controller. Given there are multiple CNOs, interaction between parties will be difficult to implement in the absence of interface standardisation.

The obvious choice would be to supplement one of the existing Common Information Model (CIM) based – IEC 61850 standards, as this will fit with other applications and will ensure compatibility and ease of integration. Figure 8 illustrates the various different communications protocols in operation.
2.3.6 Technology

There are a number of technologies available to assist in the management and control of EV, both generally and specifically, to aid load management on the network.

2.3.6.1 EV Controller

An EV Controller provides the ability to connect to, communicate with and control the charging point. Its primary function is to enable the CNO to perform its role as defined in Section 2.3.2. The EV Controller could be used to perform more advanced control in the form of load management. Provided a DNO can communicate with the EV controller, signals can be issued to the network of charge points to curtail their demand. One such application which was trialled in LCL is outlined in Section 4.1.1.2.

2.3.6.2 Active Network Management (ANM)

Active Network Management is a collective term for technologies that use network monitoring and intelligence on the network to automatically manage functions such as thermal overload, voltage control, fault levels and network restoration. ANM operates using fast and reliable communications infrastructure between substations on the network and centrally controlled loads such as a sample of EV charge points. As such, ANM is able to function in real-time to constrain-off the load from a controllable asset.

ANM achieves this by combining sensors deployed on the Low Voltage (LV) network with an IT solution deployed centrally. These sensors allow parameters (set points) to be fixed, such as maximum load; if these set points are then exceeded a notification is sent to the central system which sends the request to curtail load.

Communications is a key element of this solution; a data network is required between the ANM device and the control software. The devices are deployed onto the network grid nodes and typically make use of the SCADA network to collect the data, but must also be allowed to send the signal outside of this ultra-secure environment to a load management vendor.

For example, using an EV Controller as an enabler, load from EV infrastructure can be managed to shift load at peak times by sending a curtailment or maximum load notification to the charge point, or group of charge points in real-time. In effect this acts as protection mechanism for DNO assets.
3.1 EV Uptake Predictions

Correctly predicting the potential EV uptake by consumers is fundamental to quantifying the impact this growth will have on the electricity industry, as schemes such as Time of Use (ToU) tariffs require cooperation between market participants and as such have an impact beyond the DNO. Growth is driven mainly by external influences, as there is significant commitment from the UK Government to move to ultra-low emissions vehicles (ULEVs), as outlined in this press release from the UK Coalition Government, 29th April 2014 [Ref. 11]:

“The Government will invest £500 million to boost the ultra-low emission vehicle industry and help drivers both afford and feel confident using electric cars, the Deputy Prime Minister announced today.

The automotive sector is a success story of the UK’s economic recovery, with a new vehicle rolling off a UK production line every 20 seconds and the industry is worth £11.2 billion to the economy. The production of ultra-low emissions vehicles (ULEV) is a major part of growth now and for the future.

The investment of £500 million between 2015 and 2020 will create jobs, reduce emissions and set the agenda for the industry, for our towns and cities, and for motorists, so that Britain remains at the forefront of green technology.

The investment will:

- **Create “Ultra Low City Status”**
  Local areas coming up with the most ambitious plans can win a share of £35 million to make the leap to becoming ultra-low. Winning cities could, for example, incentivise drivers of green cars by letting them use bus lanes or allowing them to park for free. Additional funding of £50 million will also be available for local areas to invest in cleaner taxis and buses.

- **Create jobs and innovate**
  We will invest £100 million in research and development in ULEV to cement the UK’s position as a leader in the development of these technologies. The UK’s automotive industry has undergone a renaissance in recent years and we have the potential to emerge as a world leader in the development, design and manufacture of green vehicles.
This investment will help create skilled British jobs and have further positive impact down the supply chain.

- **End “range anxiety”**
  £32 million funding boost for charging infrastructure including plans to install rapid charge points across the “M” and “A” road network by 2020 so that drivers can find a rapid charge point when they need one. Rapid charge points mean that a car can be charged in as little as 20 minutes.

- **Save consumers money**
  Full details of each scheme will be published by autumn 2014, with some of the schemes “

Given the importance of understanding likely EV uptake, the growth predictions from National Grid and Department for Energy and Climate Change (DECC) have been used to provide a comparison in the predicted growth of EV numbers. National Grid have used the terms “slow progression” and “gone green” to describe their low and high predictions, whilst DECC have provided predictions in low, central and high scenarios. To provide a direct comparison between the two, published vehicle volumes from the Driver and Vehicle Licensing Agency (DVLA) for cars and Department for Transport (DfT) for buses and light goods vehicles have been used, with the DECC uplifts applied to provide the national picture.

### 3.1.1 Electric Cars

DVLA medium growth predictions [Ref. 12] of vehicle numbers across the UK and the DECC predictions of EV growth show a wide range in the predictions.

**Figure 9 – DECC EV Cars Growth Scenarios**

![Figure 9](image_url)

Figure 9 demonstrates that the variation in growth rates is quite extensive, with a two-fold increase between the low and high scenarios, illustrating the current uncertainty of EV uptake by domestic consumers. To encourage more widespread uptake, UK Government and other groups are running a number of incentive schemes. The list below gives some examples of these schemes:

- **Plug-in vehicles are currently exempt from Vehicle Excise Duty (VED);**
- **Plug-in cars are eligible for a 100% discount from the London congestion charge, worth up to £2,400 per annum;**
- **Company car drivers can benefit from a zero “benefit in kind” on EVs until 2015, as well as exemption from tax on the provision of free private fuel;**
- **Plug-in car grant scheme, which offers consumers purchasing a qualifying ULEV to receive a grant of 25% towards the cost of the vehicle, up to a maximum of £5,000. The scheme will be active until at least 50,000 cars have been sold or until 2017;**
- **Drivers with plug-in vehicles are set to benefit from a £37 million funding package [Ref. 13] for home and on-street charging, and for new charge points for people parking plug-in vehicles at railway stations; and**
- **Local authorities are providing free parking for EVs in some urban areas.**
The effectiveness of these schemes having the desired effect on the uptake of electric plug-in cars will be determined over time, but there are still a number of barriers to overcome, such as range anxiety and the cost effectiveness of the vehicle over its lifetime.

3.1.2 Electric Light Goods Vehicles
Using the DfT road transport forecasts 2013 [Ref. 14] and the DECC predictions for growth, the illustration below in Figure 10 shows the predicted growth.

**Figure 10 – DECC EV Light Goods Growth Scenarios**

As with domestic EV predictions, the figures show a wide range in the increase in the number of EVs. In order to incentivise commercial consumers to purchase an EV, a number of incentive schemes have been introduced in the UK. The list below gives some examples of these schemes:

- Plug-in vehicles are currently exempt from VED;

- Plug-in cars are eligible for a 100% discount from the London congestion charge, worth up to £2,400 per annum;

- Plug-in van grant scheme, offering consumers a grant of 20% towards the cost of the vehicle, up to a maximum of £8,000;

- Plugged-in Fleet Initiative, with the Energy Savings Trust (EST) providing free consultancy to companies to assess the pros, cons and financial benefits of the applicant moving to an EV fleet [Ref. 15]; and

- Department for Transport, Low Carbon Vehicle Public Procurement Programme (LCVPP) project managed by Cenex. Using procurement to accelerate the introduction of lower carbon technologies onto the UK vehicle market, with the ultimate objective of reducing overall carbon emissions from the vehicle fleet [Ref. 16].

3.1.3 Electric Buses
The figures for buses were derived from the DfT road transport forecasts 2013 and the DECC predictions for growth. No growth has been added, as DVLA indicate that bus numbers are dropping [Ref. 17].
As with the other predictions, for cars and light goods, the figures show a high range of values between the high and low scenarios. The primary incentives for bus companies are cost saving and the corporate responsibility of CO₂ reductions [Ref. 18].

By way of incentives:

“The Green Bus fund is a fund which is supporting bus companies and local authorities in England to help them buy new low carbon buses. Its main purpose is to support and hasten the introduction of hundreds of low carbon buses across England.” [Ref. 19]

### 3.1.4 National Grid Predictions

Each year National Grid publishes the “National Grid Future Network Scenarios” report, providing predictions of growth in demand for, amongst other things, EVs. The National Grid figures give the growth in the total number of electric vehicles across the UK; this includes cars, buses and light-goods as a single view. They provide their figures in two scenarios:

- **Slow progression** – A gentle increase in the number of EVs being purchased in the UK; and
- **Gone green** – An aggressive take-up, which might be the result of a change in technology or a significant incentive scheme to purchase EVs.

The view from “National Grid Future Network Scenarios” 2011 and 2013 is illustrated below in Figure 12.

**Figure 11 – DECC Bus Growth Scenarios**

**Figure 12 – National Grid Growth Scenarios**
As can be seen in Figure 12, in the “2011 gone green scenario”, the prediction was almost 13 million EVs by 2030, but in 2013 the same annual report was predicting only 3.5 million EVs, approximately just 25% of the figures two years earlier; similarly, for the “2011 slow progression scenario” forecast 4.5 million EVs and in 2013 the updated forecast estimated just 1 million EVs by 2030. These figures represent a significant drop in the expected growth from the same source.

For the purposes of comparison between the parties, the 2011 slow progression scenario is approximately the same as the “Low DVLA growth” and “Medium DECC” update, but for 2013 there is no comparison to the “slow progression” scenario.

This illustrates is that it is still too early to accurately predict EV growth. The drop in predictions over the two years is significant and cannot be ignored. This can be illustrated when looking at OLEV data [Ref. 20] for the past 4 years as a comparison as shown in Table 1 below:

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of EVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1,279</td>
</tr>
<tr>
<td>2011</td>
<td>2,114</td>
</tr>
<tr>
<td>2012</td>
<td>3,491</td>
</tr>
<tr>
<td>2013</td>
<td>4,359</td>
</tr>
</tbody>
</table>

As incentives are removed, there is a risk that the market with stagnate, in much the same way as the reduction of the Feed-In Tariff (FIT) has resulted in the slowing down of Photo-Voltaic (PV) installations.

### 3.1.5 Sector Sizes

To illustrate the relative size of the different sectors, the National and London pictures are shown below.

**Figure 13 – Vehicle Types – National**

**Figure 14 – Vehicle Types – London**

As expected, this illustrates the number of buses and cars is greater in London, whereas nationally there are more light and heavy goods vehicles.
3.2 Interventions

Interventions refer to the technologies and methods of changing the consumer’s charging behaviour that can be deployed to protect DNO assets. Brief introductions are provided below to each of the interventions that have been investigated to mitigate the risk of traditional reinforcement.

3.2.1 Behavioural

Many of the reports and papers on the topic of EVs have focused on the technical aspects of the subject. However, it will be the behaviour of the consumer that will drive the market, for example, plugging their vehicle in to charge at night, regardless of whether it needs charging, using their vehicles only for short journeys and following a set behavioural pattern to charge the vehicle.

In Section 2.1, it was suggested that different consumer groups have different charging requirements. These differences are not just restricted to technical requirements, such as 3kW or 100kW charging, but also to factors such as buses and fleets needing to meet schedules and requiring a full charge and private users only using their vehicles for short journeys, and in many cases only using 20-25% of the charge, as is borne out by the trials run by LCL and also the Coventry and Birmingham low emission demonstrators (CABLED), see Section 4.1.1 and Section 4.1.2.

A number of behavioural mechanisms will therefore be considered to manage these requirements and behaviours:

- **Time of Use (ToU)**
  
  ToU influences the behaviour of the consumers by increasing the cost to charge their vehicle at peak times offering a reduced rate at a time that has less impact on the network; this behaviour was analysed in the LCL EV trials - see section 4.1.11.

  There are three methods of implementing ToU:

  - To increase the amount the consumer has to pay for their electricity at peak-times, this would encourage them to move consumption to off-peak;
  - To decrease the amount a consumer pays at off-peak, thus enticing them to shift their consumption, and
  - A combination of the two methods could be offered.

- **Education**
  
  It may be sufficient, particularly when the volumes are still low, to educate consumers about the impact of EV charging on the network and potentially their electricity bill. Given that currently consumers are “engaged” or interested in the benefits of EVs financially and environmentally, describing how reinforcement will ultimately affect their electricity bill might be enough to shift their behaviour.

3.2.2 Technical

Along with behavioural interventions there are a number of technical interventions that will be considered. All of these rely on the introduction of network monitoring in areas where constraints exist, so that these are visible to network planners and support their decision-making processes. The interventions will ultimately control the charging of the vehicle, ideally without the knowledge of the consumer. However, care should be taken when considering these technologies as the needs of the consumer must come first. Shifting the load without due consideration could, for example, result in a bus not being able to complete its route.

- **EV Controller**
  
  This software is used to control and manage the charge points. See Section 2.3.6.1 for more details.

- **Active Network Management (ANM)**
  
  Sensors and central management solution for controllable loads; these act predominantly as a protection mechanism in EV scenarios. See Section 2.3.6.2 for more details.

- **SMETS2 Auxiliary Load Control Switches (ALCS) with Demand Side Response (DSR)**
  
  The Smart Metering Equipment Technology Standard (SMETS2) has proposed a separate control switch to be made available, via the DCC and the HAN, using the ZigBee SEP 1.2 protocol. This will allow a 3rd party to switch the charge point on and off, to constrain the load on and off. This is expected to be coupled with a Demand Side Response (DSR) solution. See Section 2.3.5 for details on SMETS 2 Auxiliary Load Control Switches (ALCS).

- **Timer**
  
  The timer provides a simple mechanism for switching the charger on and off. This is particularly useful when coupled with ToU tariffs, as it can be used to assist the consumer in ensuring they only charge during an off-peak period.

  Timers come in a number of different forms, for example, as built into the charging point, through an EV Controller or as a direct connection to the vehicle. A more advanced mechanism could be included with the EV Controller that allows a user to select a time when they want the vehicle
charged by, instead of simply selecting a charging start time. Some examples of how effective these have been have been given in Section 4.1.2.

- **Reinforcement**
  Traditionally reinforcement is the only mechanism for supporting additional loads, which can be very costly and disruptive. Whilst the introduction of new technologies might see this as a last resort, for some consumer groups it may be the only option available.

### 3.3 Typical EV Architecture

A typical EV architecture model is illustrated below in Figure 15. This model is likely to change depending on which interventions the DNO elects to deploy for each consumer group. The architecture is used to show issues that may arise when implementing an EV infrastructure.

**Figure 15 – Typical EV Architecture**

If the CNO wishes to communicate with a charging point then a communications module on the charging point and EV Controller software should be installed. This will allow charge demand data to be collected and remote control to be performed on the charging point itself.

For the management of domestic chargers it may in the future be possible to send control signals through the Home Area Network (HAN), using the SMETS2 ALCS, see Section 2.3.5.

The EV Controller is the only system component that is permitted to perform these actions, any other form of control will need to go through this system. ANM, for example, could react to excesses in load and will need to send signals to the EV Controller to curtail load. In addition, if the DNO uses forecasting software to predict expected loads and finds that the following day there might be a peak, then this forecast profile could be sent to the EV Controller for the system to apply curtailment to the appropriate charge point groups, at the given times.
Another emerging area is behavioural analytics. This takes EV charge session data and tries to predict where and when an EV user may charge and for how long and how often. This could be invaluable in the future, as the number of electric vehicles grows and more people need to charge their vehicles. It also has the advantage to the DNO that they can more accurately predict where there might be an issue. (This approach assumes that the relevant data is available to the DNO).

3.4 Consumer Scenarios

To illustrate the impact that clusters of EVs will have on the DNO, four consumer scenarios have been used to highlight constraints and identify potential behavioural and technological interventions that could be employed to mitigate those constraints. Detailed by consumer type, each scenario aims to provide an illustration of a potential constraint and how interventions that work for one consumer type do not necessarily work for another type.

In the following sections, four case studies have been examined using data and substation load profiles from the Merton Engineering Instrumentation Zone (EIZ), as part of the LCL programme. This is overlaid with worst-case load profiles to illustrate how the demand for EV charging from each of the consumer groups would hypothetically impact the substations in the Merton EIZ network.

3.4.1 Scenario 1: Residential Private Charging

3.4.1.1 Case Study

The area of the Merton (EIZ) examined in this case study is typical of suburban London. There is a mixture of low-rise, semi-detached and terrace housing, purpose-built flats, small shops and embedded industrial units. The substation examined in this case study is typical of this area; it is a 750kVA substation with 3 Low Voltage feeders and consists of the following:

- The first LV Feeder, serving mostly residential properties and some small industrial units with a total of 1,159 metering points;
- The second feeder is exclusively serving a new apartment complex with 292 metering points; and
- The third feeder is supplying small industrial units and shops with a total of 799 metering points.

This gives a total of 2,250 metering points being fed by this transformer. Taking a sample period of January to July 2012, it is clear that the transformer is running comfortably within capacity as shown below in Figure 16. There are only a few occasional peaks above 400kVA, with the highest peak being 440kVA in February 2012.

Figure 16 – Transformer Load Profile
In this scenario there are 2,250 metering points being fed from the transformer. To demonstrate when load will reach transformer nameplate rating, the following assumptions have been made:

- Not all of these metering points are residential;
- Not all residential home owners will own a car; and
- 50% of the total number of metering points will be car owners.

Taking the DECC / DVLA growth figures from Section 3.1 and the above three assumptions, a predicted EV uptake can be derived for the transformer, as shown below in Figure 18.

With a model established for this consumer scenario, the analysis of the excess consumption and the potential interventions can be applied.
3.4.1.3 Capacity Model
To examine the effect of EV uptake on this transformer in this case study, the baseline profile in Figure 17 has been combined with the DECC EV uptake predictions in Figure 18. The following assumptions have been made to aid the development of this model:

- All charging points will be 3.5kW;
- A power factor (PF) of 0.8 will be used for the calculations;
- Spare capacity should not exceed 85% of transformer nameplate rating, i.e. at a maximum 30 minute period;
  - \( 638\text{kVA} - 440\text{kVA} = 198\text{kVA} \) spare capacity at peak times;
  - \( 638\text{kVA} - 250\text{kVA} = 388\text{kVA} \) spare capacity at off-peak; and
- \( \text{kVA} = \frac{\text{kW}}{\text{PF}} \)

Based on these assumptions the transformer can therefore support 42.2 EVs charging simultaneously at peak times ((198kVA x 0.8) / 3.5kW).

At off-peak times the number of EVs the transformer can support will increase to 88.6 EVs charging simultaneously ((388kVA x 0.8) / 3.5kW).

Whilst only a rough guide (as formal analysis will require a full planning exercise to consider amongst other things voltage drop), this does however illustrate that a typical transformer may have issues if there are more than 45 EVs simultaneously charging at 3.5kW during peak periods, or 88 EVs simultaneously charging during off-peak periods.

Based on the anticipated growth given in Figure 19 below, and this growth being applied to the baseline profile, the tipping point would occur when the number of EVs reaches 44 in 2022.

Figure 19 – EV Charging Pattern with ToU Applied

Assuming the contribution to the peak time load from this number of EVs charging is sustained, in order for the transformer to accommodate any more EVs charging during this peak period, investment would be required on the network to increase the capacity of the transformer from 750kVA to 800 or 1000kVA as appropriate. Alternatively, either or a combination of the following mitigating actions, discussed in Section 3.2, could be considered by the DNO.

3.4.1.4 Mitigating Actions
Three potential interventions to mitigate these constraints have been outlined below. These are based on the DECC Central predicted growth from, and based on 25% of EV drivers simultaneously charging during peak periods and with 100% of EV drivers simultaneously charging during off-peak periods.
Option 1 – Behavioural: Education – By educating the consumer as to how shifting their charging to off-peak when possible will save money and reduce carbon and other noxious emissions, two of the primary reasons consumers choose an EV.

From Report B1 [Ref. 2], it has been shown that the highest demand for residential EV charging is recorded between 6 p.m. and midnight, with very low demand during the night. The average observed charging duration was about 2.5 hours, with only a very small number of charging events exceeding 5 hours.

Based on this evidence, a change in the behaviour of EV owners on this area of the network could move charging periods to the off-peak period, which, as detailed above, would allow this transformer to cater for up to 88 EVs charging simultaneously.

Enablers: Determining where increased loading on the transformer is due to EVs is a minimum requirement for this course of action to be taken. Ensuring that it is mandatory for the installer of an EV charging point unit to inform the DNO is essential. The DNO should then be pro-active in managing the effect these charging points will have on the network, allowing the DNO to adequately plan and forecast future demand, rather than be re-active to issues.

Barriers: Early adopters of EVs are likely to be more receptive to education, but as EV uptake grows the consumer base will be more diverse. It is unlikely therefore, that a change in charging behaviours through education will allow the level of reliability required for a suitable long term solution to traditional reinforcement.

Option 2 – Introduce Time of Use Tariffs:

When the transformer is close to reaching 85% of its nameplate rating, the DNO could work with Suppliers to introduce ToU tariffs. LCL EV trials have shown that consumers are willing to shift their charging to off-peak in order to achieve a lower electricity bill.

If only 50% of consumers were influenced to move to off-peak by the adoption of ToU tariffs, then further action at this stage could be avoided.

If 100% of consumers switched to off-peak charging, then the tipping point would move out to 2026.

Enablers: For the ToU tariff to work, the consumer must inform the DNO that they have installed a charging point and the customer must be in an area where there is a constraint on the network. To ensure this occurs, it will be necessary to either change policy to make it mandatory for the DNO to be informed when a point is installed or offer an incentive.

Barriers: As the decision to participate in a ToU tariff still resides with the consumer, they will not guarantee consumers will shift charging behaviour. Home charging is an extension of the consumer’s relationship with their Supplier and so the DNO has no direct influence on the end consumer. For ToU tariffs to be a reliable intervention, DNOs will need to work with Suppliers in areas where constraints and clustering of EVs exist, to actively target consumers by offering them financial incentives to charge off-peak.

Furthermore, assuming take-up of such tariffs, it is also important to ensure that the consumer adheres to the off-peak time patterns for EV charging. To assist in this, a technical intervention such as a timer could be included as an enabler on the charging point, the car or via the HAN. This timer should allow the consumer to set the time to begin charging, or a time for charging to complete.

There is a fundamental question around the application of ToU tariffs to EV load, namely, is the tariff applied strictly to the EV charging point or is it applied, as it is presently, at the household level? In the case of the former, this will involve additional infrastructure (including additionally administrative processes such as billing and settlement) and raises the question about the cost of this as a viable mechanism to deferring network reinforcement. Similarly, there could be a conflict with the latter approach, such that “normal” loads i.e. non-EV loads, could be billed at a premium. While these are considerations that need to be made for the realisation of the benefits of ToU tariffs, it is outside the scope of this report.

Option 3 – Technical Interventions

As outlined in options 1 and 2, if charging requirements were moved to the off-peak period, traditional reinforcement would be deferred until 2026. However, to ensure that this load is reliably shifted into the off-peak period, a technical intervention might be considered.

Enablers: In order to reliably control clusters of EVs on the network, there would need to be a central EV Controller that could send control signals to each of the charging points. Alternatively, the integration between the charging point and the IHD that is proposed by SMETS2, in the form of AlCS, coupled with DSR, might have the potential to allow a DNO to constrain-off the charging point by sending a message via the DCC.

Barriers: There are two limiting factors which make it unlikely that an EV Controller will be used as an intervention within the domestic consumer group. Firstly, the cost of the infrastructure and secondly the potential that charging points may be from different vendors. A mixed population of charging point vendors will also introduce complexity. The SMETS2 specification is still a work in progress and it is likely to be many years before control of charging points via the DCC will be possible.
3.4.2 Scenario 2: Residential Public Charging

3.4.2.1 Case Study
The area of the Merton EIZ examined in this case study is typical of suburban London. The transformer selected is located in a car park and feeds residential housing. The transformer examined in this case study is typical of this area, being a 500kVA substation with 4 LV Feeders.

There are around 1,800 metering points being fed by this transformer. Taking a sample period of January to July 2012, it is clear that the transformer is running comfortably within capacity as shown below in Figure 20. There are only a few occasional peaks above 260kVA, with the highest peak being 270kVA in February 2012.

**Figure 20 – Transformer Load Profile**

![Transformer Load Profile](image)

Figure 21 illustrates the demand profile for the peak day within this sample period, 5th February 2012, which will act as the baseline for the following examination.

**Figure 21 – Baseline Load Profile**

![Baseline Load Profile](image)
3.4.2.2 Public EV Charging Considerations

According to the DECC figures given above in Figure 9 in Section 3.1.1, and the emphasis being placed on encouraging EV uptake by the Government and other parties, more and more drivers will want to charge their vehicles at public charging points. Understanding the additional load that the introduction of new charging points will bring is only part of the picture; understanding the different characteristics of public charging is equally important:

- When the consumer plugs in their vehicle it is not known when they will return, therefore the default position is that the charging point charges as fast and as soon as is possible. This will limit the ability to curtail the load, which makes constraining off the charging point the only option; and

- Despite the incentives offered by the Government (see 3.1 EV Uptake Predictions), public charging infrastructure may not actually be utilised because either they are not located where the consumer wants or the consumer simply charges their vehicle at home [Ref. 21].

3.4.2.3 Capacity Model

To examine the effect of installing public charging points on this transformer, the baseline load profile in Figure 22 has been used and the following assumptions made:

- The charging points are 22kW;
- A Power Factor (PF) of 0.8 will be used for the calculations;
- Spare capacity is 85% of transformer nameplate rating, i.e:
  - 425kVA – 270kVA = 155kVA maximum spare capacity.
  - \( kVA = kW / PF \)

Based on these assumptions, the Transformer can support 5.66 EVs charging simultaneously at peak periods ((155kVA x 0.8)/22kW).

Assuming the contribution to the peak time load from this number of EVs charging is sustained, in order for the transformer to accommodate any more charging points, investment would be required on the network to update the capacity of the transformer from 500kVA to 800 or 1000kVA as appropriate. Alternatively, either or a combination of the following mitigating actions, discussed in Section 3.2, could be considered by the DNO.

3.4.2.4 Mitigating Actions

Option 1 – EV Controller

Using an EV Controller, load at particular constraint points could be capped, based on historic analysis of the load and thus protect the transformer, as illustrated below in Figure 22:

Figure 22 – Transformer Load with Limit Set
**Enablers:** The CNO EV Controller will allow load to be managed, but allowing a maximum load to be allocated to a group of charging points and thus limiting the amount of power that can be drawn from the network: Whilst this does not guarantee the transformer will be protected, it does ensure that the load is not excessive.

To make better use of the charging point, the CNO could offer the option of setting a “required by” time. If the current charge of the batteries can be read, then the EV Controller can use this information to ensure the charging is balanced with others, whilst meeting the requirement from the driver that the vehicle be ready on their return.

**Barriers:** The DNO has no direct access to the control systems that manage the public charge points, so agreements will need to be reached with CNOs, that do not exist today, to constrain their load. In addition, public charging, by its very nature, is unlikely to be clustered. Instead, the objective of OLEV is to reduce range anxiety by having a distributed network of charging points, for example, the OLEV initiative to install rapid chargers in every UK motorway service station. Where constraints exist on the network, these need to be paired with available curtailment, which might not be feasible.

The requirement of the consumer in this scenario is simple: the vehicle should be ready on their return, with sufficient range to meet their journey. Therefore, shifting the load will be difficult, unless the consumer can inform the system when they intend to return and the EV Controller is intelligent enough to manage the charging session.

**Option 2 – ANM:**

The introduction of an ANM controller could be introduced to send more intelligent control signals to the EV Controller to make best use of available power. The ANM controller will make requests to the EV Controller to constrain off or reduce load when capacity limits are being reached, as illustrated below in Figure 23:

**Figure 23 – Transformer Load with ANM Controller**

**Enablers:** Information technology (IT) integration between the SCADA network and the CNO network to allow signals to be automated. This will reduce the charging capacity available for those charging points under CNO control, but would protect the transformer.

**Barriers:** Cyber-security concerns around allowing communication between the SCADA and non-SCADA networks will need to be addressed, as currently this bridge is not allowed. The ANM controller will only be an enabler if available load can be shed where the DNO has a constraint on the network. As an extension of the EV Controller, the ANM controller will be impacted by the same barriers.
3.4.3 Scenario 3: Commercial Fleet

3.4.3.1 Case Study
For this analysis an industrial area in the Merton EIZ was selected, which has a collection of distribution warehouses and residential properties. The transformer examined in this case study is a 800kVA transformer with 3 LV feeders.

There are around 800 metering points being fed by this transformer. Taking a sample period of January to July 2012, it is evident that the transformer is almost at 85% of its nameplate rating, occasionally peaking at 680kVA.

**Figure 24 – Transformer Load Profile**

Figure 25 illustrates the demand profile for the peak day within this sample period, 14th April 2012, which will act as the baseline for the following examination. The load profile on this transformer is different to those analysed previously, as the peak load is spread across the working day in a brick pattern giving limited scope for extra capacity during the working day.

**Figure 25 – Baseline Load Profile**

From Report B1 [Ref. 2], it has been shown that peaks in charging demand are observed around 17:00 and from 22:00 onwards, which aligns with commercial vehicles finishing their shifts and leaving them plugged in overnight. The average charging duration was about 3 hours, with only a very small number of events exceeding 5 hours.

3.4.3.2 Growth Model from DECC Figures
Considering the predicted growth in light goods presented in Section 3.1, by 2020 the medium predictions from DECC suggest that there will be only around 80,000 electric fleet vehicles on the road, steadily increasing to 520,000 by 2030. Given the
range constraints of EVs, it is likely that they will be clustered and mainly in cities, which should allow opportunities for the DNO to target these sites for curtailment where network constraints exist. Outside of cities where range is greater, fleet operators will move towards PHEVs and so the opportunities for smart optimisation are less.

### 3.4.3.3 Capacity Model

Fleet light goods vehicles have been demonstrated via Report B1, to return to base and plug-in, creating two new peaks in load around 17:00 and 22:00. As shown below in Figure 26, this increase in demand around 17:00 will tip the transformer close to the nameplate rating if just ten 7kW charging points are added at this location.

#### Figure 26 – Transformer Load Profile with 10 Extra Chargers

The behaviour of the consumer will typically follow the same pattern, they arrive back at base and then the vehicle will stand until the following morning, giving potential for these loads to be managed and shifted during the off-peak hours.

### 3.4.3.4 Mitigating Actions

#### Option 1 – EV Controller:

Using an EV Controller, load at this particular constraint point could be capped, based on historic analysis of the load, and thus protect the transformer, as illustrated below in Figure 27:

#### Figure 27 – Transformer Load Profile with Limit Set
Enablers: The provision of an EV Controller by the consumer to control load within the site will allow a maximum load to be allocated to a group of charging points and thus limiting the amount of power that can be drawn from the network. This will guarantee the transformer will be protected, but the limit will be set by the consumer and thus could be changed without knowledge of the DNO. To make better use of the charging points, the EV control system could make use of scheduling information, and manage the balance between load and charging windows to ensure that the vehicle has sufficient range when required. Shifting the load should be possible, provided the EV Controller is intelligent enough to manage the charging session.

Barriers: The DNO has no direct access to the control systems that manage the charge points, so agreements will need to be reached with the consumer that do not exist today to constrain their load.

Consumers that have a fleet of EVs will by their nature be clustered and maybe the subject of a new connection request[Ref. 22]. It will depend greatly on whether these are in areas where constraints exist, as to whether they could be paired in order to offer curtailment.

Option 2 – ANM to Protect the Transformer

The introduction of an ANM controller could send more intelligent control signals to the consumers EV Controller to make best use of available power, which will enable more chargers to be deployed at the site. In this example 10 chargers have been added, the ANM controller will make requests to the EV Controller to constrain off or reduce load when capacity limits are being reached, as shown below in Figure 28:

![Figure 28 – Transformer Load Profile with ANM Control](image)

Enablers: Information Technology (IT) integration between the SCADA network and the consumers EV Controller to allow signals to be automated. This will reduce the charging capacity available, but would protect the transformer.

Barriers: The biggest barrier will be associated with the practicalities of setting up and managing a connection between the SCADA network and the consumer’s network. Cyber-security concerns around allowing communication between the SCADA and non-SCADA networks will need to be addressed, as currently this bridge is not allowed. The ANM controller will only be an enabler if available load can be shed where the DNO has a constraint on the network. As an extension of the EV Controller, the ANM controller will be impacted by the same barriers.

3.4.4 Scenario 4: Public Transport – TfL Electric-bus Trial

3.4.4.1 Case Study
For this scenario a distribution centre has been used, as it has similar characteristics as a bus garage. This has a dedicated feed from a 750kVA substation, as illustrated in Figure 29 – Transformer Load Profile. As can be seen from Figure 29, this substation is running well under 85% of nameplate rating.
As seen on Figure 30, in April 2012, the total kVA peaked just over 200kVA.

3.4.4.2 Growth Model from DECC Figures

Using the predictions given in Section 3.1 for the Medium DECC scenario, it can be seen that there are likely to be only approximately 5,500 electric buses in use by 2030. For all DNOs, concerns will be about clustering of buses on a single transformer, as the more electric buses there are clustered, the more new connections are likely to be required.

3.4.4.3 Capacity Model

In 2013 Transport for London introduced two EV buses [Ref. 23], with an additional six planned for 2014, marking a commitment to eco-friendly buses in London. The intention is to trial their feasibility with a view to begin a larger rollout in 2016. By comparison, around 1700 hybrid buses are planned to be introduced by 2016 and 120 zero emissions buses have already been introduced by 2013.

Using TfL as the example, two EV buses have been trialled on routes 507 and 521; the two route timetables outline behaviours that are typical:

**Route 507: Victoria Station -> Millbank -> Waterloo Station = Distance of 4.4 miles**

The first bus leaves Victoria bus station at 06:27 and last bus returns to Victoria at 00:32. Buses on average leave every 6 minutes in each direction, 10 an hour in each direction, with a journey time of 20 minutes. There is only one bus deployed on this route, therefore over a day the maximum number of journeys the bus could take over the 18 hours is 27 journeys. That gives
a total distance travelled of 118.8 miles, within the range stated of 200-250 miles by EV bus manufacturer BYD [Ref. 24].

**Route 521: Waterloo Station -> Holborn Station->Holborn Circus -> St Pauls Station -> Cannon Street Station -> London Bridge Station = Distance of 4.8 miles**

The first bus leaves Waterloo station at 06:30 and last bus returns to Waterloo at 00:33. Buses leave on average every 10 minutes in each direction, 6 an hour in each direction, with a journey time of 20 minutes. There is only one bus deployed, therefore over a day the maximum number of journeys the bus could take over the 18 hours is 27 journeys. That gives a total distance travelled of 129.6 miles, within the range stated of 200-250 miles by BYD.

Assuming it takes 30 minutes for the bus to drive from the depot at the start of the day and the same time to return, this gives a charging window of 5 hours (01:00 to 06:00). BYD have stated that charge time is between 4-5 hours [Ref. 24] which is challenging, but achievable.

In addition, the bus chargers are 80kW, so for these two buses charging from 01:00 to 06:00 will have a limited impact on the transformer as illustrated in Figure 31 below.

**Figure 31 – Transformer Load for 2 Buses**

For this case study, two routes were examined and illustrate the impact on the transformer when each bus on these two routes changes to an EV. There will be 32 buses that require charging at the same time with no opportunity to load shift given the short available window, the result is shown below in Figure 32:

**Figure 32 – Transformer Load for an additional 32 Buses**
In fact the maximum number of buses that could be charged concurrently is 7, as shown in Figure 33 below:

**Figure 33 – Additional Load for 7 Buses**

3.4.4.4 Mitigating Actions
There are no alternative interventions that can be deployed in this scenario, as the power requirements are high and will have a serious impact on the network. The impact will need a full planning exercise to reinforce the network, as was the case with this example with a new connection being installed.

3.4.5 Conclusions
As shown by the case studies in this section, growth in EVs within each consumer group will have a different impact on the network. Public and Fleet consumers will be clustered and thus more likely to be the subject of a new connection request, making them less suitable for smart optimised control. As part of that new connection request, the DNO could offer these consumers a lower connection cost in return for allowing the DNO to introduce load control at these sites. This is made easier as the DNO will have direct contact with the end consumer group, which is not the case for domestic consumers.

Domestic consumers are more unpredictable and introduce incremental loads onto the network. This implies that direct control of these consumer groups without the introduction of ACLS and the DCC will not be cost-effective, instead behaviourally interventions should be considered to shift domestic load to off-peak.
4.1 LCL Trials

The LCL trials on regulating new loads examined the effects of two mechanisms on managing the demand from EV charging. The first, used the behavioural mechanism of a ToU tariff on a sample of residential EV users. The second used a technical mechanism using ANM and an EV controller to regulate the demand from a sample of public charge points. The details, outcomes and implications of the trials will be presented in the following subsections.

Both trials demonstrated that a positive response can be derived by the application of devised mechanisms. The ToU trial showed that participants tend to modify their behaviour and charge in the off-peak periods to take advantage of the cheaper rate. Similarly, the EV ANM trial demonstrated that a combination of ANM and an EV controller can provide an automated, real time distribution network load management solution for public access charge points, with minimum impact on EV drivers. Furthermore, the trial examined areas where further data and experience of using the solution could support the case for its wider adoption, namely, running the trial at scale using both home and workplace EV charge point clusters.

4.1.1 LCL EV Trials

The LCL project carried out two distinct EV charging control trials:

- “Time of Use” trial, investigating the impact of ToU tariffs on domestic customers’ recharging behaviour at home, and
- “Regulated” trial, investigating the impact of controlling charging points by cyclic switching at times of high demand.

4.1.1.1 Electric Vehicle ToU Tariff Trial

The trial looked to encourage diversity in EV charging and shifting load to off-peak periods. The main hypothesis this trial was investigating was whether EV charging patterns coincided with early evening peak demand and whether offering consumers an attractive price for off-peak power would see a switch from this peak period to off-peak.

The trial monitored participants’ charging behaviour when they were offered a reduced rate to charge off-peak. This was compared to a control set of participants that were on a flat rate tariff, to see whether the consumers on the reduced rate were encouraged to switch charging to off-peak periods.
Trial Details
UK Power Networks recruited 10 customers, via EDF Energy, who each agreed to sign up to the EDF Energy ECO 20:20 tariff which provides a 20% discount on electricity between 21:00 and 07:00 and all day at weekends. These participants agreed to have a sub-smart meter installed, to allow LCL to monitor consumption and charging patterns.

In addition, LCL signed up an additional 58 EV owners, who agreed to the installation of a sub-smart meter to act as a control group. These participants were from a variety of electricity Suppliers, and it is not known whether any incentive was offered by those Suppliers for off-peak charging.

By using these two groups of participants, analysis of the data will indicate whether the small discount offered by the ECO 20:20 tariff was enough to shift charging to off-peak, or whether consumers continued to charge at convenience.

The analysis considers the volume of charging that occurs in and outside the off-peak period. The off-peak period is the period when the 20% discount on the nominal cost, between 21:00 and 07:00.

ToU Trial Participant Results
LCL undertook surveys of participants that were participating in the trial, not all participants completed the survey, but from these surveys a profile can be derived and is summarised in this section, along with the charging patterns and outcomes.

ToU1 – Participant Type – Retired Professional

Table 2: Participant ToU1 – Profile

<table>
<thead>
<tr>
<th>Profile</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
</tr>
<tr>
<td>Age Group</td>
<td>66+</td>
</tr>
<tr>
<td>Employment Status</td>
<td>Retired</td>
</tr>
<tr>
<td>Income Range</td>
<td>£101k – £150k</td>
</tr>
</tbody>
</table>

Vehicle Details

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Smart EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicated Weekday Use</td>
<td>10 miles</td>
</tr>
<tr>
<td>Indicated Weekend Use</td>
<td>12 miles</td>
</tr>
<tr>
<td>Commuting Distance</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Main Use</td>
<td>Social and Leisure</td>
</tr>
<tr>
<td>Charging Points Used</td>
<td>Home Only</td>
</tr>
<tr>
<td>Maximum Distance comfortable to drive on a Full Charge</td>
<td>50</td>
</tr>
<tr>
<td>Longest Distance Driven between charges</td>
<td>60</td>
</tr>
<tr>
<td>Typical charge when</td>
<td>50% battery or 30 miles range</td>
</tr>
<tr>
<td>Charger</td>
<td>7kW</td>
</tr>
</tbody>
</table>

As a retired professional, the vehicle is being used for social and leisure use only, the charging pattern over the year is shown above in Figure 34.

Analysing this data when charging was taking place by day of the week, as shown below, this participant is always avoiding peak times.

Table 3: Participant ToU1 – Charging Breakdown

<table>
<thead>
<tr>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thur</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>140.824</td>
<td>88.003</td>
<td>136.999</td>
<td>123.958</td>
<td>110.238</td>
<td>57.39</td>
</tr>
<tr>
<td>On</td>
<td>0.045</td>
<td>0.041</td>
<td>0.343</td>
<td>0.044</td>
<td>0.045</td>
<td>0</td>
</tr>
<tr>
<td>Off</td>
<td>140.779</td>
<td>87.962</td>
<td>136.656</td>
<td>123.914</td>
<td>110.193</td>
<td>57.39</td>
</tr>
</tbody>
</table>

This is not surprising, given that this participant has indicated they actively look to charge when the electricity is cheapest and also is retired using the vehicle very infrequently.

Conclusion: This participant is being influenced by the availability of a cheaper rate during off-peak, but this might be just due to environmental responsibility, given that the financial benefit to the participant is low and they have indicated they have a high income.
ToU2 – Participant Type – Professional Non-Commuter

Table 4: Participant ToU2 – Profile

<table>
<thead>
<tr>
<th>Profile</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
</tr>
<tr>
<td>Age Group</td>
<td>56-65</td>
</tr>
<tr>
<td>Employment Status</td>
<td>Full Time</td>
</tr>
<tr>
<td>Income Range</td>
<td>£101k – £150k</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Vehicle</td>
<td>Smart EV</td>
</tr>
<tr>
<td>Indicated Weekday Use</td>
<td>10 miles</td>
</tr>
<tr>
<td>Indicated Weekend Use</td>
<td>30 miles</td>
</tr>
<tr>
<td>Commuting Distance</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Main Use</td>
<td>Social and Leisure</td>
</tr>
<tr>
<td>Charging Points Used</td>
<td>Home Only</td>
</tr>
<tr>
<td>Maximum Distance comfortable to drive on a Full Charge</td>
<td>75</td>
</tr>
<tr>
<td>Longest Distance Driven between charges</td>
<td>95</td>
</tr>
<tr>
<td>Typically charge when % left</td>
<td>65% battery or 70 miles range</td>
</tr>
<tr>
<td>Charger</td>
<td>3.5kW</td>
</tr>
</tbody>
</table>

The charging pattern over the year is shown below in Figure 35 for a professional who does not use the vehicle for commuting.

Figure 35 – Participant ToU2 – Total

Monthly Consumption

Analysing this into when charging was taking place by day of the week, as shown below, this participant is avoiding peak times.

Table 5: Participant ToU2 – Charging Breakdown

<table>
<thead>
<tr>
<th></th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thur</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Peak</td>
<td>0.366</td>
<td>0.351</td>
<td>0.673</td>
<td>0.373</td>
<td>0.293</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Off Peak</td>
<td>61.82</td>
<td>65.645</td>
<td>66.47</td>
<td>49.9</td>
<td>121.337</td>
<td>281.035</td>
<td>189.835</td>
</tr>
</tbody>
</table>

This is not surprising given, that this participant has indicated they actively look to charge when the electricity is cheapest and only uses the vehicle for social and domestic use.

Conclusion: This participant is being influenced by the availability of a cheaper rate during off-peak, but this might be just due to environmental responsibility, given that the financial benefit to the participant is low and they have indicated they have a high income.

ToU3 – Participant Type – Professional Commuter

Table 6: Participant ToU3 – Profile

<table>
<thead>
<tr>
<th>Profile</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
</tr>
<tr>
<td>Age Group</td>
<td>46-55</td>
</tr>
<tr>
<td>Employment Status</td>
<td>Full Time</td>
</tr>
<tr>
<td>Income Range</td>
<td>£101k – £150k</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Vehicle</td>
<td>Smart EV</td>
</tr>
<tr>
<td>Indicated Weekday Use</td>
<td>35 miles</td>
</tr>
<tr>
<td>Indicated Weekend Use</td>
<td>50 miles</td>
</tr>
<tr>
<td>Commuting Distance</td>
<td>24 miles</td>
</tr>
<tr>
<td>Main Use</td>
<td>Social, Leisure and Commuting</td>
</tr>
<tr>
<td>Charging Points Used</td>
<td>Home Only</td>
</tr>
<tr>
<td>Maximum Distance comfortable to drive on a Full Charge</td>
<td>65</td>
</tr>
<tr>
<td>Longest Distance Driven between charges</td>
<td>85</td>
</tr>
<tr>
<td>Typically charge when % left</td>
<td>40% battery or 40 miles range</td>
</tr>
<tr>
<td>Charger</td>
<td>3.5kW</td>
</tr>
</tbody>
</table>
As the participant has indicated they use the vehicle for commuting, it would be expected that range anxiety would play a bigger part in their charging patterns which over the year is shown below in Figure 36.

**Figure 36 – Participant ToU3 – Total Monthly Consumption**

![Monthly Consumption graph](image)

### Table 7: Participant ToU3 – Charging Breakdown

<table>
<thead>
<tr>
<th>Day</th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thur</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>145.045</td>
<td>268.988</td>
<td>167.639</td>
<td>219.538</td>
<td>168.836</td>
<td>172.078</td>
<td>124.34</td>
</tr>
<tr>
<td>On Peak</td>
<td>38.827</td>
<td>112.59</td>
<td>62.279</td>
<td>91.484</td>
<td>48.916</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Off Peak</td>
<td>106.218</td>
<td>156.398</td>
<td>105.36</td>
<td>128.054</td>
<td>119.92</td>
<td>172.078</td>
<td>124.34</td>
</tr>
</tbody>
</table>

This participant is not avoiding peak times as much as the other participants, but is charging when this is convenient to them. This is not surprising, given that the participant is using their car more than the other two participants previously analysed. The flattening of the curve from November onwards is due to the car not being used as much as previously.

**Conclusion:** This participant is not as influenced by the ECO 20:20 tariff. This can be explained by the savings they would have made over the year if they had tried to charge only off peak. Over the year, this participant has used 1,266 kWh charging their vehicle, of which 28% has been on-peak and 72% has been off peak. Using the published ECO 20:20 rates, this equates to a cost of charging of

- **Off Peak:** \((1266 \times 72\%) \times 11.39p = £129.83\)
- **On Peak:** \((1266 \times 28\%) \times 14.23p = £40.33\)

Given the low cost benefit to this participant of charging off-peak, and that the amount of charge the car is taking daily would indicate a reasonable daily use and the reduced rate is not influencing this participant to charge off-peak, as range anxiety is probably more of a concern.

**EV ToU Trial Participants Overall Charging Profile**

Of the ten participants that took part in the EV ToU trials, seven appeared to be influenced by the ECO 20:20 and charged off-peak and one had no data to analyse. However, considering that the overall cost savings to be made over a year are marginal by charging off peak, it is somewhat surprising that consumers on this trial were so willing to shift their behaviour given the limited cost benefits, as shown in Table 8.
Table 8: EV ToU Trial Participants – Overall Charging Profiles

<table>
<thead>
<tr>
<th>Participant</th>
<th>On Peak kWh</th>
<th>%</th>
<th>Off Peak kWh</th>
<th>%</th>
<th>On Peak Saving</th>
<th>Off Peak Saving</th>
<th>Total Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>ToU1</td>
<td>0.518</td>
<td>0.07</td>
<td>761.267</td>
<td>99.93</td>
<td>£0.01</td>
<td>£14.45</td>
<td>£14.46</td>
</tr>
<tr>
<td>ToU2</td>
<td>2.056</td>
<td>0.25</td>
<td>836.042</td>
<td>99.75</td>
<td>£0.05</td>
<td>£15.87</td>
<td>£15.92</td>
</tr>
<tr>
<td>ToU3</td>
<td>354.096</td>
<td>27.96</td>
<td>912.368</td>
<td>72.04</td>
<td>£8.40</td>
<td>£17.32</td>
<td>£25.72</td>
</tr>
<tr>
<td>ToU4</td>
<td>176.376</td>
<td>7.83</td>
<td>2077.565</td>
<td>92.17</td>
<td>£4.18</td>
<td>£39.44</td>
<td>£43.62</td>
</tr>
<tr>
<td>ToU5</td>
<td>165.606</td>
<td>12.08</td>
<td>1205.23</td>
<td>87.92</td>
<td>£3.93</td>
<td>£22.88</td>
<td>£26.81</td>
</tr>
<tr>
<td>ToU6</td>
<td>20.101</td>
<td>2.40</td>
<td>818.519</td>
<td>97.60</td>
<td>£0.48</td>
<td>£15.54</td>
<td>£16.02</td>
</tr>
<tr>
<td>ToU7</td>
<td>152.029</td>
<td>23.28</td>
<td>501.035</td>
<td>76.72</td>
<td>£3.61</td>
<td>£9.51</td>
<td>£13.12</td>
</tr>
<tr>
<td>ToU8</td>
<td>54.877</td>
<td>6.21</td>
<td>828.8</td>
<td>93.79</td>
<td>£1.30</td>
<td>£15.73</td>
<td>£17.03</td>
</tr>
<tr>
<td>ToU9</td>
<td>0.002</td>
<td>28.57</td>
<td>0.005</td>
<td>71.43</td>
<td>£0.00</td>
<td>£0.00</td>
<td>£0.00</td>
</tr>
<tr>
<td>ToU10</td>
<td>27.697</td>
<td>6.58</td>
<td>393.541</td>
<td>93.42</td>
<td>£0.66</td>
<td>£7.47</td>
<td>£8.13</td>
</tr>
</tbody>
</table>

Control Group
LCL captured survey data for a number of participants that did not participate in the ToU trial and three participants who demonstrate similar characteristics to those detailed above have been used as a control set to establish whether the ToU tariff was the reason for the shifting demand.

Table 9: Participant CG1 – Profile

| Profile | |
|---------| |
| Gender  | Female |
| Age Group | 36-45 |
| Employment Status | Full Time |
| Income Range | £15k+ |

Vehicle Details

| Type of Vehicle | Nissan Leaf |
| Indicated Weekday Use | 10 miles |
| Indicated Weekend Use | 8 miles |
| Commuting Distance | 2 miles |
| Main Use | Social, Leisure and Commuting |
| Charging Points Used | Home Only |
| Maximum Distance comfortable to drive on a Full Charge | 45 |
| Longest Distance Driven between charges | 55 |
| Typically charge when % left | 50% battery or 30 miles range |
| Charger | 3.5kW |
This participant uses their vehicle for commuting, but they have only a very short distance to travel, their charging pattern over the year is shown below in Figure 37.

**Figure 37 – Participant CG1 – Total Monthly Consumption**

Analysing this into when charging was taking place by day of the week.

**Table 10: Participant CG1 – Charging Breakdown**

<table>
<thead>
<tr>
<th></th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thur</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>708.398</td>
<td>659.04</td>
<td>741.965</td>
<td>854.311</td>
<td>707.584</td>
<td>257.317</td>
<td>815.886</td>
</tr>
<tr>
<td>On</td>
<td>557.003</td>
<td>258.782</td>
<td>532.837</td>
<td>532.527</td>
<td>386.126</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Off</td>
<td>151.395</td>
<td>400.258</td>
<td>209.128</td>
<td>321.784</td>
<td>321.458</td>
<td>257.317</td>
<td>815.886</td>
</tr>
</tbody>
</table>

This participant is not avoiding peak times, but is charging when this is convenient to them. This is not entirely surprising, given that amount of charge that the participant is using. Looking at the underlying data, there is no pattern to when this consumer is charging their EV; rather it appears they are just plugging it in when they arrive home.

**Conclusion:** As the participant is not signed up to a ToU Tariff, they are not encouraged to charge during off peak hours.

**CG2 – Participant Type – Professional Non-Commuter**

<table>
<thead>
<tr>
<th>Table 11: Participant CG2 – Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Profile</strong></td>
</tr>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>Age Group</td>
</tr>
<tr>
<td>Employment Status</td>
</tr>
<tr>
<td>Income Range</td>
</tr>
<tr>
<td><strong>Vehicle Details</strong></td>
</tr>
<tr>
<td>Type of Vehicle</td>
</tr>
<tr>
<td>Indicated Weekday Use</td>
</tr>
<tr>
<td>Indicated Weekend Use</td>
</tr>
<tr>
<td>Commuting Distance</td>
</tr>
<tr>
<td>Main Use</td>
</tr>
<tr>
<td>Charging Points Used</td>
</tr>
<tr>
<td>Maximum Distance comfortable to drive on a Full Charge</td>
</tr>
<tr>
<td>Longest Distance Driven between charges</td>
</tr>
<tr>
<td>Typically charge when % left</td>
</tr>
<tr>
<td>Charger</td>
</tr>
</tbody>
</table>
This participant has indicated that they use the vehicle for commuting, but with a small distance covered each day. They use the vehicle a lot at weekends and have signed up to a Time of Use tariff with another Supplier; their charging pattern over the year is shown below in Figure 38.

**Figure 38 – Participant CG2 – Total Monthly Consumption**

![Graph showing monthly consumption](image)

Analysing this into when charging was taking place by day of the week.

**Table 12: Participant CG2 – Charging Breakdown**

<table>
<thead>
<tr>
<th>Day</th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thurs</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.366</td>
<td>0.351</td>
<td>0.673</td>
<td>0.373</td>
<td>0.293</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On Peak</td>
<td>20.6</td>
<td>18.6</td>
<td>34.3</td>
<td>20.3</td>
<td>15.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Off Peak</td>
<td>186.2</td>
<td>185.6</td>
<td>185.4</td>
<td>166.7</td>
<td>183.3</td>
<td>281.0</td>
<td>189.835</td>
</tr>
</tbody>
</table>

**Conclusion:** It is interesting that this participant has actively sought to sign up to a ToU tariff from another Supplier and that they are actively managing their charging so as to make full use of the off-peak rate.

**CG3 – Participant Type – Retired Professional**

**Table 13: Participant CG3 – Profile**

<table>
<thead>
<tr>
<th>Profile</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Age Group</td>
<td>66+</td>
</tr>
<tr>
<td>Employment Status</td>
<td>Retired</td>
</tr>
<tr>
<td>Income Range</td>
<td>£41k – £70k</td>
</tr>
</tbody>
</table>

**Vehicle Details**

| Indicated Weekday Use | 7 miles |
| Indicated Weekend Use | 8 miles |
| Commuting Distance | Not Applicable |
| Main Use | Social and Leisure |
| Charging Points Used | Home and Public |
| Maximum Distance comfortable to drive on a Full Charge | 60 |
| Longest Distance Driven between charges | 75 |
| Typically charge when % left | 10% battery or 8 miles range |
| Charger | 3.5kW |

As a retired professional, this participant is using their vehicle for social and recreational use, with only a small distance covered each day. They are not signed up to a ToU tariff and their charging pattern over the year is shown below in Figure 39.

**Figure 39 – Participant CG3 – Total Monthly Consumption**

![Graph showing monthly consumption](image)

**Conclusion:** It is interesting that this participant has actively sought to sign up to a ToU tariff from another Supplier and that they are actively managing their charging so as to make full use of the off-peak rate.

**Consumption**

Breaking this down into when charging was taking place by day of the week.
Table 14: Participant CG3 – Charging Breakdown

<table>
<thead>
<tr>
<th></th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thurs</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>145.045</td>
<td>268.988</td>
<td>167.639</td>
<td>219.538</td>
<td>168.836</td>
<td>172.078</td>
<td>124.34</td>
</tr>
<tr>
<td>On Peak</td>
<td>38.827</td>
<td>112.59</td>
<td>62.279</td>
<td>91.484</td>
<td>48.916</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Off Peak</td>
<td>106.218</td>
<td>156.398</td>
<td>105.36</td>
<td>128.054</td>
<td>119.92</td>
<td>172.078</td>
<td>124.34</td>
</tr>
</tbody>
</table>

This participant is not avoiding peak times, but is charging when this is convenient to them. Looking at the underlying data, there is no pattern to when this participant is charging; rather it looks like they are just plugging it in when they arrive home.

**Conclusion**: As the participant is not signed up to a ToU tariff, they are not encouraged to charge during off peak hours.

Control Group Trial Participants Overall Charging Profile
Ten participants were selected from the pool of consumers that were used as a control group, summarised in Table 15 below:

Table 15: EV Control Group Trial Participants – Overall Charging Profiles

<table>
<thead>
<tr>
<th>Participant</th>
<th>On Peak kWh</th>
<th>Off Peak kWh</th>
<th>On Peak %</th>
<th>Off Peak %</th>
<th>On Peak £</th>
<th>Off Peak £</th>
<th>Total £</th>
<th>Saving £</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG1</td>
<td>371.957</td>
<td>405.327</td>
<td>47.85</td>
<td>52.15</td>
<td>8.82</td>
<td>7.69</td>
<td>16.52</td>
<td>1.76</td>
</tr>
<tr>
<td>CG2</td>
<td>474.5</td>
<td>104.066</td>
<td>82.01</td>
<td>17.99</td>
<td>11.25</td>
<td>1.98</td>
<td>13.23</td>
<td>2.25</td>
</tr>
<tr>
<td>CG3</td>
<td>1306.19</td>
<td>1511.45</td>
<td>46.36</td>
<td>53.64</td>
<td>30.98</td>
<td>28.69</td>
<td>59.67</td>
<td>6.18</td>
</tr>
<tr>
<td>CG4</td>
<td>194.091</td>
<td>87.063</td>
<td>69.03</td>
<td>30.97</td>
<td>4.60</td>
<td>1.65</td>
<td>6.26</td>
<td>0.92</td>
</tr>
<tr>
<td>CG5</td>
<td>394.305</td>
<td>617.846</td>
<td>38.96</td>
<td>61.04</td>
<td>9.35</td>
<td>11.73</td>
<td>21.08</td>
<td>1.87</td>
</tr>
<tr>
<td>CG6</td>
<td>574.712</td>
<td>573.15</td>
<td>50.07</td>
<td>49.93</td>
<td>13.63</td>
<td>10.88</td>
<td>24.51</td>
<td>2.72</td>
</tr>
<tr>
<td>CG7</td>
<td>303.531</td>
<td>552.514</td>
<td>35.46</td>
<td>64.54</td>
<td>7.20</td>
<td>10.49</td>
<td>17.69</td>
<td>1.44</td>
</tr>
<tr>
<td>CG8</td>
<td>0.518</td>
<td>761.267</td>
<td>0.07</td>
<td>99.93</td>
<td>0.01</td>
<td>14.45</td>
<td>14.46</td>
<td>0.00</td>
</tr>
<tr>
<td>CG9</td>
<td>2.056</td>
<td>836.042</td>
<td>0.25</td>
<td>99.75</td>
<td>0.05</td>
<td>15.87</td>
<td>15.92</td>
<td>0.01</td>
</tr>
<tr>
<td>CG10</td>
<td>354.096</td>
<td>912.368</td>
<td>27.96</td>
<td>72.04</td>
<td>8.40</td>
<td>17.32</td>
<td>25.72</td>
<td>1.68</td>
</tr>
</tbody>
</table>

Comparison and Conclusion
By comparing the control group to those consumers that took part in the ToU trial, it can be seen that participants tend to modify their behaviour if they believe they are getting a better rate off-peak. If there is no incentive, then participants tend to plug in when it was convenient to them. Whilst the savings were modest, the data would suggest that believing there is a saving to be had is enough to shift participants to charging off-peak. This conclusion is further reinforced by the participant from the control group that signed to a ToU and actively charged off-peak when the cost benefits would be marginal in doing so.

It is also observed that participants tend to charge when they must still have range left in the vehicle, as charging times tend to be short and flatten to a trickle charge, indicating that the batteries are full charged and maintaining. Detailed analysis of this is discussed in Report B1 [Ref. 2], and shows that participants tend to still experience range anxiety, even when they have had the vehicles for a number of months.

Extending the ToU tariff so that there is a greater difference between on-peak and off-peak charges would undoubtedly drive more participants to charge off-peak, in the same way that the LCL Report A3 [Ref. 4] has shown. However, unless the price point is vastly improved it is unlikely to shift all demand.

The following tables illustrate the average charging profile for the ToU and Control Group over the course of the trial period, which illustrate that ToU consumers were more likely to charge off peak.
Figures 40 and 41 illustrate the average charging profile for the ToU and Control Group over the course of the trial period, which show that ToU consumers were more likely to charge off peak.

**Figure 40 – Average On/Off Peak Charging**

**Figure 41 – Comparing On Peak Consumption**

4.1.1.2 Electric Vehicle ANM Trial

On this trial [Ref. 4], the LCL project worked with POD Point and Smarter Grid Solutions to develop a system to control a sample of public access charge points. The purpose of the trial was to establish a mechanism to curtail the demand from charge points during times of network constraint, by integrating POD Point’s EV Controller (Carbon Sync), with the ANM technology from Smarter Grid Solutions.

**Table 16: ANM Load Groups**

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Charge Points</th>
<th>Sockets</th>
<th>Power</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>47</td>
<td>94</td>
<td>518kW</td>
<td>Across London</td>
</tr>
<tr>
<td>City Road B</td>
<td>5</td>
<td>10</td>
<td>47kW</td>
<td></td>
</tr>
<tr>
<td>Newham</td>
<td>10</td>
<td>20</td>
<td>73kW</td>
<td>Sainsbury’s Beckton</td>
</tr>
</tbody>
</table>

ANM’s controller uses a substation monitoring device to measure the load on a substation and regularly polls Carbon Sync (CS), which then controls the amount of charging demand that can be interrupted, “shedable load”, from the EV charge points connected to that substation. When the substation gets close to its operating capacity, the ANM controller requests CS to shed a percentage of its available shedable load, i.e. restricting the power supply to the EV charge points.
The ANM controller was configured to issue load shed events to the EV Controller, which then tried to shed load from the load groups. Depending on the time of day and volume of EV charging from a group, ANM requests for load shed may or may not be satisfied. The amount of load available varied due probability and volume of consumer demand, Figure 42 below illustrates when load is available to shed on public charging infrastructure (302 charge events over trial period Dec 2013 to Apr 2014).

Figure 42 – Use of charge points in LCL trial

![Frequency vs. Hour of the Day Graph](image1)

Figure 43 below shows that the availability of shedable load on the wider POD point network is predominately during the working day, with more available early to mid-morning which coincides with commuters arriving at work and plugging in to charge (67,000 charge events over 12 months to March 2014).

Figure 43 – Use of Pod-point public charge points

![Percentage Graph](image2)

Figures 44 & 45 illustrate examples of the response that the EV controller was able to offer after a signal to curtail load. As expected, there was some variation in the level and nature of the response due to dynamics that include, the length of time an EV is charging and the maximum period that load can be interrupted.
In example 1, shown in Figure 44, the ANM controller requested a constant load shed of 12kW, the EV Controller responded after 45 seconds and shed just over 12kW. The EV Controller then ran out of shedable load, probably due to consumers disconnecting, and then was able to respond again a few minutes later, when more load became available.

In example 2, shown in Figure 45, the ANM controller requested a load shed of 30kW for around 70 minutes and then reduced this to 10kW for a further 20 minutes. The response was initially good, but as available load to shed reduced, the EV Controller was unable to respond, however, when more load became available it did respond fairly consistently.

Conclusion

The trial successfully demonstrated that a combination of ANM and Carbon Sync can provide an automated, real-time distribution network load management solution for public access charge points, with minimum impact on EV users.

The trial results have highlighted some key considerations that a DNO should consider before investing in this approach to regulate EV loads. Firstly, consideration should be given to the “availability” of EV load on the system. The benefit of the system solution will need to be examined against the probability and volume of EVs that provides a suitable level of availability. Similarly, the availability of the system to respond dependably during times of constraints on the network would need to be examined i.e. the “reliability” of the system.

For this approach to be considered as a business-as-usual solution to manage thermal overloads on the network, a level of reliability will be required that ensures that the network is not exposed to an unacceptable level of risk of failure. Over the course of the LCL trial a high level of operational compatibility was achieved, with only one significant outage during the trial period. The trial results suggest that, with some additional work, there is a high likelihood that the system could provide considerable network benefits.

4.1.3 Other Trial Observations

Charging Profiles by Vehicle Type

An interesting observation is the difference between vehicles used in the trials, in terms of charging profile and how consistent this is during a typical charge. Newer Vehicles, such as the Nissan Leaf and the Mitsubishi i-MiEV, demonstrate a fairly consistent block charging pattern, as shown below in Figure 46:
When comparing this to the older G-Wiz vehicle, the charging pattern shown in Figure 47 exhibits a gradual tail-off in demand.

**Figure 47 – Charging Profiles**

GWhizz - Active Power

In comparison, the plug-in hybrids all had similar charging profiles, as shown in Figure 48 below.

**Figure 48 – Charging Profiles**

Prius - Active Power

Volt- Active Power

And finally the charging profile for the “Citroen C1 ev’ie”, shown in Figure 49, which has been converted from petrol to electric drive, demonstrates a greater demand for maintaining the battery, which could indicate an early battery failure.

**Figure 49 – Charging Profiles**

C1 EVE - Active Power

These charging profiles indicate that battery technology is moving forward, and based on the charging profiles of the newer vehicles, the DNO can assume a block charging profile going forward.

# 4.1.2 Other EV Trials UK and International

## UK Trials

**CABLED**

CABLED (Coventry and Birmingham Low Emission Demonstrators), was one of eight real-world trials that formed the Technology Strategy Board’s (TSB) ultra-low carbon vehicle (ULCV) demonstrator programme (see [Ref. 25, 26 and 27]). Launched in 2008, the ULCV Demonstrator Programme was the first large-scale UK-wide trial to support the development of technologies and markets for ULCVs. The programme was jointly funded by the TSB and the Office for Low Emission Vehicles (OLEV).

During the trials, analysis was undertaken to determine when consumers were actively charging. The report found that 83% of charge events occurred during weekdays where morning, afternoon and evening peaks occurred at 08:00, 14:00, and 21:00, as shown in Figure 50 below.
Whilst the trials did not actively pursue ToU tariffs, they did look to actively shift charging using simple timers to delay charging till after 21:00. The peak at 21:00 on the graph below showed that this was an effective method of transferring the charging load of EVs outside peak electricity demand hours. In the trial data, 27% of charges commenced between the hours of 21:00 to 01:00, compared to just 5.9% of journeys that ended within the same time period, illustrating a shift to off-peak charging.

This shifting is less than that seen during the LCL trials, which might be due to an absence of any financial incentive to shift to off-peak hours. It is also not clear in the final report how many of the trial participants were involved in using timers to shift demand, and so it is possible that only a small number were involved.

The CABLED trial also aligned broadly with the charging behaviour seen in the LCL trials, in that on average EVs were charged around 3 times a week, and the average distance between charges was around 25 miles.

A key observation from CABLED however, and one not seen in the LCL EV trial data, is that distances between charges gradually increased over the trial period, indicating that consumers gradually became more confident undertaking more journeys between charge events, so range anxiety reduced over time.

It is also observed that consumers who used timed charging achieved a higher average mileage between charging of 30 miles, compared with those without timed infrastructure, who achieved 21 miles. This suggested that timed infrastructure, which also offered lower cost off-peak electricity, both decreased opportunity charging during the day and charging at times of peak electricity demand.

**International Trials**

**Boulder Smart Grid City, Colorado**

As a technology pilot in Boulder, Colorado, Smart Grid City explored technologies that play a part in the smart grid in a real world setting, in much the same way that LCL looked to do on a smaller scale in London. As part of a much wider programme of trials, they have introduced approximately 23,000 automated smart electric meters to enable both DSR and attractive price points to be offered in the form of ToU tariffs [Ref. 28].

Apart from providing consumers with a breakdown of their energy consumption in 15 min segments and improving billing for the end consumer, the introduction of these smart meters has enabled Boulder to investigate whether consumers will shift demand to off-peak periods if the price points are attractive enough.

Boulder has introduced four different tariffs to entice consumers to switch to off-peak usage, Shift and Save, Peak Plus Plan or Reduce Your Use Rebate. The Shift and Save is designed to encourage customers to shift their flexible energy use to a time of day when the cost of energy is lower. Rates are divided into on-peak periods (between 14:00 and 20:00 weekdays only), when energy costs more to produce and deliver, and off-peak periods, when it costs less.
The Peak Plus Plan builds on the Shift and Save rate and is designed to encourage customers to eliminate as much electricity use as possible all year round and especially during the peak demand days and times. During peak energy events, the Peak Plus Plan can be invoked for capacity or economic reasons. When that happens, the price for electricity increases significantly above the on-peak price. The Reduce Your Rate Rebate encourages customers to reduce their usage below what they would normally use during peak energy events. Customers will receive an electricity bill credit for the energy saved during peak energy events, compared to similar consumption in the recent past. Customers will be notified of a peak energy event the day before it is to take effect. Peak energy events are in effect for about 15 days during the year, and customers will be notified by e-mail or a phone call prior to peak energy events. The tariffs are summarised in the Table 17 below.

**Table 17: Xcel Energy Tariffs**

<table>
<thead>
<tr>
<th></th>
<th>OFF Peak Price per kWh (8 p.m. to 2 p.m. weekdays, weekends &amp; holidays)</th>
<th>ON Peak Price per kWh (2 p.m.-8 p.m. weekdays)</th>
<th>Peak Energy Event Price per kWh (2 p.m.-8 p.m. up to 15 weekdays p/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shift &amp; Save</strong></td>
<td>Year round: 4¢</td>
<td>Non-Summer: 6¢</td>
<td>Not applicable</td>
</tr>
<tr>
<td><strong>Peak Plus Plan</strong></td>
<td>Year round: 4¢</td>
<td>Non-Summer: 5¢</td>
<td>Non-Summer: 33¢</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer: 17¢</td>
<td>Summer: 51¢</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stationary: 12¢</td>
<td></td>
</tr>
<tr>
<td><strong>3-Tiered Rate</strong></td>
<td>0-500 kWh: 4¢</td>
<td>Year round: 5¢</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>500+ kWh: 9¢</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reduce-Your-Use Rebate</strong></td>
<td>0-500 kWh: 4¢</td>
<td>Year round: 5¢</td>
<td>Non-Summer Rebate: 29¢</td>
</tr>
<tr>
<td></td>
<td>500+ kWh: 9¢</td>
<td></td>
<td>Summer Rebate: 47¢</td>
</tr>
</tbody>
</table>

According to Xcel Energy the expectation is that consumers will begin to experience the benefits of the smart grid by participating in this pricing program, where ToU tariffs are an integral part of the programme, to see if consumers will change their energy usage when they have visibility into pricing, choice and control.

**Demand management of electric vehicle charging using Victoria’s Smart Grid**

This trial was an in-field demonstration of EV charging management, using the Australian state of Victoria’s Smart Grid, aimed at helping Victoria better understand the process, timelines and barriers for transitioning to EV technologies and managing electric vehicle charging [Ref. 29].

During the trial, electricity demand was managed for the first time using the Victorian Advanced Metering Infrastructure (AMI). The End-to-End system configuration used in the trial is shown in Figure 51. The system is based on the ChargeIQ system and the United Energy (UE) Advanced Metering Infrastructure (AMI) Network.
Smart Charging
The charging points were integrated into the HAN and an initial period of uncontrolled charging was monitored, with between 11 and 24 charging events logged for each household participant over the pre-analysis period and the distribution of charging behaviours varying markedly.

The most significant influence on charging behaviour was the choice of charge mode – On-demand versus ‘Smart’ charging (known to the project participants as “ChargeNow” and “ChargeIQ” respectively). For those participants who predominantly used the default “Smart” charging option, charging event times commenced between 22:00 and 23:00. Conversely for those who favoured On-demand charging, their session times commenced between 18:30 and 21:00. Once charging commenced, the average duration was between two and three hours.

Figure 52 – Summary of charging events and load shift

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total overall vehicle charging load across ten participants / three months</td>
<td>4,444.4 kWh</td>
</tr>
<tr>
<td>Average charge event duration / standard development (hh:mm)</td>
<td>2:35 / 1:22</td>
</tr>
<tr>
<td>Average vehicle charging load per participant</td>
<td>37 kWh / week</td>
</tr>
<tr>
<td>Total On-demand charging load</td>
<td>1,930.3 kWh</td>
</tr>
<tr>
<td>Total “Smart” charging load (load shifted to off-peak times)</td>
<td>2,514.1 kWh</td>
</tr>
<tr>
<td>Percentage charging load shifted to off-peak times due to “Smart” charging</td>
<td>57%</td>
</tr>
</tbody>
</table>
Load Control

The trials also considered whether charging load could be shed on request and thus play a part in managing overall load. Two types of load shed event where trialled. Firstly, a Peak Charge Management Event, where the control system requests a load shed, in much the same way as LCL tried to implement using ANM. The result is shown in Figure 53.

**Figure 53 – Peak Change Management Event**

This shows the vehicle charging under load control. At 18:45 the vehicle started to charge at full load (around 32 W min or 3.2 kW). This continued until 20:00, when the load control event took effect, reducing the vehicle load by 50 per cent (to around 16 W min or 1.6 kW), until it stopped charging at 22:45. In this instance the vehicle completed charging prior to the end of the load control event at 23:00.

The second type trialled was an emergency charge management event, where a complete reduction of load was requested, the result is shown below in Figure 54.

**Figure 54 – Emergency Change Management Event**

This shows a 100% load adjustment with the vehicle ceased charging altogether between 19:00 and 22:00.

Key Findings

In managing EV charging through the smart grid, the project has arrived at three key conclusions:

- EVs can be integrated into the electricity networks, easily, conveniently and cheaply. For consumers who have signed up to ToU tariffs, the savings are around $250 per year, or around 50 per cent on their charging costs, simply by ensuring they are charging off-peak. By introducing “Smart” charging technology this saving could be delivered without any addition effort from the consumer;

- For utilities, the potential challenge posed in adding electric vehicle charging to existing demand may actually be an opportunity. Managing electric vehicle charging at the network level will not only defer costly infrastructure upgrades through peak demand management, but may deliver better returns on existing investments through improved asset utilisation. The introduction of EV control systems would deliver these benefits and avoid creation of a second peak in electricity demand, as drivers individually defer charging to the off-peak period. Importantly, the outcome from these improvements will be lower costs for all electricity consumers – not just those who drive EVs; and

- The relationship between utilities and consumers is a key to delivering the best outcomes for all. Consumers have indicated a willingness to defer their vehicle charging, including having it managed remotely, if provided with easy, convenient and financially-beneficial options. For a utility to control a potentially significant load on their network, consumer cooperation may be increased through the provision of real-time information via the AMI.

GridPoint and Duke Energy, Arlington, Virginia

Duke Energy have recently trialled GridPoint’s smart charging capability (see [Ref. 30]). The charging points are controlled by the GridPoint SmartGrid Platform and load control signals can be sent to the charging points so they can be constrained off in the late afternoon. GridPoint’s smart charging capability enabled Duke Energy to control charging, regardless of when consumers plug in their EVs, which is typically in the early evening when peak demand is high. Duke Energy are looking to limit peak load growth and offer customers significantly reduced charging costs, by billing lower rates for off-peak charging. Additionally, Duke Energy gain complete control over when and how fast EVs are charged, allowing the optimization of assets.

“Smart charging is an essential capability for Duke and all electric utilities as PHEVs enter the market” said David Mahler, Chief Technology Officer, Duke Energy. “Through this capability, we’re able to reduce stress on the grid during peak periods and keep rates low.”
4.2 **HP Trials UK and International**

Due to the urban environment of London, there were few heat pumps available to monitor, so the LCL project has relied on external power quality data collected by the EST as part of their wider field trials (see [Ref. 31]).

**EST - Heat Pump Trials**

These trials took place between 2008 and 2013, in two phases and presented data on the performance of both air and ground-source heat pumps in 83 homes.

The detailed analysis carried out was published in March 2012 and as a result the Microgeneration Certification Scheme (MCS), installation standards were updated and improved. A second phase focused on 38 of the homes from phase one for further interventions, such as re-sizing or altering control parameters to examine more closely system efficiencies.

The results of this second phase showed that there were significant improvements in performance at all but three of the sites which received major or medium interventions. Minor interventions had little effect on performance.

- 20 out of 21 ground-source heat pumps in the trial met or exceeded the performance criteria to be considered “renewable” under the EU renewable energy sources directive the figure for air-source was 9 out of 15. It is important to remember that many of these heat pumps were installed before the new MCS standards came into force, five of the six new air-source heat pumps, installed and designed to these standards, met the renewability criteria.

- DECC considers the most useful measure of performance for the household to be SPFH4, weighted over both space and water heating. This is a comprehensive metric that takes account of all electricity used by the heating system including the auxiliary heater, domestic hot water immersion and building circulation pumps. According to this metric, the average performance was 2.82 for the ground-source heat pumps in the trial and 2.45 for the air-source heat pumps in the trial.

Following the completion of the second phase, DECC and EST are continuing to work with industry and the MCS to further improve standards and training. DECC has also incorporated lessons learned from this trial into its design of the domestic renewable heat incentive policy, by providing, for example, an additional incentive for householders to install metering and monitoring packages so that they know how much energy their heat pump is consuming.

**Kingston Heights, Mitsubishi Heat Pumps and the Thames**

Mitsubishi have worked with NHP Leisure Developments to implement a HP solution that uses the Thames to heat and provide hot water on a new development in Kingston upon Thames (see [Ref. 31]). The £70 million mixed-use development has been created on the site of a former power station right in the heart of Kingston and 200 metres from the banks of the river.

There are 137 apartments that will be supplied by a HP system from Mitsubishi that harvests naturally stored energy from the Thames. The scheme takes renewable heat from the sun, stored in river water and boosts it to the temperature required for the under-floor heating and hot water needed by residents. The river temperature two metres below the surface of the water never falls below 7°C, even in winter, which is stable enough energy to heat the apartments.

The system is built inside a plant room adjacent to the river, the water passes through high-efficiency heat exchangers and, once the low grade heat has been harvested, the water is immediately fed back into the river, untreated in any way. Up to 13 million litres of water each day, passing through a two-stage filtration process that ensures no marine life can enter the system.

The heat exchangers transfer this low grade heat from the river water to an internal “Closed” loop water system. This is then carried 200 metres to a plant room in the apartment building, where the heat pump boosts the low grade heat to the temperature required for the apartments heating and hot water.

The savings in carbon are around 500 tonnes when compared to gas boilers and the equivalent heating cost for a couple living in a one bedroom apartment would be 18% more. Towards the end of 2014, the construction of a new 142-bedroom hotel, with meeting, banqueting and conference facilities, will also be completed at the site, which will increase the efficiency of the heating scheme further still. The hotel will derive all its heating and hot water, as well as its cooling, from the open water heat pump installation. Heat recovered from cooling the individual hotel rooms will be reclaim and returned to the community system to support the heating and hot water demand for the whole site. The developer believes the scheme paves the way for other developments taking place near an open body of water, to also benefit from this highly energy-efficient system, as it is capable of producing over two megawatts of thermal energy 24/7, 365 days a year, regardless of the weather or air temperature, even in the depths of winter.

“Kingston Heights is a great example of how sustainable solutions can help power entire communities. I want to see a community energy revolution where projects like this are the norm, not the exception”, Edward Davey, Secretary of State for Energy and Climate Change and MP for Kingston and Surbiton.
4.3 Comparable Initiatives

4.3.1 Economy 7

A good historical example of successful demand building/shifting was the introduction of the “Restricted Hours” and “Economy7” tariffs before privatisation of the electricity industry. These tariffs were designed to build night-time demand by encouraging the use of electric storage heating and water heating systems. The original restricted hour’s tariff provided a normal 24 hour feed for miscellaneous domestic loads, together with a dedicated, cheap rate, feed for heating, which was live only during defined night time hours (the compulsion approach). The Economy 7 tariff was later extended to provide this idea to offer cheap night time electricity for all other domestic loads, and subsequently extended further to allow 3 hours of on-peak consumption, known an Economy 10.

The establishment of the radio teleswitch service (RTS) allowed the electricity companies to control Economy 7 (sometimes known as “heatwise”), meters that were installed with a radio teleswitch to remotely apply tariffs and control when electricity is being used via the central teleswitch control unit (CTCU). This system controls consumer tariffs and loads by broadcasting an embedded signal alongside the long wave output of BBC Radio 4 long wave, which the meters teleswitch is listening for, and so provides a low cost and reliable way of control meters.

Initially, night storage heaters and hot water heaters would be installed on a separate house circuit and the meter would control when power was switched on, normally when the night rate was activated, although as time passed meters were connected to the whole house circuit with consumers choosing when to set devices such as storage heaters and water heaters to turn on, ideally during the hours of Economy 7 to save money. As a general rule of thumb, consumers would be better off using Economy 7 is they used more than 40% of their electricity at night, but the downside is that the consumer’s home and water would be warm in the morning, but would cool down again by the evening. There is a 3-fold difference between on-peak and off-peak rates, on-peak is typically around 16p/kWh and Off-Peak around 6p/kWh, giving the consumer a significant incentive to shift consumption.

The introduction of Economy 10 typically provided consumers with greater flexibility, but providing three blocks of cheap electricity, an example is:

- 3 hours in the afternoon (13:30 16:30)
- 4 hours in the evening (20:30 – 00:30)
- 3 hours in early morning (04:30 – 07:30)

Spreading this across the day gave Economy 7 a new lease of life, but as storage heaters have fallen out of favour and with the advent of smart meters on the horizon, the lifespan of Economy 7/10 is now limited.

However, the success of Economy 7 and its ability to offer remote control and load-shedding is a good example of how the network can be managed for little cost. This can be demonstrated by the very significant night time demand in the system load profiles that still exist to this day, so much so, that the energy Suppliers are still able to participate in the National Grid Short Term Operating Reserve (STOR) by offering frequency response to the National Grid by being able to control Economy 7 meters in real-time, such that demand can be reduced as required. The average load profile for Economy 7 consumers is shown in Figure 55.

![Figure 55 – Typical Switched Load / Base Load Split](Image)

With the widespread adoption of EV’s, lessons can be learnt from the introduction of Economy 7 in the way it was introduced and load subsequently managed (see [Ref. 33]).

4.3.2 Feed In Tariffs (FITs)

The EV market is predominantly driven by the Government and other groups in an attempt to reduce CO₂. Various stimuli through incentive schemes are being used to encourage drivers and companies to purchase EVs over ICE vehicles, in a similar way that incentives were offered to home owners and businesses to install solar panels. The incentives for using photovoltaic (PV) panels were introduced in April 2010, through the UK Government’s feed-in tariff (FIT) scheme, which paid generators a tariff for each unit of electricity generated, and an additional tariff for each unit of electricity exported to grid. As these schemes closed then the number of new installations reduced and there is a danger the same pattern will be repeated as subsidies for EVs are removed.

Whilst vehicle, battery and charging point manufacturers are all constantly improving their products, the removal of the subsidies may become a barrier and hence may delay the number of consumers purchasing an EV.
Value Proposition

Using evidence gleaned from the LCL EV trials, the business scenarios and assessment of the key interventions, a set of value propositions can be developed. Figure 56 considers each consumer group, using an incremental approach to suggest the most suitable forms of intervention. Each step in the value chain represents an increase in cost and complexity.

**Figure 56 – Value Chain**
5.1 Stakeholder Assessment

Each consumer group exhibits different behaviours and requirements, which make them more or less responsive to load shifting and load reduction. Based on the finding from the LCL EV trials, stakeholder assessment looks at the opportunities to shift or manage load.

5.1.1 Domestic – Private Charging

There are two key variables of behaviour for domestic private charging, the amount of range required and the available charging duration. Evidence from the LCL EV trials illustrates that most consumers typically “plugged in” overnight. Based on these two variables there is a potential opportunity for charging sessions to be flexible.

An example for optimising a charging pattern is the professional commuter who uses their EV to travel to and from work, as illustrated in Figure 57.

**Figure 57 – Domestic: Private Charging**

Scenario a: Load Shifting – this consumer group exhibits behaviour that allows the load to be shifted.

5.1.2 Domestic – Public Charging

As with private charging, there are two key variables of behaviour for domestic public charging, these are the amount of range required and the available charging duration. Based on these two variables there are three possible outcomes and potentially two opportunities for imposing control over the charging session, as shown in Figure 58:

**Figure 58 – Domestic: Public Charging**

Scenario a: Ready on return – the consumer expects the vehicle to have been charging continually from when they plugged in;

Scenario b: Load shifting – the consumer leaves their vehicle for duration in excess of the time required to achieve the desired range, and

Scenario c: Load limiting – the same as (b) Load shifting except the charge point allows the amount of power to be consumed to be limited, thus increasing the charge time but reducing the impact at peak charging times.

An example of either (b) or (c) as opportunities for optimising the charging pattern, is a commuter parking at a railway station for an extended period.
5.1.3 Fleet

There are two key variables of behaviour for fleet consumer charging, these are the amount of range required and the available charging duration. Based on these two variables there are potentially two opportunities for imposing control over the charging session, as shown in Figure 59.

**Figure 59 – Fleet**

- **Scenario a**: Load shifting – the consumer leaves their vehicle for duration in excess of the time required to achieve the desired range.
- **Scenario b**: Load limiting – the same as (b) Load shifting except the charge point allows the amount of power to be consumed to be limited, thus reducing the impact on the peaks.

An example of either of these opportunities for optimising the charging pattern is a logistic company that uses EV vans for deliveries. This is supported by evidence from the LCL trials on the charging profile derived for commercial EV users.

5.1.4 Public Transport

The nature of public transport charging is that the vehicle will only have a short available period for charging and therefore there will be no opportunity for optimisation, illustrated in Figure 60.

**Figure 60 – Public Transport**

5.2 Intervention Assessment

To arrive at the value propositions set out in Figure 56 – Value Chain each form of intervention has been reviewed using the criteria set out below. The assessment encompasses the results of LCL EV trials and business scenarios with a forward looking view of how each intervention could benefit to DNO. The necessary changes required to successfully implement each intervention within the EV landscape are also included.

- Effectiveness – has the method of intervention been demonstrated or known to be effective;
- Complexity – the complexity to set up and operate;
- Reliability – is the intervention fail-safe;
- Scalability – can the intervention scale to meet a significant increase in demand on the network; and
- Benefit to DNO – to what degree is this intervention of benefit to the DNO - this will form the conclusion for the assessment of this intervention.
The colours used in the tables in the following sections represent:

- **Well understood and manageable**
- **Understood, but requires careful planning**
- **Understood, but will require complex planning or proven to be ineffective**
- **N/A**

Not Applicable for this consumer group.

### 5.2.1 Education

Education requires consumer groups that have the window of opportunity to shift their load, and also have control over when the charging can start either through behaviour change (switching the charging on before going to bed) or technically (use of a timer).

**Effectiveness** – no formal evidence has been collected during the LCL EV trials to measure the effectiveness of education, however domestic consumers who were aware of ToU tariffs did modify their charging behaviour in order to realise these benefits.

Consumer-initiated load shifting is however voluntary, and therefore limited in its effectiveness as it cannot be relied upon to protect the network.

**Complexity** – education is the simplest of the steps shown in the value chain. Providing the DNO has been informed, the DNO can target that individual directly with an education pack.

Being informed of an installation at this stage has the benefit to the DNO that they can begin to identify clusters of EVs and therefore proactively manage the network by identifying areas where constraints begin to manifest themselves. Installers already are aware of the IET guidelines, they should be mandated to comply with these guidelines in a similar manner to micro-generation installers required to do so for the MCS.

**Reliability** – It is anticipated that education may influence some individuals, but is not a guarantee of changing charging patterns.

**Scalability** – Sending out an introduction pack to every new EV owner will be very simple and could scale very easily. An alternative to this would be to mandate a pack be included with the charging point equipment which has to be completed and returned to the DNO or Supplier, if the Supplier is informed then the Supplier must in turn inform the DNO.

### Table 18: Education Assessment

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As can be seen from Table 18 and the scenarios in Chapter 5, education could be applied to domestic private and fleets, because the behaviours, as outlined in Sections 5.1.1 and 5.1.3 are compatible with those required to enable education.

The behaviour of the domestic user when using public charging Infrastructure is unpredictable and on-demand, therefore their charging pattern cannot be influenced by education.

All deployment of EV charge points for buses will require new connections, therefore education is not applicable.

### 5.2.2 Time of Use

ToU requires consumer groups to have a window of opportunity to shift their load, and uses a monetary incentive to influence behaviour.

**Effectiveness** – the evidence in Chapter 6 suggests that a high percentage of domestic consumers responded well to ToU and were successfully influenced to shift their load to off-peak. This would indicate that a wider roll-out would be effective.

**Complexity** – assuming that the existing ToU tariff is used, the complexity to the DNO of ToU is low. However, the DNO will be required to inform the Supplier of where the EV charge points are on the network and build the required relationship with the Supplier to ensure that sufficient financial incentive is offered.

**Reliability** – ToU is a behavioural intervention and therefore cannot be a guaranteed mechanism for load shifting.

**Scalability** – it is highly likely that once a Supplier introduces a ToU tariff it will be at a national level and therefore once implemented it will become easy to manage.

**Required Relationships** – to enforce ToU, an agreement with the different Suppliers needs to be reached with that will shift the load to off-peak. This could be a new tariff or an existing ToU, however the Supplier may wish to request a reward from the DNO for doing so.
Table 19: Time of Use Assessment

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Table 19 above summaries the ToU assessment. The behaviours and static locations of both domestic private and fleet are such that they are susceptible to load shifting, and therefore are ideally suited to ToU.

The behaviour and location of the domestic user when using public charging Infrastructure is unpredictable and on-demand; therefore their charging pattern cannot be influenced by ToU.

Bus charging is very restrictive and must meet a demanding schedule, therefore ToU will not be applicable.

5.2.3 SMETS 2 ALCS

This intervention applies to domestic private only, because it forms part of the DCC and smart metering rollout to domestic properties in the UK by 2020. The DCC will need to introduce a method of communicating with various loads in the home via the HAN.

Effectiveness – as yet, this solution is not available and is subject to change; therefore SMETS ALCS will be considered in the future, perhaps post-DCC rollout in 2020. It is also not clear how it will work, or if agreements will be needed with the end consumer or with their Supplier.

The benefit of SMETS ALCS is direct control through pricing signals, Demand Response and perhaps ANM triggering a shift. Obviously this will need agreements and standards in place as described above.

Complexity – the SMETS standards and the DECC lead agreements will also be a key factor in the success of this intervention to provide interoperability between charge point vendors, DCC and the DNOs solutions.

This will be a complex intervention to establish, as SMETS ALCS will rely upon agreements with the end consumer (probably through their Supplier), as well as a system and communications mechanism, to send the messages via the DCC to the charging point. At present the systems that could send the signal to the HAN have not been defined.

Reliability – assuming all DNO systems, standards and agreements are put in place, this could prove to be a very reliable mechanism for constraining on and constraining off the load at a property.

Scalability – SMETS will be rolled out nationally and so providing ALCS continues to be included, the DNO will potentially have access to the charge point in every domestic property in the UK.

Required Relationships – the primary relationship with the domestic consumer will remain with the Supplier, however, with SMETS ALCS, it may be possible for the DNO to control the load at the charge point and therefore the consumer will need to agree to this. It is not yet known who will own this agreement, the DNO, DCC or the Supplier.

DECC, being responsible for the smart metering rollout, will need to define the agreements that need to be put in place for the DNO to take advantage of SMETS ALCS.

Table 20: SMETS ALCS Assessment

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SMETS ALCS will only be made available to domestic smart metering, therefore it cannot be applied to domestic public, fleet or public transport. Table 20 summarises the assessment for SMETS ALCS interventions.
5.2.4 EV Controller

The EV Controller provides the ability to centrally control the load shifting and limiting at a single, or group of, charge points. Any consumer group that has centralised control which allows the load to be shifted or limited can make use of an EV Controller.

Currently an EV Controller is provided and operated by a CNO for public charging, however fleet operators may decide to make use of such software as their EV fleet expands and they need more control.

Effectiveness – Scenarios 2 and 3 in Sections 3.4.2 and 3.4.3 illustrated the load shifting that could be achieved by limiting the load through the EV Controller. Future integration with the DNO and EV Controller could make the load limit variable, based on day ahead forecasting.

Complexity – all CNOs will have some form of EV Controller; however the sophistication of the EV Controllers will vary. To be of use to the DNO, the EV Controller will need load-management capabilities.

Reliability – ultimately, it is unlikely the DNO will have direct access to the EV Controller (unless they are operating the EV Controller on behalf of the fleet operator), which means that a contract will be required to make use of load-management capabilities.

Scalability – as this intervention is based on a contract and not on technical integration, the ability to scale should be straightforward.

Required Relationships – a contract or agreement will be needed between the DNO and the CN0, or other 3rd party such as an aggregator, and will not be directly with the consumer. Therefore, any contract for load shifting or limiting will have to support the agreement between the CNO and consumer. For larger installations >60kW, a contract, or agreement, could be created to allow the DNO to curtail the load at the charge points on a given transformer.

Table 21: EV Controller Assessment

Table 21 summarises the assessment for an EV Controller intervention. Domestic public and fleet consumers both exhibit the behaviours required to support the EV Controller intervention, i.e. centralised control and load shifting or limiting.

It is highly unlikely that an EV Controller will be used with domestic private consumers, as the charge point is privately owned and therefore does not require external control; however if external control is required for domestic private then SMETS ALCS will become a better option.

It is technically possible for public transport to make use of an EV Controller; however, the restricted nature of tight bus schedules will preclude public transport from using it for load management.

5.2.5 Active Network Management (ANM)

Any consumer group that has centralised control which allows the load to be shifted or limited can make use of ANM.

Effectiveness – Scenarios 2 and 3 in Sections 3.4.2 and 3.4.3 illustrated how the load could be effectively shifted through the use of ANM. LCL EV Trials were carried out that demonstrated that load can be shifted by ANM sending signals to the EV Controller, which in turn curtailed the load at the charge point.

Complexity – ANM relies on the following:

- Communications enabled charge points;
- An EV controller, Carbon Sync in this case, being available to carry out the load management request from the DNO;
- Communication with the DNO to integrate the control signal with the EV controller;
- The EV controller having load management capabilities; and
- The consumer groups permission for their charging to be curtailed.
Reliability – over the course of the trial a high level of operational reliability was achieved using the combination of active network management and Carbon Sync as the EV controller. It is expected that this level of reliability can be improved even further on a scaled roll-out.

Scalability – in theory the scalability of the solution is such that it could be implemented everywhere. It can be used not only for managing loads but also distributed generation assets. However, the complexity of rolling it out to all substations could make it very costly, suggesting that it should be targeted at “at risk” transformers.

Required Relationships – to enable this solution a contract will need to exist between the DNO and a vendor such as a charge point operator, or provided through a 3rd party such as an aggregator. In order to make best use of the DNO signals the vendor will have to provide a solution that manages load across a single or group of charging points. To this ends an interoperable standard will need to be developed, or an enhancement to an existing standard, that will allow a DNO to provide agnostic control signals to a 3rd party system or vendor.

Development of an interoperability standard, or enhancement to an existing standard, to sit alongside the IEC 61850 CIM that will allow a 3rd party system to provide Load Control signals to be sent from the ANM to an EV Controller. Table 22 below summarises the assessment for ANM interventions.

### Table 22: Active Network Management Assessment

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Domestic public and fleet EVs both exhibit the behaviours required to support the ANM intervention, i.e. centralised control load shifting or limiting; however it may not be possible for all groups to be controlled, for example, consumers that exhibit behaviour shown in Figure 58 – Domestic: Public Charging (a) do not allow their load to be managed.

ANM could be considered in the future for use with SMET ALCS and an associated controller (e.g. DSR), to manage the load at the LV. However, it is considered that this is some time away and therefore will need further investigation once the standards and agreements are understood.

It may also be possible to implement ANM for buses if bus schedules are such that they allow for load shifting, e.g. they are only used at peak times, and can therefore charge during the day then ANM could be considered.

### 5.2.6 Reinforcement

Reinforcement is currently the only intervention for avoiding failures for all consumer groups. With the possibility of other interventions discussed previously, with the exception of buses, reinforcement should be considered as a last resort.

In the case of buses, due to the demand the charge points have (>60kW), all bus charge points will require immediate DNO planning, which will result in new infrastructure being implemented to support the extra demand.

Required Relationship – the bus company will go through the new connections process. However, there may be a need to amend or introduce contracts between the DNO and the bus company to ensure a given level of availability.
Building on the trials conducted on the LCL programme, as highlighted in Section 4.1, examining the TOU and ANM as mechanisms to controlling loads, a cost benefit analysis (CBA) is performed in the areas of the LCL project where there are clearly defined network interventions that a DNO might implement to yield benefits for consumers in future.

This CBA builds on data collected during the LCL trials, the trials highlighted in this report as well as learning from the Dynamic Time of Use trial (Report A1 [Ref. 5]), the Industrial and Commercial Demand Response trials (Report A4 [Ref. 6]) and the Distributed Generation trial (Reports A8 [Ref. 7] and A9 [Ref. 8]). It uses the data from these trials to inform the costs and benefits that might be incurred or realised through an intervention. The CBAs are intended to evaluate the quantum of the business case for implementing these interventions both in specific selected case study situations and on a wider basis across the network.

6.1 Time of Use for EVs cost benefit analysis

6.1.1 Overview

Considering the EV ToU trial was conducted on a small sample of EV owners using a static tariff with relatively small price differences, the tariff and the learning from the dynamic ToU (dToU) trial which did not relate to EVs have been used to develop the assumptions for this analysis. The trialled dToU tariff had much more extreme price signals (i.e. a high price of 67.20p/kWh and a low price of 3.99p/kWh; note that these prices are not reflective of underlying costs), and the response achieved by the tariff was much higher. This tariff is used in the CBA.
6.1.2 Approach

For this analysis, a similar approach to that used for the analysis of primary network reinforcement in a high EV uptake scenario was adopted. To estimate the impact that ToU tariffs could have in mitigating the reinforcement costs previously evaluated, the following analysis is required:

- **Estimate the impact of a ToU tariff on the EV charging peak** – The dToU trial indicated that the tariff used in the LCL trial can be depended upon (using an approach consistent with P2/6 and ETR 130) for 48W of response per household during the winter period. Assuming that 20% of the total household consumption peak is made up of discretionary load, and assume an 800W average household winter peak, then this 48W equates to 30% of discretionary load. Further assuming that EV charging can be considered a discretionary load, and so in the analysis presented here that assumption is that ToU tariffs can reduce the EV charging peak by 30%. This is obviously a significant assumption that would need to be validated through further trials and analysis.

- **Infer the consequential impact on substation maximum demand** – The Element Energy load growth model was again deployed here, and load growth projections were prepared for each primary substation for a range of scenarios: the UK Power Networks Base Case, and the DECC Low, Medium, and High EV uptake scenarios. This results in a number of different data points to show how the substation maximum demand varies as a function of the number of EVs charging beneath that substation. If it is assumed that a 30% reduction in charging peak is equivalent to a 30% reduction in the number of EVs charging, then the peak substation load after application of a ToU tariff can be inferred as illustrated in Figure 61.

- **Infer the impact of increased peak load on the timing**

- **Calculate the cash flow impact and NPV of deferred reinforcement** – Changes in timing of reinforcement requirements were then used to calculate a cash flow line to indicate the impact that a ToU tariff associated with EV charging might have on network reinforcement.

The key assumptions used in the analysis presented below, in addition to those presented previously, are summarised in Table 23.
Table 23: Additional assumptions for analysis of the impact of ToU on EV-related reinforcement costs

<table>
<thead>
<tr>
<th>Assumption heading</th>
<th>Assumption value</th>
<th>How / where is assumption used in CBA analysis?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impact of ToU on EV charging</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of EV charging peak during high price periods</td>
<td>30%</td>
<td>As explained above it was assumed that EV charging is discretionary load and that 30% of this load can be shifted. As illustrated in Figure 61 this assumption was then used to infer the impact of the resulting load shifting on substation maximum demand.</td>
</tr>
<tr>
<td><strong>Costs of implementing a ToU tariff</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recruitment costs</td>
<td>£350/household</td>
<td>If ToU tariffs were to be targeted at consumers with an EV charging load then suppliers would need to recruit customers to the tariff. DNOs might pay suppliers to carry out this activity. The cost was based upon data received from EDF Energy, who managed the dToU trial for LCL. A more detailed breakdown of the £350/household number is presented in the CBA write-up for Learning Report A1 [Ref. 5].</td>
</tr>
<tr>
<td>Wider industry system costs</td>
<td>Not modelled</td>
<td>A portion of these recruitment costs would be incurred even if a ToU tariff were made mandatory for all domestic EV charging. Costs would include, for example, setting up new supplier settlement system, to the extent that suppliers do not already have these in place. It is assumed that DNOs do not incur any significant overhead costs if ToU tariffs were made mandatory for EV owners, as it is assumed that in this case (in contrast to Learning Report A1 [Ref. 5]) the tariff could be static, because the tariff is aiming to keep diversified EV charging away from peak hours.</td>
</tr>
</tbody>
</table>

6.1.3 Findings on the benefit of ToU tariffs on the costs of high EV uptake

Using the interpolation approach described above and illustrated in Figure 61 the impact that a ToU tariff could have in mitigating the increase in peak load resulting from a high EV uptake is estimated. The results of our analysis of this effect are summarised in Figure 62. The increase of peak load at each substation due to EV has been reduced with ToU and now rarely exceeds 1%.

Figure 62: Estimated impact of ToU tariff on peak load at LPN substations, 2029/30

The reduction in peak load illustrated in the Figure 62 is again used to infer the change in totex that results from the ToU tariff. This is illustrated in Figure 63, which shows that the cumulative additional reinforcement costs incurred (on the primary network) are reduced to c. £8.8m across LPN in the period to 2035. Reinforcement costs over the period are therefore £4.8m less than they would be in the absence of ToU.
Figure 63: Impact of ToU tariff on reinforcement spend under a high EV uptake scenario

With a mandatory uptake of the modelled ToU tariff for all domestic EV charging, such a tariff could yield a positive NPV (before any implementation costs are taken into account) of £5.5m when compared to the high EV uptake scenario without ToU. This result along with the distribution of the benefit between the DNO and consumers is summarised in Table 24.

Table 24: Net benefit results for mandatory roll out of ToU tariffs for EV charging

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mandatory ToU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net benefit (£k real 2012/13)</td>
<td>5,541</td>
</tr>
<tr>
<td>Totex cash flows (£k real 2012/13)</td>
<td></td>
</tr>
<tr>
<td>Totex impact ED1</td>
<td>2,410</td>
</tr>
<tr>
<td>Totex impact ED2</td>
<td>5,623</td>
</tr>
</tbody>
</table>

The net benefit analysed here would remain positive so long as total implementation costs remained below £20/household (i.e. per household with an EV), or a total of £5.5m NPV in LPN. The costs that would actually be incurred in setting up a ToU tariff are discussed further in Report A1 [Ref. 5], and would depend on how the tariff was implemented:

- If, for example, EV owners were targeted for recruitment to ToU tariffs by suppliers in order to realise the estimated network benefit, the recruitment costs would almost certainly exceed £20/household. The recruitment costs incurred in setting up the dToU trial for LCL were c. £350/household. However, the supplier may realise additional benefits (e.g. wholesale cost savings) that may also contribute towards total recruitment costs.

- These recruitment costs could be at least partly mitigated through mandating the use of ToU tariffs for domestic EV charging. This would most likely be done through a ToU DUoS structure for these customers, combined with a mandate on suppliers to pass through that ToU price signal to customers. This would require significant changes to the settlement and billing system in place for Daily Use of System (DUoS) charges, as domestic customers are mostly settled on a super-customer (i.e. aggregated) basis. Suppliers would also incur costs to update their systems so that they could administer the billing implications for these customers. If these costs could be covered for an NPV of £5.5m then the business case for such a tariff may be positive.

6.2 Active Network Management for EVs cost benefit analysis

6.2.1 Overview

The EV ANM trial, Section 4.1.1.2, highlighted the use of ANM to control the demand from public access charge points. However, further examination in Section 5.2.5 concluded that this application will be limited in terms of the “effectiveness” and “reliability”. Furthermore, it identified anecdotally that the Domestic Private and Fleet segments are better suited for control via this mechanism. As such, this CBA analysis is presented of two applications of ANM:

(a) requiring ANM to be fitted to regulate the charging of domestic EVs; and (b) the use of ANM to regulate the charging of a fleet of commercial EVs such that a smaller connection size is required by that fleet.

6.2.2 Approach

For the full approach to the analysis of the potential benefits of ANM on the costs of EV uptake see Report B2 [Ref. 1].

6.2.3 Findings on the benefits of ANM on the costs of high EV uptake

6.2.3.1 Domestic Private EV users

Using the interpolation approach presented previously in Section 6.1.2, the impact of ANM in reducing substation peak load, when compared against a high EV uptake scenario with no ANM, can be estimated as presented in Figure 64. The increase in peak load due to the uptake of EVs has been reduced with ANM. The increase in peak load is more efficiently mitigated with ANM than with ToU. The increase in peak load now never exceeds 1% and more than 85% of the substations see their peak increase by 0.75% or less.
These estimations of the impact of ANM of substation peak load can again be used to infer the change in Totex that results from using ANM to help mitigate the increase in reinforcement spend that results under a high EV uptake scenario. This is shown in Figure 65. The reinforcement spend required under the high EV uptake scenario when ANM is deployed is closer to the UK Power Networks Base Case than when ANM is not used.

If the use of ANM to implement regulated charging were to be mandated for all new domestic EV charging then this could yield an NPV of £6.7m when the costs of implementing ANM are not taken into account. After addition of the Capex and Opex costs of the control and monitoring equipment required to implement the solution, as well as the related overheads, the NPV drops to negative £300m. This result, and a breakdown of the NPV between the DNO and consumers, is presented below in Table 25.

Based on current ANM costs, the analysis indicates that the costs of this particular ANM solution far outweigh the benefits, and that this is likely to remain the case even for very high uptake scenarios.

### 6.2.3.2 Fleet EV users

In addition to the impact of domestic EV charging captured in the analysis, ANM can be used in a more focused way to regulate the charging of a fleet of commercial EVs. In a case where the connection required for charging a fleet of EVs is expected to be expensive, it is possible that this cost could be moderated through the use of ANM. Using ANM and regulated charging to reduce the charging peak can reduce the connection size required, and hence the cost of that connection.

The impact of ANM on peak load can again be estimated by using the commercial charging profile derived from the LCL trial analysis, Report B2 [Ref. 1]. A window is defined overnight between 16h and 5h during which it is assumed that vehicle charging can be deferred. The impact that this could have on the diversified charging profile is illustrated in Figure 66. It can be seen that the impact on the peak itself is quite pronounced as all of the fleet vehicles being plugged in to charge on a given evening are plugged in at a similar time. The figure also shows the impact of ANM on the maximum charging profile, which was also derived from the EV trials. The reason for analysing the impact of ANM on the maximum profile is that this profile is more in line with how the new connection would be sized.
The analysis presented in Figure 66 suggests that the size of the connection required by a fleet of commercial vehicles (or at least a fleet with similar properties to that monitored through the LCL trials) can be reduced by c. 31.8% when ANM is deployed. Across a fleet of commercial EVs examined in the LCL trial the analysis suggests that a connection size of c. 6 kW per vehicle should be allowed. Deployment of ANM could therefore reduce the connection size required by c. 2 kW per vehicle. Clearly the cost of connections can vary greatly and depends on the characteristics of the connection required and of the surrounding network. However, assuming that typical new connection costs are £200k/MVA and that the ANM equipment required to implement regulated charging would cost c. £50k (assuming that any contribution towards fixed overheads is small compared to the ANM equipment costs for the purpose of this analysis), it can be concluded that using ANM is a competitive connection option for commercial fleets of more than 131 vehicles.
Conclusions

The conclusion that is drawn from this report is that behavioural and technical interventions will be applicable to one or more consumer groups, and there is no single mitigating action against the impact on the network from EV charging and HP loads. In order for the DNO to deploy these interventions as an alternative to reinforcement a number of factors need to be understood:

- The responsiveness of the consumer group to behavioural and technological influences;
- Predicted LCT growth in a given location and the potential for clustering;
- Constraints that exist on the network at these locations;
- The peak demand at the location at the time most likely charging will take place; and
- The size of the load being applied to the transformer that feeds the location.

The LCL EV trials outlined in Chapter 4 showed that both ToU and ANM could successfully shift load; ToU was applied to shift peak load to off peak, and with ANM it was demonstrated that the EV Controller could curtail load on request from the ANM system.
Table 26 below illustrates EV consumers expected responsiveness to the various interventions proposed in Chapter 3. The assessment was derived in Section 5.1, which provided specific details by consumer type.

### Table 26: Interventions

<table>
<thead>
<tr>
<th></th>
<th>Domestic Private</th>
<th>Domestic Public</th>
<th>Fleet</th>
<th>Public Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behavioural Intervention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of Use</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td><strong>Technical Intervention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMETS ALCS</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>EV Controller</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>ANM *</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Reinforcement / New Connection</td>
<td>✓</td>
<td>✓**</td>
<td>✓***</td>
<td>✓***</td>
</tr>
</tbody>
</table>

*ANM requires an EV Controller to communicate with the charge points.
**The use of Time of Use is limited with Fleet because they have a schedule, but it could be used to shift the load to a more appropriate time, i.e. after the working day.
***Due to the potential high demand (i.e. >70kVA) it will be necessary to pass this through network planning by default.

The table matches each step in the value chain as illustrated in Figure 56 – Value Chain, with the complexity and effectiveness increasing with each intervention as predicted in Chapter 5.

### 7.1 Optimisation Opportunities

In order to determine the circumstances these interventions might be deployed, several factors need to be taken into account. As the scenario showed in Section 3.4.3, transformers may be close to their nameplate rating and the addition of just a few charging points charging concurrently would cause a problem. As the scenarios showed in Sections 3.4.1 and 3.4.2, there was more headroom capacity and hence considerably more charging points could be added without exceeding the nameplate rating.

The EV growth figures shown in Section 3.1 provide an indication of the anticipated uptake of various vehicle types year on year. These are a guide, as uptake will be higher in urban areas where range is not an issue, and they do not provide any idea of clustering and hence make these impossible to apply to a specific location on the network.

It is clear that from a DNO perspective, the primary issue of EVs is concerned with the impact on distribution transformers from the addition of new load, which will predominately be caused by the concurrent charging where there are clusters of charge points. Given that the traditional method of mitigating this extra load is through reinforcement is a significant investment for the DNO, utilising interventions that avoid this could be considered as an alternative.

As was illustrated in Chapter 3, each consumer group applies a different additional load to the load profile as charging takes place at different times of the day and night. As was shown in the LCL EV trials, public charging is used through the day and private charging overnight.

The key concern for the DNO is the accuracy of the capacity model, Figure 67 illustrates typical demand, duration and an indication of the number of concurrent charging sessions required to reach 85% of transformer nameplate rating.
As can be seen from the above diagram, moving left to right, charging durations and demand increases, and therefore the number of concurrent charging sessions that a transformer can maintain varies considerably for each consumer group. The “window of charging opportunity”, also varies by consumer group, opening up the possibility for load shifting in some cases (e.g. fleet), but not all (e.g. public transport).

To understand the impact on a transformer an understanding of the load profile is first required, to determine whether there is any headroom capacity at the point the consumer group in question is likely to charge. If there is spare capacity at times when the consumer behaviour permits it then it should be possible to make use of interventions appropriate to that consumer type, otherwise the only alternative will be reinforcement.

As the numbers of EVs increases, clustering will become an issue for the DNO, with each consumer group having a different impact and therefore different interventions will come into play to mitigate the risks as shown in Chapter 5 and support in Chapter 3.
7.2 Key Behaviours

Key behaviours have been identified for several EV consumer groups and these are shown in Table 27. It provides an indication of the level of impact each will have on the network and the anticipated charging times of peak demand, along with the degree of flexibility in their demand.

It is important to note that it is expected that the higher the charge point rating and the higher the likelihood of clustering, the greater chance of a new connection request being required. At this stage, depending on the constraints on the network in question, interventions could be deployed instead of reinforcement to meet this new demand as indicated below.

Table 27: Key Behaviours and Requirements by Consumer Group

<table>
<thead>
<tr>
<th></th>
<th>Domestic Private</th>
<th>Domestic Public</th>
<th>Fleet</th>
<th>Public Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak time demand</td>
<td>Y</td>
<td>N**</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Flexibility in demand (Diverse)</td>
<td>H (N)</td>
<td>L (N)</td>
<td>M (Y)</td>
<td>L (N)</td>
</tr>
<tr>
<td>Typical charge point rating</td>
<td>3kW</td>
<td>7 – 50kW</td>
<td>22kW</td>
<td>&gt;60kW</td>
</tr>
<tr>
<td>Likelihood for connection request</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Likelihood of multiple deployment**</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Consider for smart optimised connection (prescribed intervention e.g. EV Controller/ANM/Traditional)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

*Is there flexibility in the way in which the load can be managed, i.e. load shifting, load limiting.
**Will there be a high possibility of multiple charge points being installed in one go, i.e. a fleet operator is likely to install multiple charge points in one go, thus creating a cluster.
***This will depend on where the charge points are deployed, for example if they are deployed to a car park on an industrial estate then the impact could be high.

7.3 CBA Key Findings

Deploying ToU tariffs or ANM technologies widely to mitigate primary reinforcement requirements is unlikely to be cost effective.

Mandatory application of ToU tariffs to domestic EV charging could reduce reinforcement costs by an NPV of £4.4m. However, this would then need to cover the costs required to implement such a mandate, such as changes in DNO and supplier settlement systems.

Mandatory application of ANM for regulated charging of domestic EVs would be very expensive, based upon current costs assumptions, and the benefits of regulating domestic EV charging would be significantly outweighed by the cost incurred.

There are likely to be cases where a more limited application of ANM to regulate EV charging can reduce the connection cost for connecting large fleets of commercial EVs.

The analysis presented in this report shows that for large fleets of EVs, the benefit of the reduced connection size required for a fleet of commercial EVs when ANM is used, is likely to start outweighing the costs of installing the ANM equipment for fleets of over 131 vehicles.

7.4 Recommendations

In order for the DNO to consider the smart optimisation of loads via the interventions described in this report, it will be necessary for the DNO to forge closer commercial relationships with intermediaries, such as CNOs and Suppliers, in order to release the potential value these interventions will bring to the DNO. In addition, it is essential that the DNO is made aware of additional load being added to the network in order to be proactive in avoiding potential issues that might be caused.
Finally a summary of the recommendations as found by this report are provided:

- **Visibility of charging point installations**
  It is imperative that the DNO understands the distribution and location of charging points, particularly when clustered, across their network. It is critical that Charging Network Operators (CNOs) and other infrastructure providers are mandated to inform the DNO when connections are made. This may require a change to the relevant connection policies which should be facilitated by a change in the appropriate regulation, which will also require a mandatory scheme similar to the MCS.

- **Load monitoring**
  Additional monitoring of the LV network will enable areas where constraints are being introduced due to clusters of charging points to be established, and will enable the protection of the assets either via the deployment of an intervention or via traditional reinforcement.

- **Standardised Communications and Integration between DNO and CNO**
  There are currently no standards for the control signals that would be sent from the DNO to the CNO or other 3rd party, instead these require complex integration. It is therefore recommended that a standard be developed that includes load management as one of its functions that will allow interoperability between parties and this forms part of the IEC 61850 CIM standards.

- **Continuation of currently SMETS capability**
  There is a possibility that the SMETS standards will drop ALCS, the result of which will be the removal of any ability in the future for the DNO to control EV charging in the home. Therefore the DNOs must continue to ensure that ALCS remains part of SMETS.

- **Make use of existing TOU tariff**
  There are currently significant barriers to the implementation of TOU to enable the efficient charging of EV. The LCL EV trials have provided evidence that consumers will respond to the necessary price stimuli to charging behaviour.

  It is not deemed necessary for the Supplier to create a new tariff specific to EV, if a tariff that supports on-peak and off-peak already exists, or is planned.

- **Education**
  Simply educating the consumers from the outset could have an impact on shifting load at peak times, to avoid reinforcement and damage to DNO assets. This could be in the form of education packages issued by the DNO directly or as material provided as part of the charging point sale. The material should include details of the environmental and financial benefits of load shifting mechanisms such as TOU and timers.
References

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.</td>
<td><a href="https://www.gov.uk/news/london/6000-electric-car-charging-point-used-for-less-than-five-hours-in-four-years-8004709">https://www.gov.uk/news/london/6000-electric-car-charging-point-used-for-less-than-five-hours-in-four-years-8004709</a></td>
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<td>19.</td>
<td><a href="http://www.standard.co.uk/news/london/6000-electric-car-charging-point-used-for-less-than-five-hours-in-four-years-8004709">http://www.standard.co.uk/news/london/6000-electric-car-charging-point-used-for-less-than-five-hours-in-four-years-8004709</a></td>
</tr>
<tr>
<td>23.</td>
<td>25.</td>
</tr>
</tbody>
</table>

33. Elexon – Load Profiles and their use in Electricity Settlement

This assumption is consistent with the DECC smart metering impact assessment, which notes that 17% of household electricity consumption relates to wet goods, which are most likely to provide potential load shifting opportunities. See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/276656/smart_meter_roll_out_for_the_domestic_and_small_and_medium_and_non_domestic_sectors.pdf


<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALCS</td>
<td>Auxiliary Load Control Switches</td>
</tr>
<tr>
<td>AMI</td>
<td>Automated Meter Infrastructure</td>
</tr>
<tr>
<td>ANM</td>
<td>Active Network Management</td>
</tr>
<tr>
<td>ASHP</td>
<td>Air Source Heat Pump</td>
</tr>
<tr>
<td>Asset</td>
<td>Network component that combines to provide the distribution network</td>
</tr>
<tr>
<td>BMS</td>
<td>Building Management System</td>
</tr>
<tr>
<td>BSC</td>
<td>Balancing and Settlement Code</td>
</tr>
<tr>
<td>CABLED</td>
<td>Coventry and Birmingham Low Emission Demonstrators</td>
</tr>
<tr>
<td>Charge Point</td>
<td>Electric Vehicle charging equipment</td>
</tr>
<tr>
<td>CIM</td>
<td>Common Information Model, a standard developed to allow application software to exchange information about an electrical network</td>
</tr>
<tr>
<td>Clustering</td>
<td>A group of loads, such as EV on a given transformer</td>
</tr>
<tr>
<td>CNO</td>
<td>Charging Network Operator</td>
</tr>
<tr>
<td>Constrain On/Off</td>
<td>The action of curtailing or holding load on the network</td>
</tr>
<tr>
<td>Consumer Groups</td>
<td>Groups of EV users with similar behaviours and requirements</td>
</tr>
<tr>
<td>CTCU</td>
<td>Central Teleswitch Control Unit</td>
</tr>
<tr>
<td>DCC</td>
<td>Data and Communications Company; the collective name for the set of organisations responsible for operating Smart Metering across Great Britain</td>
</tr>
<tr>
<td>DECC</td>
<td>Department of Energy and Climate Change</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>DfT</td>
<td>Department for Transport</td>
</tr>
<tr>
<td>DNO</td>
<td>Distribution Network Operator</td>
</tr>
<tr>
<td>DSMA</td>
<td>Demand Side Management Aggregator</td>
</tr>
<tr>
<td>DSR</td>
<td>Demand Side Response</td>
</tr>
<tr>
<td>DVLA</td>
<td>Driver and Vehicle Licensing Agency</td>
</tr>
<tr>
<td>EST</td>
<td>Energy Savings Trust</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>EV Controller</td>
<td>Use of an IT to manage the charging point</td>
</tr>
<tr>
<td>FIT</td>
<td>Feed-In Tariff</td>
</tr>
<tr>
<td>GAHP</td>
<td>Gas Absorption Heat Pumps</td>
</tr>
<tr>
<td>GSHP</td>
<td>Ground Source Heat Pumps</td>
</tr>
<tr>
<td>HAN</td>
<td>Home Area Network</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>HP</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>ICL</td>
<td>Imperial College London</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electro-technical Commission</td>
</tr>
<tr>
<td>IET</td>
<td>Institution of Engineering and Technology</td>
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<tr>
<td>IHD</td>
<td>In-Home Display</td>
</tr>
<tr>
<td>Intervention</td>
<td>An approach to reducing load as an alternative to traditional reinforcement</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organisation</td>
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<tr>
<td>LCL</td>
<td>Low Carbon London</td>
</tr>
<tr>
<td>LCNF</td>
<td>Low Carbon Networks Fund</td>
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<tr>
<td>LCT</td>
<td>Low Carbon Technology</td>
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<tr>
<td>LCVPP</td>
<td>Low Carbon Vehicle Public Procurement</td>
</tr>
<tr>
<td>LCZ</td>
<td>Low Carbon Zone</td>
</tr>
<tr>
<td>Light Goods</td>
<td>Commercial vehicles under 7.5 tonnes</td>
</tr>
<tr>
<td>Load Limiting</td>
<td>Reducing the amount of power that can be drawn down by a group of charging points</td>
</tr>
<tr>
<td>Load Management</td>
<td>Application of a technical intervention, such as load shifting or limiting</td>
</tr>
<tr>
<td>Load Shifting</td>
<td>The ability to shift electricity demand using behavioural or technical interventions</td>
</tr>
<tr>
<td>LV</td>
<td>Low Voltage</td>
</tr>
<tr>
<td>MCS</td>
<td>Microgeneration Certification Scheme</td>
</tr>
<tr>
<td>OCPP</td>
<td>Open Charge Post Protocol</td>
</tr>
<tr>
<td>Ofgem</td>
<td>Office of Gas and Electricity Markets</td>
</tr>
<tr>
<td>OLEV</td>
<td>Office for Low Emission Vehicles</td>
</tr>
<tr>
<td>OSI</td>
<td>Open Systems Interconnections</td>
</tr>
<tr>
<td>PF</td>
<td>Power Factor</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
</tr>
<tr>
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<tr>
<td>PHEV</td>
<td>Plugin Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>PMS</td>
<td>Participant Management System</td>
</tr>
<tr>
<td>PV</td>
<td>Photo-Voltaic</td>
</tr>
<tr>
<td>Range Anxiety</td>
<td>The consumer fear of insufficient range to reach their destination</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>The process of planning and upgrading the network to cater for increased demand</td>
</tr>
<tr>
<td>RTS</td>
<td>Radio Teleswitching System</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote Terminal Unit</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SLA</td>
<td>Service Level Agreement</td>
</tr>
<tr>
<td>SMETS2</td>
<td>Smart Metering Equipment Technical Specifications Version 2; the standards being applied to Smart Metering in the UK</td>
</tr>
<tr>
<td>STOR</td>
<td>Short Term Operating Reserve</td>
</tr>
<tr>
<td>TSB</td>
<td>Technology Strategy Board</td>
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<tr>
<td>ToU</td>
<td>Time of Use</td>
</tr>
<tr>
<td>UE</td>
<td>United Energy</td>
</tr>
<tr>
<td>UKPN</td>
<td>UK Power Networks</td>
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<tr>
<td>ULCV</td>
<td>Ultra Low Carbon Vehicle</td>
</tr>
<tr>
<td>ULEV</td>
<td>Ultra Low Emissions Vehicles</td>
</tr>
<tr>
<td>US DoE</td>
<td>United States Department of Energy</td>
</tr>
<tr>
<td>VED</td>
<td>Vehicle Excise Duty</td>
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</tbody>
</table>
Instrumenting a Smart Grid

Electrification of heat

ANM/network operation

Electrification of transport

Dynamic Time of Use tariff

Energy efficiency

Demand Side Response – demand

Demand Side Response – generation

Smart meter

Network planning

Distributed Generation
**Project Overview**

Low Carbon London, UK Power Networks’ pioneering learning programme funded by Ofgem’s Low Carbon Networks Fund, has used London as a test bed to develop a smarter electricity network that can manage the demands of a low carbon economy and deliver reliable, sustainable electricity to businesses, residents and communities.

The trials undertaken as part of LCL comprise a set of separate but inter-related activities, approaches and experiments. They have explored how best to deliver and manage a sustainable, cost-effective electricity network as we move towards a low carbon future. The project established a learning laboratory, based at Imperial College London, to analyse the data from the trials which has informed a comprehensive portfolio of learning reports that integrate LCL’s findings.

The structure of these learning reports is shown below:

<table>
<thead>
<tr>
<th>Summary</th>
<th>SR DNO Guide to Future Smart Management of Distribution Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distributed Generation and Demand Side Response</strong></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>Residential Demand Side Response for outage management and as an alternative to network reinforcement</td>
</tr>
<tr>
<td>A2</td>
<td>Residential consumer attitudes to time varying pricing</td>
</tr>
<tr>
<td>A3</td>
<td>Residential consumer responsiveness to time varying pricing</td>
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<tr>
<td>A4</td>
<td>Industrial and Commercial Demand Side Response for outage management and as an alternative to network reinforcement</td>
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<tr>
<td>A5</td>
<td>Conflicts and synergies of Demand Side Response</td>
</tr>
<tr>
<td>A6</td>
<td>Network impacts of supply-following Demand Side Response report</td>
</tr>
<tr>
<td>A7</td>
<td>Distributed Generation and Demand Side Response services for smart Distribution Networks</td>
</tr>
<tr>
<td>A8</td>
<td>Distributed Generation addressing security of supply and network reinforcement requirements</td>
</tr>
<tr>
<td>A9</td>
<td>Facilitating Distributed Generation connections</td>
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<tr>
<td>A10</td>
<td>Smart appliances for residential demand response</td>
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<tr>
<td><strong>Electrification of Heat and Transport</strong></td>
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<tr>
<td>B1</td>
<td>Impact and opportunities for wide-scale Electric Vehicle deployment</td>
</tr>
<tr>
<td>B2</td>
<td>Impact of Electric Vehicles and Heat Pump loads on network demand profiles</td>
</tr>
<tr>
<td>B3</td>
<td>Impact of Low Voltage – connected low carbon technologies on Power Quality</td>
</tr>
<tr>
<td>B4</td>
<td>Impact of Low Voltage – connected low carbon technologies on network utilisation</td>
</tr>
<tr>
<td>B5</td>
<td>Opportunities for smart optimisation of new heat and transport loads</td>
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<tr>
<td><strong>Network Planning and Operation</strong></td>
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</tr>
<tr>
<td>C1</td>
<td>Use of smart meter information for network planning and operation</td>
</tr>
<tr>
<td>C2</td>
<td>Impact of energy efficient appliances on network utilisation</td>
</tr>
<tr>
<td>C3</td>
<td>Network impacts of energy efficiency at scale</td>
</tr>
<tr>
<td>C4</td>
<td>Network state estimation and optimal sensor placement</td>
</tr>
<tr>
<td>C5</td>
<td>Accessibility and validity of smart meter data</td>
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<tr>
<td><strong>Future Distribution System Operator</strong></td>
<td></td>
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<tr>
<td>D1</td>
<td>Development of new network design and operation practices</td>
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<tr>
<td>D2</td>
<td>DNO Tools and Systems Learning</td>
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<tr>
<td>D3</td>
<td>Design and real-time control of smart distribution networks</td>
</tr>
<tr>
<td>D4</td>
<td>Resilience performance of smart distribution networks</td>
</tr>
<tr>
<td>D5</td>
<td>Novel commercial arrangements for smart distribution networks</td>
</tr>
<tr>
<td>D6</td>
<td>Carbon impact of smart distribution networks</td>
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</tbody>
</table>