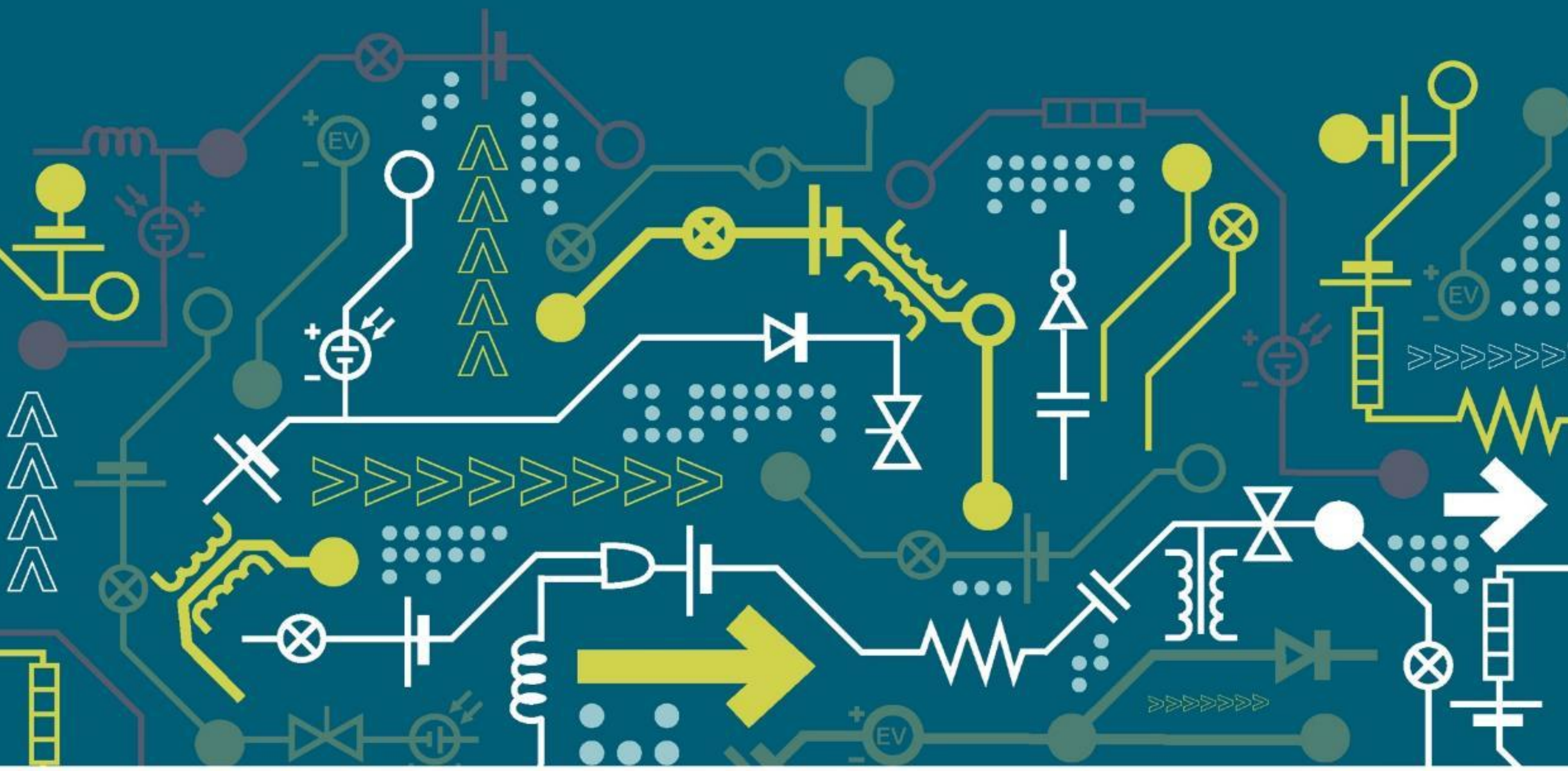
WPD INNOVATION

Take Charge

System Capacity Optimisation



WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Version Control

Issue	Date
V01	17.07.2020
V02	20.08.2020

Publication Control

Name	Role
David Thorn	Author
Daniel Hardman	Reviewer
Neil Murdoch	Approver

Contact Details

Email
wpdinnovation@westernpower.co.uk

Postal
Innovation Team
Western Power Distribution
Pegasus Business Park
Herald Way
Castle Donington
Derbyshire
DE74 2TU

Disclaimer
Neither WPD, nor any person acting on its behalf, makes any warranty, express or implied, with respect to the use of any information, method or process disclosed in this document or that such use may not infringe the rights of any third party or assumes any liabilities with respect to the use of, or for damage resulting in any way from the use of, any information, apparatus, method or process disclosed in the document.

Contents

Tables

Figures

Glossary

Acronym	Definition
ABB	Asea Brown Boveri
AC	Alternating Current
ANPR	Automatic Number Plate Recognition
BESS	Battery Energy Storage Solution
BEV	Battery Electric Vehicle
BP	British Petroleum
BSP	Bulk Supply Point
bvm	Billion vehicle miles
CAGR	Compound Annual Growth Rate
CCS	Compact Connection Solution
DC	Direct Current
DFES	Distribution Future Energy Scenarios
DfT	Department for Transport
DNO	Distribution Network Operator
ENA	Energy Networks Association
ESB	Electricity Supply Board
ESO	Electricity System Operator
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FES	Future Energy Scenarios
GB	Great Britain
GDP	Gross Domestic Product
HGV	Heavy Goods Vehicle
HH	Half hourly
INEA	Innovation and Networks Executive Agency
IRENA	International Renewable Energy Agency
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
LGV	Light Goods Vehicle
LV	Low Voltage
MDD	Market Domain Data
MEA	My Electric Avenue
MSA	Motorway Service Area
MV	Medium Voltage
MVA	Mega Volt-Ampere
MW	Megawatt
NI	Northern Ireland
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
NTM	National Transport Model
OLEV	Office for Low Emission Vehicles
PC	Profile Class
PHEV	Plug-in Hybrid Electric Vehicle

Acronym	Definition
PICG	Plug-in Car Grant
PP	Priority Projects
PSV	Public Service Vehicle
PV	Photovoltaic
RAF	Royal Air Force
RCN	Rapid Charge Network
RMU	Ring Main Unit
ROI	Republic of Ireland
SOC	State of Charge
SRN	Strategic Road Network
SSE	Scottish and Southern Energy
SSEN	Scottish and Southern Energy Networks
UKPIA	UK Petroleum Industry Association
UKPN	UK Power Networks
ULEV	Ultra-Low Emission Vehicle
VW	Volkswagen
WPD	Western Power Distribution
ZEV	Zero-Emissions Vehicle

1 Introduction

Take Charge is a £1.38m Network Innovation Allowance (NIA) project that aims to develop a new Compact Connection Solution (CCS) to supply large power capacity required for new rapid Electric Vehicle (EV) chargers at Motorway Service Areas (MSAs). The project will help support the transition from petrol and diesel vehicles to EVs by providing a more cost-effective and faster solution to connect multiple rapid chargers compared with traditional solutions.

MSAs have been identified as important locations where rapid EV charging would need to be implemented on a large scale to allow simultaneous charging by multiple customers when undertaking journeys on the Strategic Road Network (SRN). Western Power Distribution (WPD) has been in discussions with Moto (the largest MSA operator in Great Britain) and Ecotricity (who provide EV charging facilities at a number of MSAs) to partner on Take Charge and help trial this new solution.

The first stage of the project involved producing a methodology to select the most suitable MSA for conducting the project trials. The ‘Site Selection Methodology’ report was finalised in June 2020 and assessed each of the Moto MSAs within WPD’s licence areas with respect to location, Point of Connection (PoC), available network capacity, visitor numbers and space on the site. The report concluded that Exeter MSA, located on the M5 in Devon, was the most suitable trial location due to its close proximity to a 33kV PoC with sufficient capacity, large visitor numbers and ample space within the MSA.

This report captures the next stage of Take Charge and will analyse EV uptake, charging behaviours, traffic information and infrastructure to determine the optimum capacity for the new CCS at the trial location. Given the increasing uptake of EVs and Net Zero 2050 target, there is a need for Distribution Network Operators (DNOs) and MSA operators to prepare these strategic sites to ready for future demand associated with rapid EV charging infrastructure. Therefore, this report will detail how to calculate the optimum capacity of the CCS to ensure that the substation is designed to meet the charging requirements over the next 30 years.

The report details the approach that has been derived to calculate the capacity based on data made available by Moto, Ecotricity and other external data sources. A capacity assessment of Exeter MSA, the chosen trial site, is then carried out using the approach.

2 Approach

2.1 Overview

Access to rapid charging points is a major consideration for many EV drivers when undertaking long journeys to ensure they can charge their vehicles efficiently en-route. This report considers the required power capacity of the CCS (peak MW) to provide for the needs of customers for charging at MSA locations in the future. The time horizon for the assessment is up to 2050, which corresponds to a period of significant anticipated change for transport in the UK (in particular, increasing uptake of EVs). As stated in our EV Strategy document, we believe that the solution developed in this project will be essential bearing in mind that electrical plant has a service life of fifty years that all criteria are taken into consideration and that it follows the Committee for Climate Change view of “touch it once till 2050”’.

The location of charging infrastructure has an impact on drivers due to both the frequency of charging events and the chosen route for journeys. The ‘Site Selection Methodology’ report considered potential locations for the implementation and trial of the CCS.

Through our research and investigations we have identified a number of other factors that could influence the required capacity of the CCS, resulting from the behaviour of customers relating to EV charging and other aspects.

The following subsections provide an overview of the research that has been carried out. The assessment has been carried out through consideration of each of the categories shown in Figure 2-1, summarised as follows:

- EV uptake to determine the projected number of vehicles that require to be charged (at MSAs or other locations);
- Forecast of road traffic to determine the projected changes in the number and length of journeys, which relates to the overall energy consumption and need for recharging (at MSAs or other locations);
- Customer behaviour, comprising rapid charging habits that dictate the frequency of charging events at MSA locations, the overall number of customers visiting MSAs and the average dwell time at MSAs to determine the expected usage of MSA rapid charging points;
- Charging demand corresponding to the electrical power demand profile for public rapid charging and the distribution of charging events throughout the day, to inform the assessment of the capacity requirement at the peak time;
- Network demand, considering the local network demand and whether there is potential complementarity to enable demand profile smoothing to reduce the capacity requirement through sharing of infrastructure;
- MSA infrastructure, comprising a summary of existing refuelling points and associated infrastructure, providing the basis for expected developments in future; and
- Hardware, comprising research of the capacity of EV batteries and power ratings of individual charging points, which define the duration of charging and, therefore, the behaviour of customers in view of potential disruption during journeys. In addition, this section presents practical considerations about the installation of the charging point infrastructure.

Figure 2-1 Factors influencing CCS capacity requirement

The research of the above factors has been carried out based on the principal sources selected for the assessment that are identified in Figure 2-2.

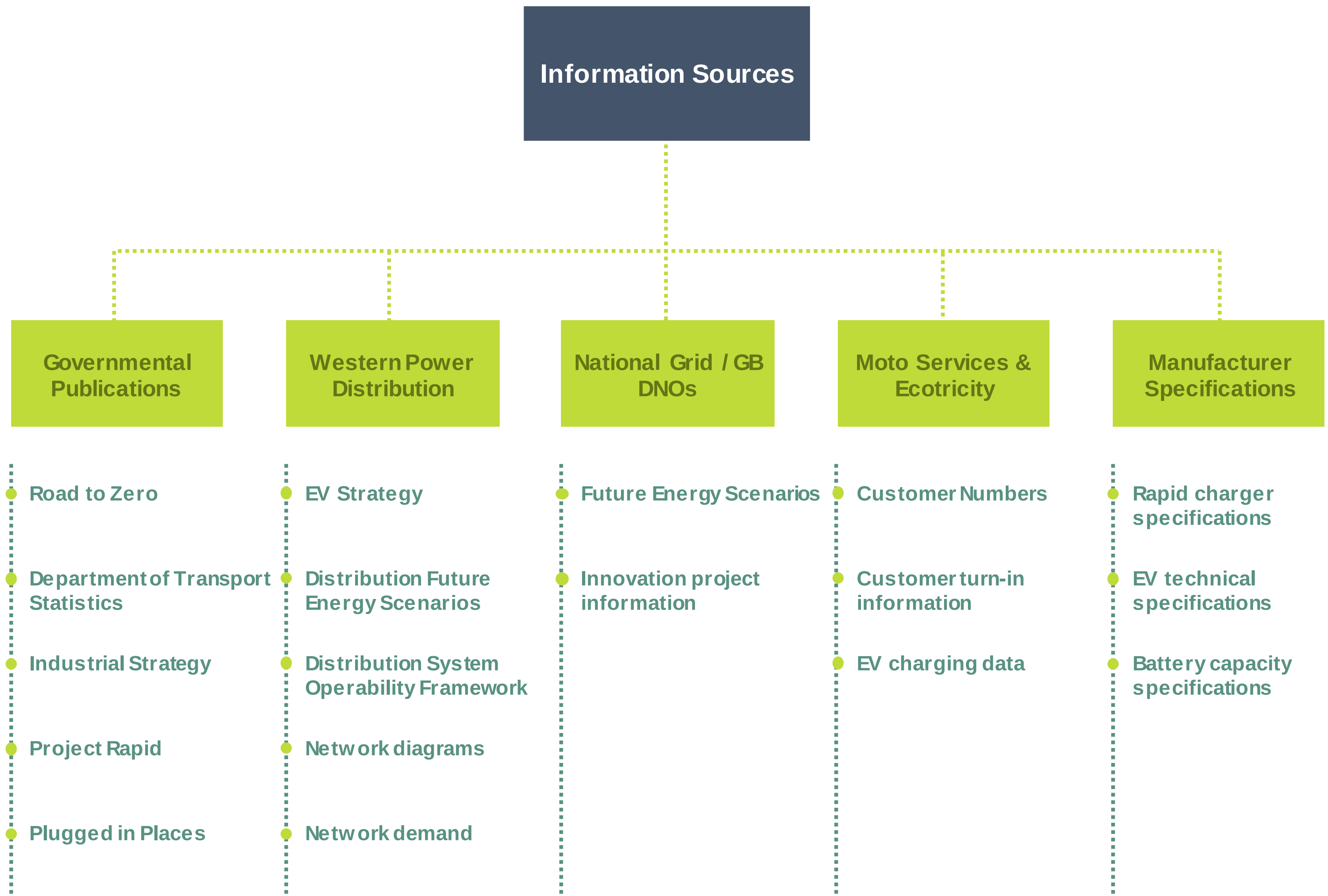


Figure 2-2 Selection of information sources used in the assessment

2.2 EV uptake

EV uptake is a key consideration when determining the required capacity of the CCS to support drivers in making journeys in the context of the future plans for sustainable transport. Several publications detail projections of EV uptake to meet 2050 net zero objectives, as well as other related policy objectives. The policy direction is principally shared between the following UK Government bodies: Department for Transport (DfT), Department for Business, Energy & Industrial Strategy (BEIS) and Office for Low Emission Vehicles (OLEV). Publications by these departments and other organisations, notably the Future Energy Scenarios (FES) prepared by National Grid ESO, strive to ensure future levels of EVs are feasible and sustainable over the next 30 years as well as meeting ambitious targets.

The planned uptake of EVs in the UK is largely governed by the plan set out by the UK government in the 'Road to Zero' document [1], which determines that all new cars and vans should effectively have 'zero emissions' by 2040. The National Grid 2019 FES document [2] states that by 2050 the main options for powering vehicles will be either battery or hydrogen. To enable the predicted levels of uptake, significant steps will need to be implemented in terms of EV charging and battery capacity to provide consumers the confidence to transition from petrol and diesel vehicles to EVs.

2.2.1 Determining factors

There are several determining factors that will affect the uptake of EVs within the UK. The first of these to be considered is the cost of ownership of EVs. The scale at which this factor will change is uncertain, however, the Road to Zero [1] document suggests that there will be a ban on all sales of conventional vehicles by 2040 and a subsequent Government consultation is looking at bringing this forward to 2035 [3]. It is, therefore, expected that the market will almost certainly become saturated by EVs in the time horizon up to 2050 due to the lack of alternative vehicles. The Road to Zero document provides illustrative trajectories for the uptake of Ultra Low Emission Vehicle (ULEV) cars up to 2030, presented in Figure 2-3.

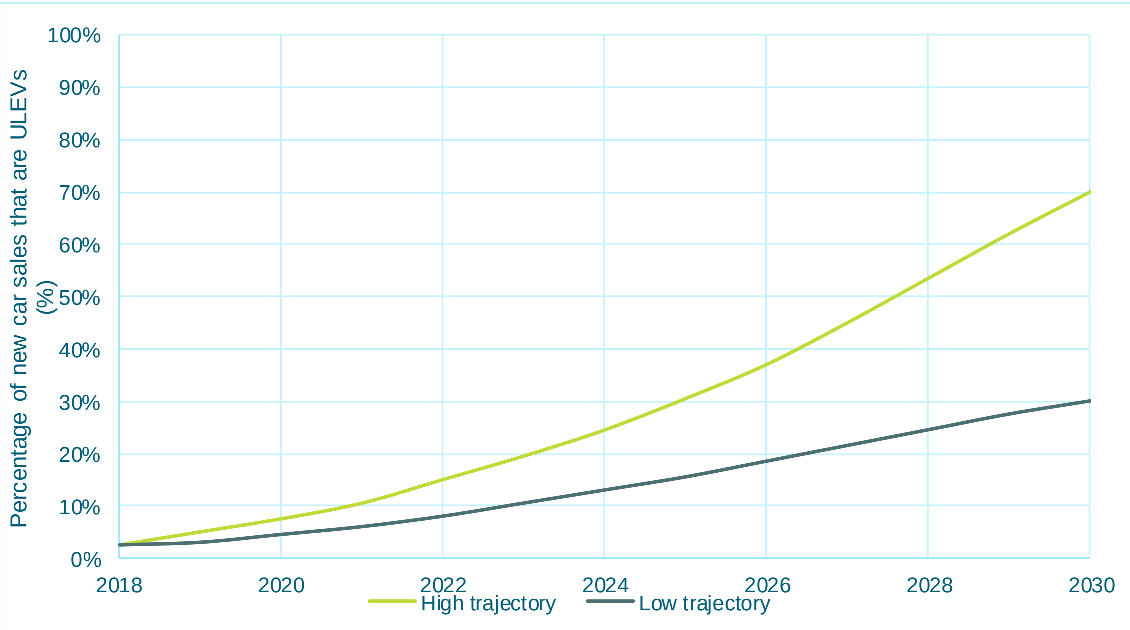


Figure 2-3 Illustrative trajectories of ULEV uptake

Another determining factor to be considered is the implementation of EV charging points in MSAs. Currently within the UK there are more than 1,300 rapid chargers out of a total of around 14,000 public chargers, as stated in the Road to Zero report. It is unclear how many of these rapid chargers are installed near to main roads, however, and the document also states that 'the number of rapid chargers located near the major roads network needs to expand to 1,170 by 2030 (from 460 in 2016)'. The numbers of EV public charging points should be compared with the number of conventional fuel station forecourts, which is approximately 8,400 according to the UK Petroleum Industry Association (UKPIA) 2019 Statistical Review document [4].

The decrease of the hybrid market will also become a determining factor. In 2018 the UK government extended the Plug in Car grant (PICG) to help establish the plug-in hybrid market [5], however, during this extension hybrid vehicles such as PHEVs were no longer eligible for the grant. There is currently a consultation being undertaken by the DfT investigating the feasibility of moving the end of sales date of petrol and diesel from 2035 to 2030 [6, 7], and for this to include hybrid cars. This consultation would suggest that the use of PHEVs is purely as an intermediary step between petrol and diesel vehicles to Battery Electric Vehicles (BEVs).

If the consultation mentioned is successful, the uptake of BEVs within the UK will shift with a quicker than anticipated uptake as a result of the EV being possibly the only vehicle type available for purchase.

2.2.2 Uptake forecasts

Projections published by National Grid in their FES [2] suggest that the uptake of EVs in 2050 would be between 88-98% of around 41.0m vehicles [7], compared with approximately 0.5% of 38.2m vehicles on the road in 2019. The figures for 2050 correspond to between 35.8-38.0m vehicles in total for the different scenarios. The assumptions for the proportions of cars owned that are EVs in each of the FES 2019 scenarios are presented in Figure 2-4.

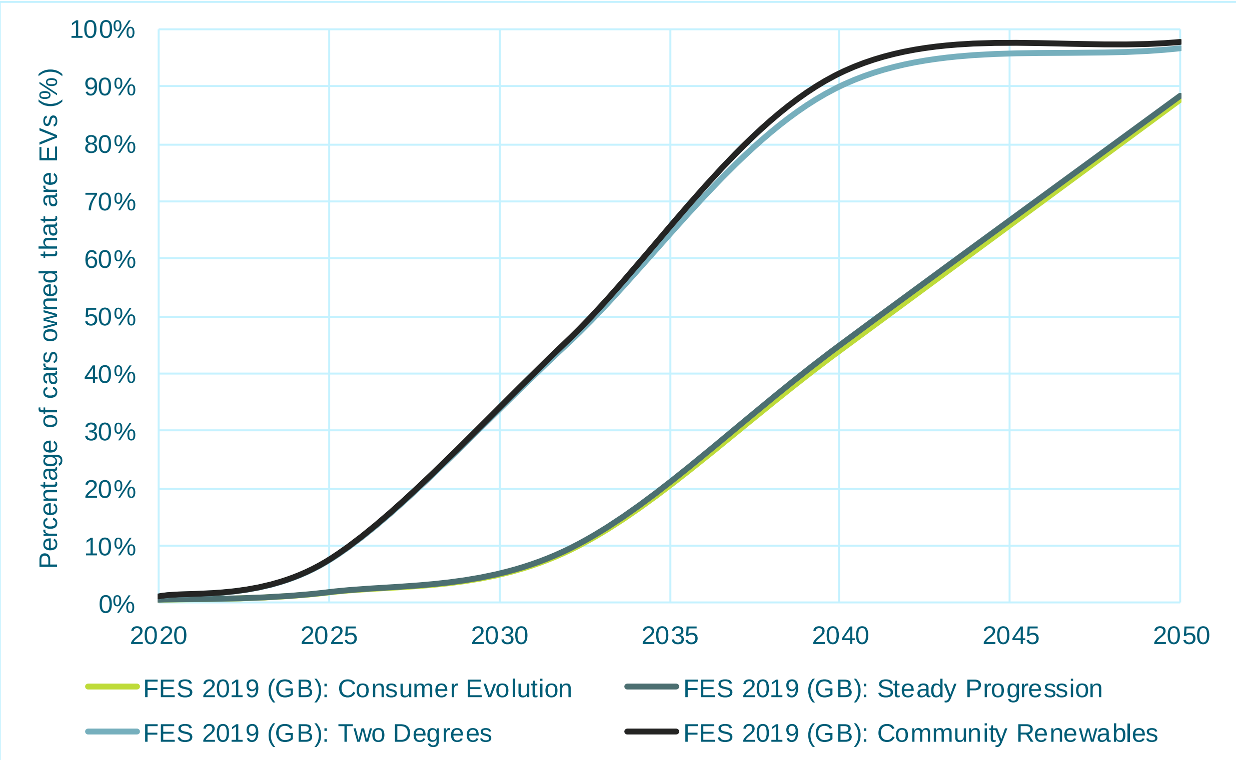


Figure 2-4 FES 2019 assumed proportions of cars owned that are EVs

In summary, the Road to Zero document is the principal policy paper that is driving the changes to promote uptake of EVs and development of required infrastructure, including rapid charging points. The annual National Grid FES publication strives to predict the impact of these policy changes on the supply of energy, which is subsequently translated into predictions at a local level in the WPD DFES document described in the following sub-section.

2.2.3 Forecast uptake in the South West region

Currently, the proportion of EV ownership in the South West region is low, consistent with the rest of the UK. In our Distribution Future Energy Scenarios (DFES) document for the region [8] we estimated that

0.3% of all cars owned in the region were EVs in 2017 and that this would rise to between 7.1 and 31.7% in 2032, as illustrated in Figure 2-5.

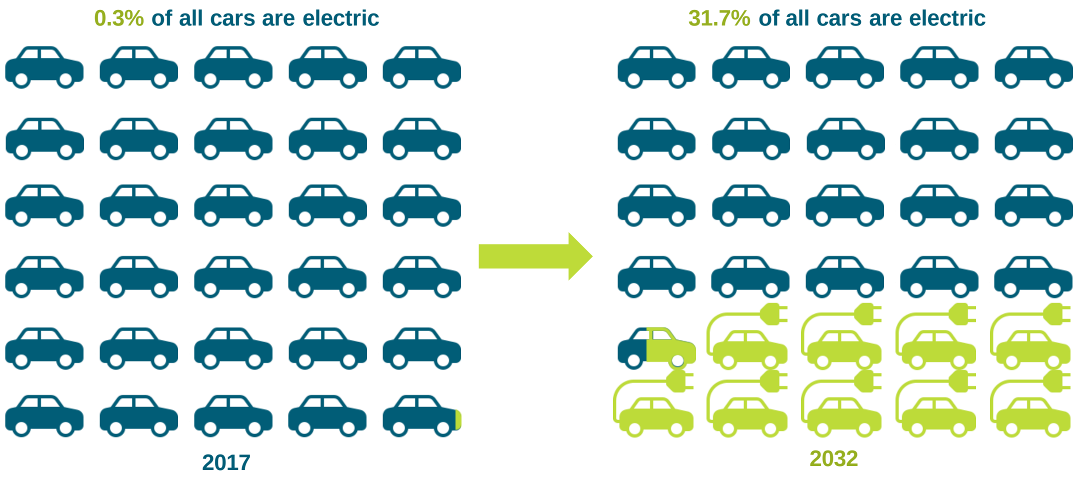


Figure 2-5 Level of EV ownership in 2017 and 2032 for WPD South West Region

Figure 2-6 presents a comparison of the percentages of cars that are EVs, showing percentages for the South West region from the DFES (published in 2018) and the national percentages based on data from FES 2019.

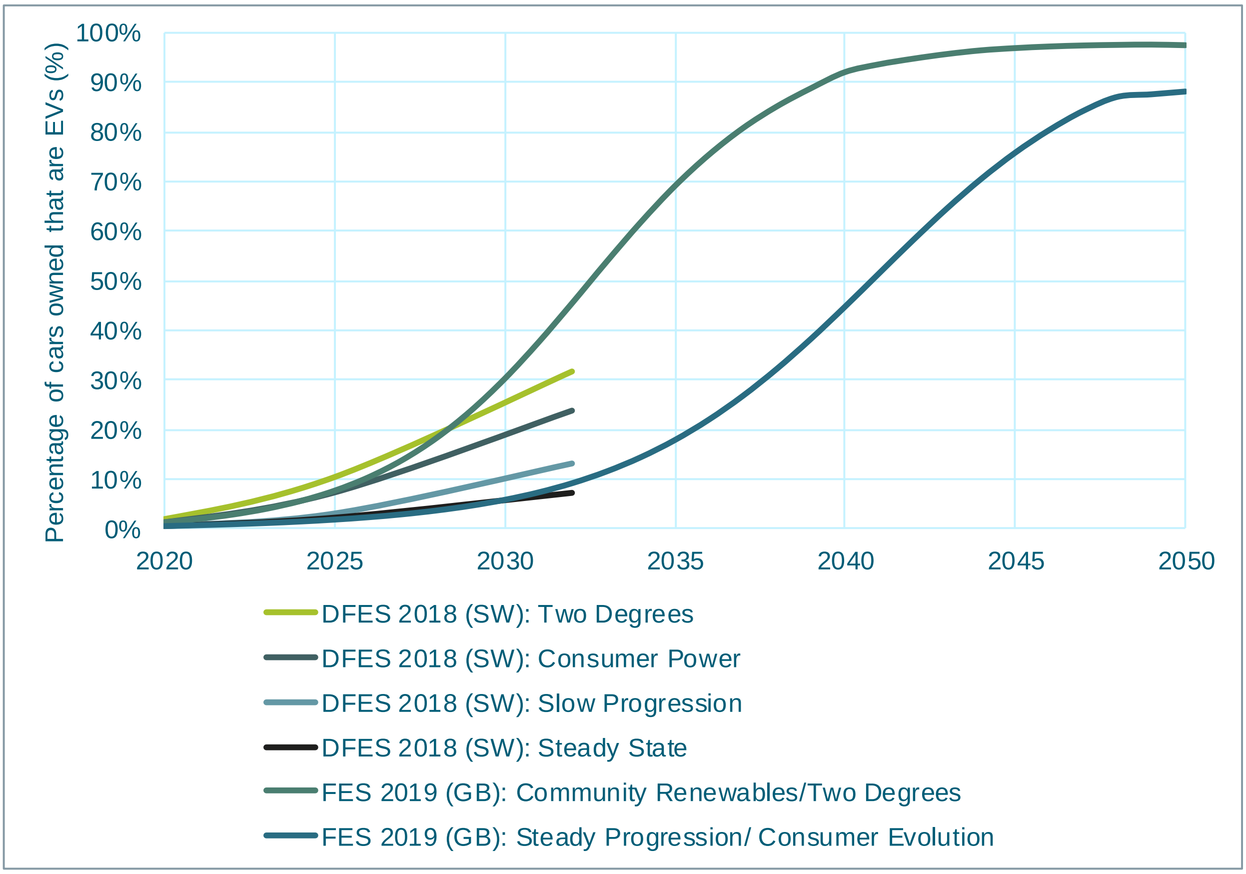


Figure 2-6 Comparison of percentages of cars owned that are EVs

Figure 2-6 shows that it is expected that EV ownership in the South West region is expected to be broadly in line with that in GB as a whole, albeit with the possibility of a slightly slower uptake in the period up to 2032 than the highest FES scenarios.

2.3 Road Traffic

This area considers future-looking road traffic forecast data, comprising the projected total number of vehicle miles travelled in each region in England and Wales up to 2050. The traffic forecast data are considered in the assessment of the capacity of the CCS since they correspond to the number and length of journeys, which relate in turn to the overall energy consumption and need for recharging (at MSAs or other locations).

The DfT published its latest Road Traffic Forecasts in 2018 [9]. This document presents results of the forecast modelling for traffic in England and Wales up to 2050. The forecast data comprises projected total vehicle miles travelled in each region. The traffic forecast data are considered in the assessment of the capacity of the CCS since they correspond to the length (and number) of journeys, which relate in turn to the overall energy consumption and need for recharging (at MSAs or other locations).

The DfT forecast results, determined using the National Transport Model (NTM), are presented in a disaggregated form showing: road type (motorway, principal A, trunk A, and minor roads); vehicle type (car, HGV, LGV and PSV); and UK region.

The DfT analyses comprise forecasts for 7 scenarios, which, in addition to the reference case, represent combinations of high/low gross domestic product (GDP) and fuel cost projections, high/low migration levels, a trend of declining trip rates and the shift to zero emissions vehicles (ZEVs). The projection considered in this report corresponds to scenario 7 (shift to ZEVs).

Figure 2-7 presents the projection of the total traffic on motorways and principal A roads in the South West, compound annual growth rates (CAGRs) covering each 5 year period, and the corresponding projection for England and Wales for comparison. The projections of traffic on motorways and principal A roads have been selected since they correlate to the passing traffic that will be observed by MSAs. The units of the projections prepared by the DfT correspond to the sum of all of the journey lengths, in billion vehicle miles (bvm). The CAGR is a constant growth rate corresponding to geometric progression across multiple periods. It is a valuable measure for comparison of growth rates on a consistent basis.

Figure 2-7 Comparison of total motorway and principal A road traffic projections for South West and England & Wales (DfT Scenario 7, all vehicle types)

Figure 2-7 shows that traffic, or total journey length, is projected to increase in the South West and across England and Wales by 2050. The average CAGR over the 2015-2050 period is 1.25%, which corresponds to growth from 15.6 bvm in the South West region in 2015 to 24.1 bvm in 2050. The CAGR is positive in each of the 5-year periods considered, and declines towards the end of the forecast period. This is deemed to be a reasonable approach, which results in significant growth over 30 years, but avoids unmitigated growth in this period of greater uncertainty.

This CAGR figure of 1.25% for the projected increase in traffic in the South West region has been carried forward to the specific analysis of traffic at Exeter MSA (and impact on EV charging demand), which is presented in section 3.2.2.

2.4 Customer behaviour

Customer behaviour has an impact on when, why and how long drivers will charge their vehicles. In turn, this also has an impact on the required charging capacity since it allows us to understand how the total number of EVs, and journeys completed by EVs, translate into use of rapid charging facilities at MSAs.

The following sub-sections present the assessment of charging behaviour of EV owners in three sub-categories: number of MSA customers; charging habits; and time spent at MSAs (average dwell time).

2.4.1 Number of MSA customers

The total number of customers visiting an MSA, and the percentage of those customers that are EV drivers that may need to charge their vehicles, are important considerations in determining the required capacity of the CCS at the MSA.

Annual footfall for MSAs across the UK varies between 1.0 and 5.7 million [10], corresponding to averages of 2,700 to 15,600 visitors per day. Figure 2-8 presents the reasons provided by survey participants for stopping at MSAs, according to the Motorway User Survey 2019 [11].

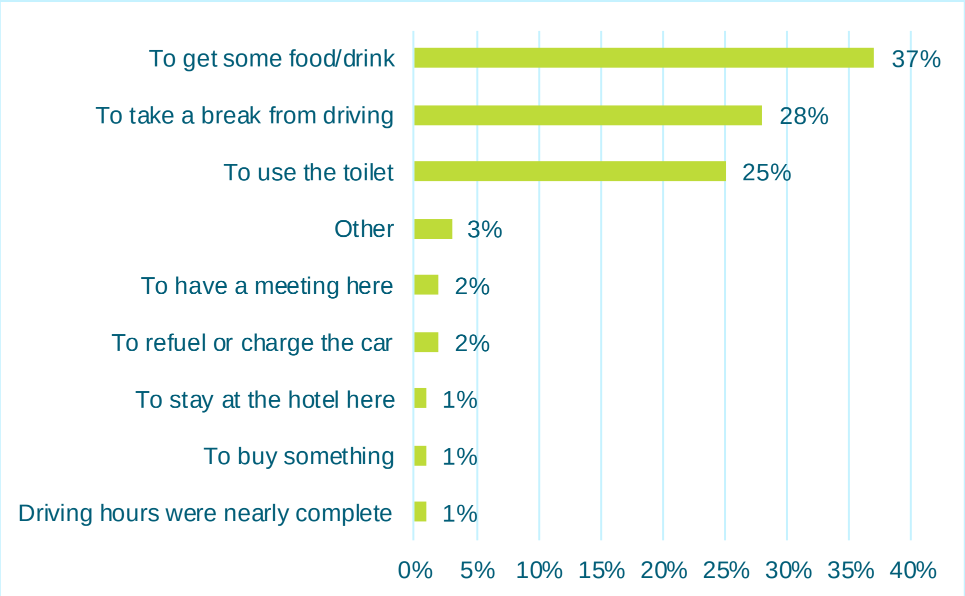


Figure 2-8 Reasons for visiting MSA from Motorway User Survey

Figure 2-8 shows that only 2% of survey participants declared that they visit MSAs to refuel or charge their vehicles. The most popular reasons for customers visiting MSAs are to get food/drinks, take a break from driving or to use the toilet.

It is important to note that the South West region is principally a rural area, which is likely to be reflected in the nature of charging infrastructure available in the region at present (further apart than in urban settings, located at convenient centres on major routes). In addition, the region is a well known tourist destination and, as such, EVs owned in other regions undertaking long journeys to visit the region will need to be charged in addition to EVs owned locally. As such, it is expected that the number of EVs visiting MSAs in areas such as the South West, would increase in the future in line with the trends in uptake, supporting the need to provide reliable rapid charging infrastructure for future EV owners.

2.4.2 Charging habits

Charging habits were investigated with a particular focus on rapid charging points, which are available in MSAs to provide a fast and convenient service to increase the state of charge (SOC) of batteries during long journeys. According to the National Grid ESO [12] only 5% of charging demand is currently satisfied by using rapid charging points. This figure is likely to be influenced by the limited experience from:

- The small population of EVs on the road at present;
- Possible limits on the availability of rapid chargers in suitable locations (more than 1,300 rapid chargers out of a total of around 14,000 public chargers, as stated in the Road to Zero report [1]); and
- Limited use cases of existing EVs, i.e. relatively low frequency of long-distance journeys in EVs linked to ownership of EVs as a second vehicle.

The Charger Use Study report [13], prepared as part of the UK Power Networks (UKPN) Recharge the Future project, provides a good overview of the behaviour of drivers in relation to different charging methods (home, on-street residential, work, slow/fast public and rapid public charge points). This study draws on data from many other sources, principally:

- My Electric Avenue (MEA) project undertaken by Scottish and Southern Electricity Networks (SSEN) [14];
- Plugged-in Places programme operated by OLEV [15];
- ESB ecars programme operated by ESB in NI and ROI [16];
- Interim outputs from WPD's Electric Nation trial, which was ongoing at the time of publication; and
- Detailed data on usage of the UK's public charging infrastructure purchased from Zap-Map.

In summary, the study found that the profiles of rapid public charging events were broadly consistent between weekdays and weekend days. The profile typically corresponds to a consistent number of charging events occurring through the day between about 10:00 and 20:00. The profiles are shown to align across three different data sources (MEA, ESB and Zap). It should be noted that the Charger Use Study report also states that the 'same pattern is found for rapid public charge points regardless of whether they are located near motorways/A-roads or not'. The representative weighted average profile of daily charging events per hour, based on the Zap data, is presented in Figure 2-11 as part of the discussion about charging demand in section 2.5.

A paper published by Zero Carbon Futures [17] in December 2017 claims to provide a 'methodology to determine the number of rapid chargers needed for electric vehicles in the UK'. This paper considers the capability of cars to receive power and average power delivery, as well as supporting information relevant to this analysis. It includes a reference to a 2015 Rapid Charge Network (RCN) study report "(INEA, 2015)" [Innovation and Networks Executive Agency], which is no longer available. However, some of the details have been reproduced from that report, which was developed under the European-funded project looking at 'Accelerating the introduction of Electric Vehicle Rapid Charging by studying adoption and use along PP axes 13 and 26 [Priority Projects corresponding to defined major road routes] in the UK and Ireland' (project: 2012-EU-13066-S). The project was carried out between January 2013 and December 2015, with a scope that include 'the installation of 74 multi-standard rapid chargers in 64 sites' [18].

Figure 2-9 shows the percentage of daily plug-in events for rapid charging that occurred in each 2-hour period to show diurnal charging behaviour, based on data presented in the 2015 report from the 2012-EU-13066-S project. This profile appears to align with those presented in the Charger Use Study report, with the bulk of the plug-in events occurring between 10:00-20:00, during which period there is a reasonably consistent spread of events. It could be suggested that the rise in the number of events in the morning is attributed to charging before longer trips. The number subsequently persists during the day as drivers make ad hoc stops for breaks during journeys, mealtimes, and during the return portion of a single excursions.

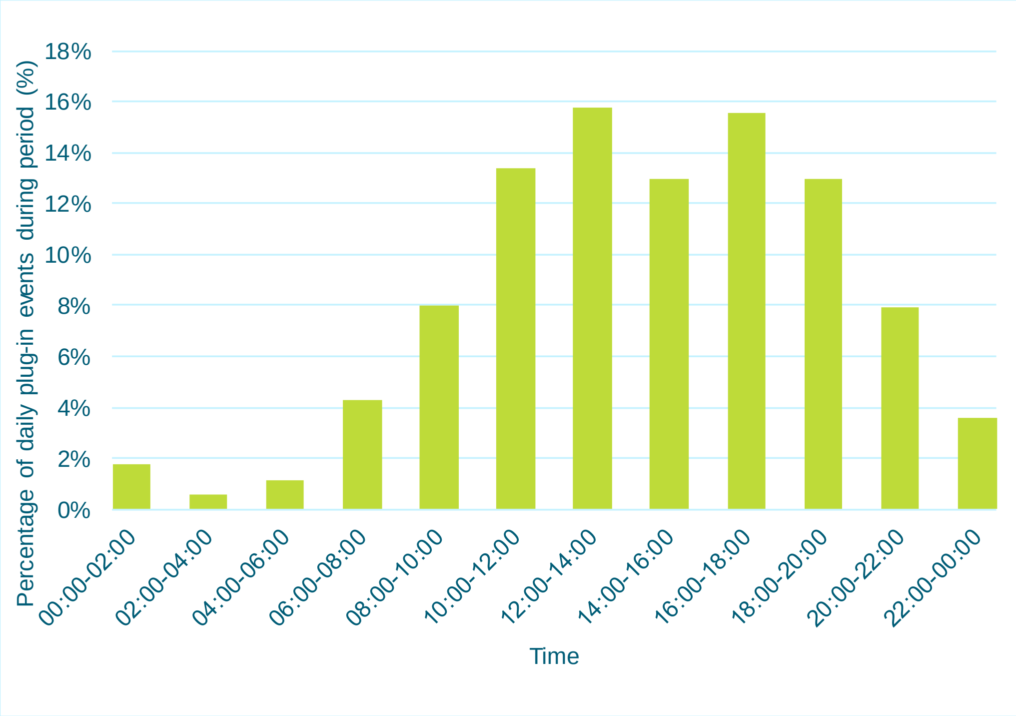


Figure 2-9 Percentage of chargers within day using rapid chargers according to [17]

In addition, whilst the Electric Nation project focused on home charging (and the impact of smart charging on local networks), the interim survey data from the project references in the Charger Use Study report indicated that 'BEV drivers use rapid charge points approximately once every 3 weeks, which is a similar frequency to slow/fast public charging'. This supports the understanding that the majority of charging is done at home.

However, the survey results also indicated that this pattern of behaviour may be changing for some users. Experience to date has been that BEVs are in many cases second cars used for short journeys close to home, primarily charged at home and not used for longer journeys for which a conventional vehicle is used. However, it was found that 'unlike slow/fast charging, charging frequency is found to increase with battery capacity. It is proposed that this is because the BEVs with large batteries, such as the Tesla Model S, are more suitable for long distance motorway driving'. This conclusion indicates that drivers are purchasing EVs with larger capacity batteries in order to use them for long distance journeys with the expectation of using rapid chargers. This reliance on BEVs for longer journeys will be required to achieve the objectives of the Road to Zero report whilst supporting current journey length behaviour.

It is expected that the majority of charging events will continue to take place at home and that most EVs would probably leave a house with a fully charged battery [19]. However, it is anticipated that range anxiety [20] will remain a feature of journey planning for EV drivers, albeit mitigated by larger battery capacities and a greater amount of charging infrastructure. The Charger Use Study report states that 'only one PHEV, the Mitsubishi Outlander, is currently compatible with rapid public charge points, although its small battery means that the actual rate it charges at is considerably lower than 50kW'. In addition, the report states that 'since PHEVs are not dependent on battery power to drive long distances, it is unlikely that any further PHEV models will be released with rapid charge point compatibility'. As such, drivers are expected to rely more heavily on BEVs to complete all journeys that they want to make in future.

It is important to consider what battery level is considered to be low by EV drivers in order to determine how often they would charge their cars. According to the MEA project, most participants in the study declared that they considered an SOC level between 11-30% to be low, which would necessitate charging [21]. However, it was also mentioned in the study that concern over the battery charge level could be reduced with higher availability of rapid charging points.

2.4.3 Average dwell time

The average dwell time at MSAs is 20 minutes, according to the Motorway User Survey [11]. The main aim of rapid charging is to increase the battery SOC in as short a period of time as possible in order to avoid unnecessary disruption to journeys.

Figure 2-10 shows the range of charging durations based on the data from MEA, ESB ecars and Zap-Map considered in the study.

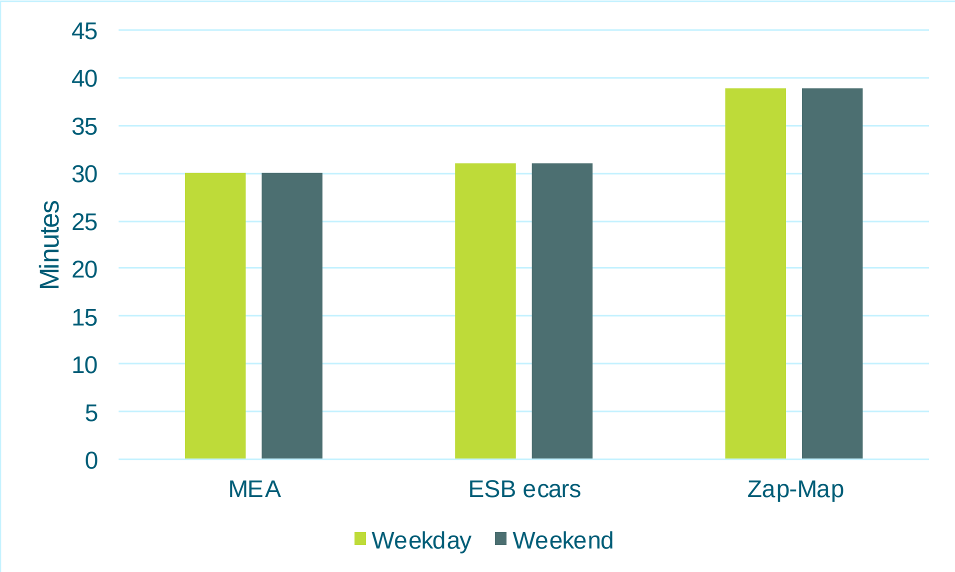


Figure 2-10 Average time of charging using rapid chargers according to [13]

It should be noted that the charging duration is highly dependent on the charge power rating and battery capacity. However, Figure 2-10 shows an average charge time close to 30 minutes, which is consistent with EV manufacturers' specifications for rapid charging time with relatively small battery capacities [22, 23, 24]. In addition, the Charger Use Study report states that 'this is comparable to the 30 minutes that Ecotricity recommends it takes to charge a Nissan Leaf from 0-80%, and so suggests that BEV drivers will not leave their vehicles plugged in longer than necessary. This supports the idea that rapid charging is done as quickly as possible to avoid unnecessary delays to journeys'.

Currently there are several EVs which have large battery capacities and can, therefore, travel long distances on a single charge (in excess of 250 miles). For example, the Tesla S has a battery capacity of 100kWh can travel 379-mile distance on a single charge [25]. The highest capacity rapid charging point currently in use is 150kW, but the trend towards higher capacity charging points is envisaged to support truly rapid charging of EVs with large battery capacities (with charge durations in the region of 10-15 minutes).

In light of reduced charge durations resulting from higher capacity chargers (up to 350kW), it is envisaged that the duration of MSA visits for EV drivers would remain approximately the same in the range 20-30 minutes. As such, further development of rapid charging points at MSA locations would appear to suit existing customer behaviours and dwell times.

2.5 Charging demand/profile

In this section, the power demand characteristics of rapid charging are investigated as charging profiles have a direct influence on the peak capacity required for the CCS. To estimate average and maximum power demand on a rapid charger, attention should be paid to the shape of the daily charging demand profile.

Figure 2-11 presents the weighted average share of rapid charging plug-in events per hour (as a percentage of the daily total), based on data from weekday and weekend profiles presented in the Charger Use Study report [13]. This representative profile is based on data from Zap-Map. It should be noted that a similar trend is observed in the raw data for weekdays and weekend days.

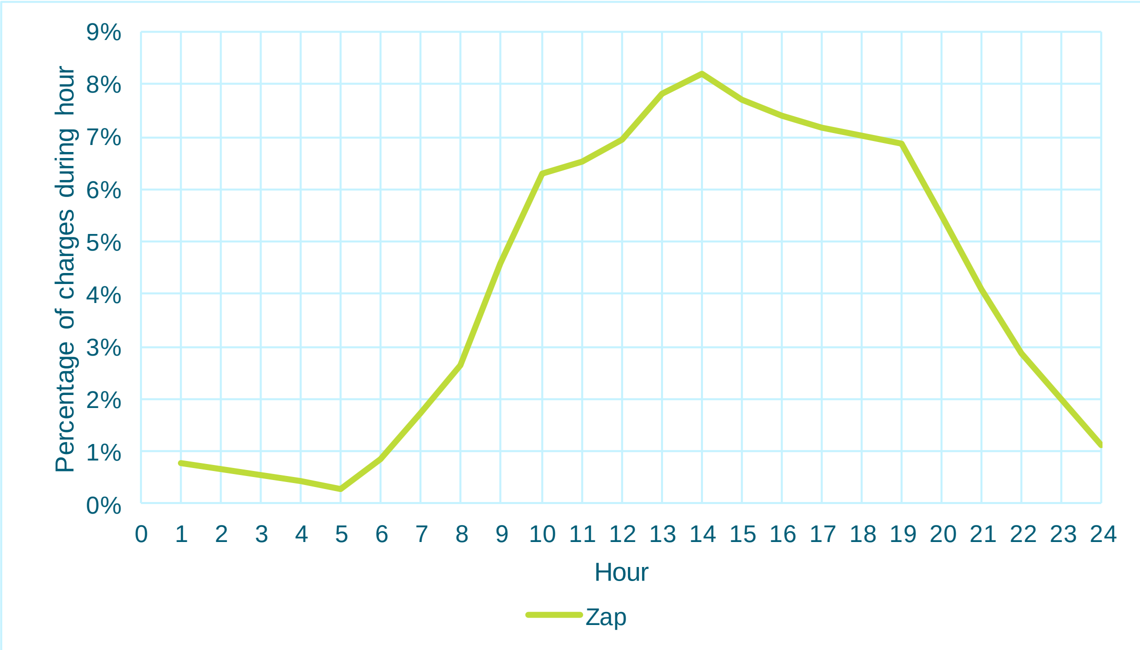


Figure 2-11 Weighted average share of daily charging events per hour ([13])

The profile presented in Figure 2-11 appears to correspond to a standard normal distribution, and align with the profile presented in section 2.4.2 based on data from the Zero Carbon Futures paper [17].

Figure 2-12 below presents the average public charging point power demand profile for a typical week, as presented in the National Grid 2019 FES document [2].

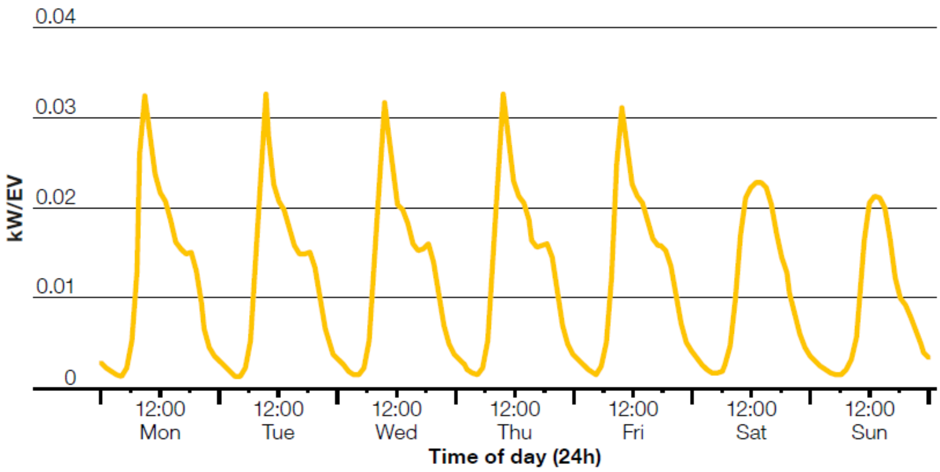


Figure 2-12 Average public charging point power demand profile for a typical week [2]

Figure 2-12 shows that the public charging demand during weekdays is significantly higher than during the weekend, and the weekday profile has an exaggerated morning peak in the 06:00-12:00 period. This morning peak is not present in the weekend day profile, but in both cases the bulk of the public charging occurs during the daytime hours of 06:00-21:00. It should be noted that this profile covers a range of public settings, including those near shopping and workplace areas. It could be that the exaggerated peak on weekday mornings reflects use of public charging close to workplaces. In addition, this may reflect a greater number of professional trips taking place during the week, which may be more likely to require rapid charging than recreational trips due to longer journeys. It should be noted that the charging profile for MSAs in the future could differ from those shown in Figure 2-12 primarily due to changing volumes of traffic during busy times such as bank holidays.

In view of the limitations of the FES public charging demand profile, which covers all public charging locations, it is anticipated that the demand profile for rapid charging will align more closely with the profiles of charging plug-in events taken from the Charger Use Study report. These latter profiles, shown in Figure 2-11, have been developed through consideration of rapid charging in isolation and validated against those presented in the Zero Carbon Futures paper, which were taken from the 2015 Rapid Charge Network Study (RCN) study report from the 2012-EU-13066-S project of rapid charging on defined major routes.

2.6 Network demand

The electricity demand on the network varies continuously throughout each day and according to seasonal variations observed. System operators act to balance the supply and demand of electricity in real time, since it cannot generally be stored (except in limited quantities in batteries). In managing their networks, network operators prepare plans to install new network reinforcement schemes (to support system developments) and to replace existing equipment to meet capacity requirements. These plans are typically developed based on the annual instantaneous peak demand, which means that infrastructure is not fully utilised throughout the year. Consideration of demand profiles, and possible measures to smooth them, may enable infrastructure development (such as the CCS) to be optimised to install lower capacity equipment and achieve greater utilisation at all times.

Figure 2-13 illustrates the mean and peak-day normalised half-hourly demand for the GB system, using data taken from Elexon Portal and retrieved from the ‘Gridwatch’ website [26].

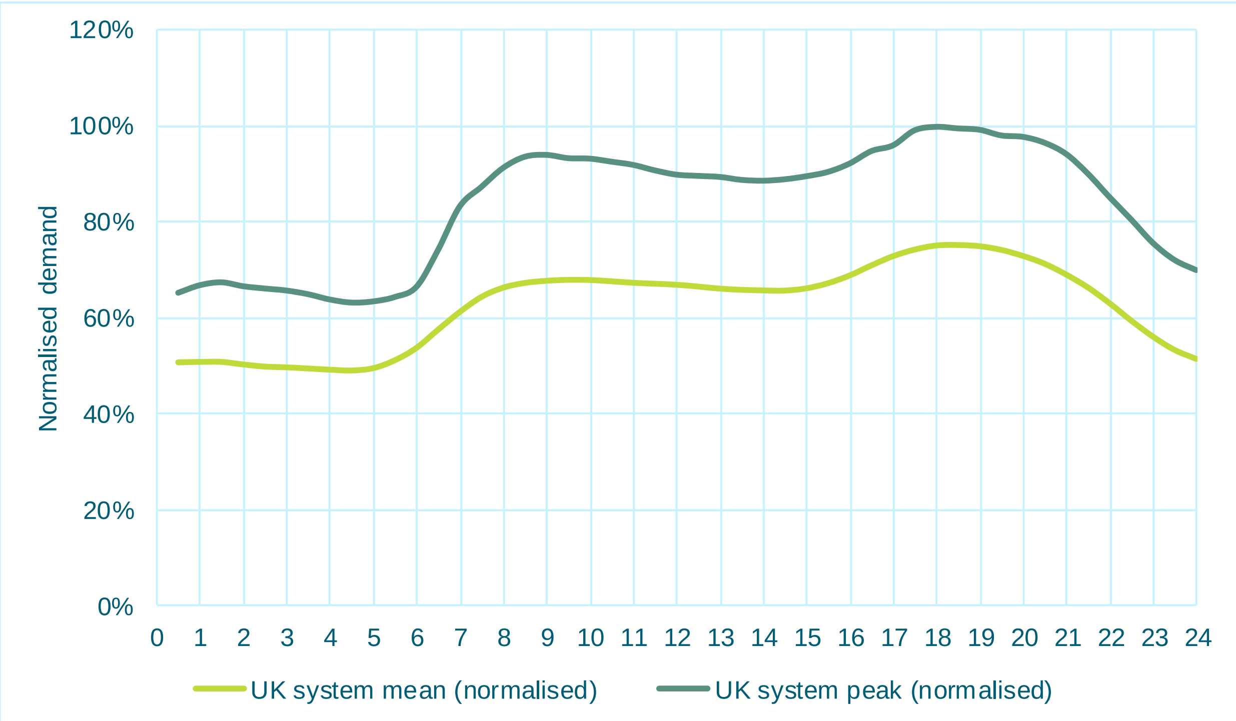


Figure 2-13 UK system demand profile

The profile presented in Figure 2-13 indicates a daily peak for the GB system in the early evening (18:00-19:00), with a relatively flat profile during the day and a slight secondary peak observed in the morning (08:00-09:00).

The total system profile shown above reflects the combination of different types of demand on the system, which have different characteristics. Elexon prepare typical profiles for different groups, categorised as ‘Profile Classes’ (PCs), for use in their settlement calculations for supply companies and generators. Figure 2-14 presents a comparison of the typical profiles for two such PCs: PC1 – domestic unrestricted customers; and PC3 non-domestic unrestricted customers.

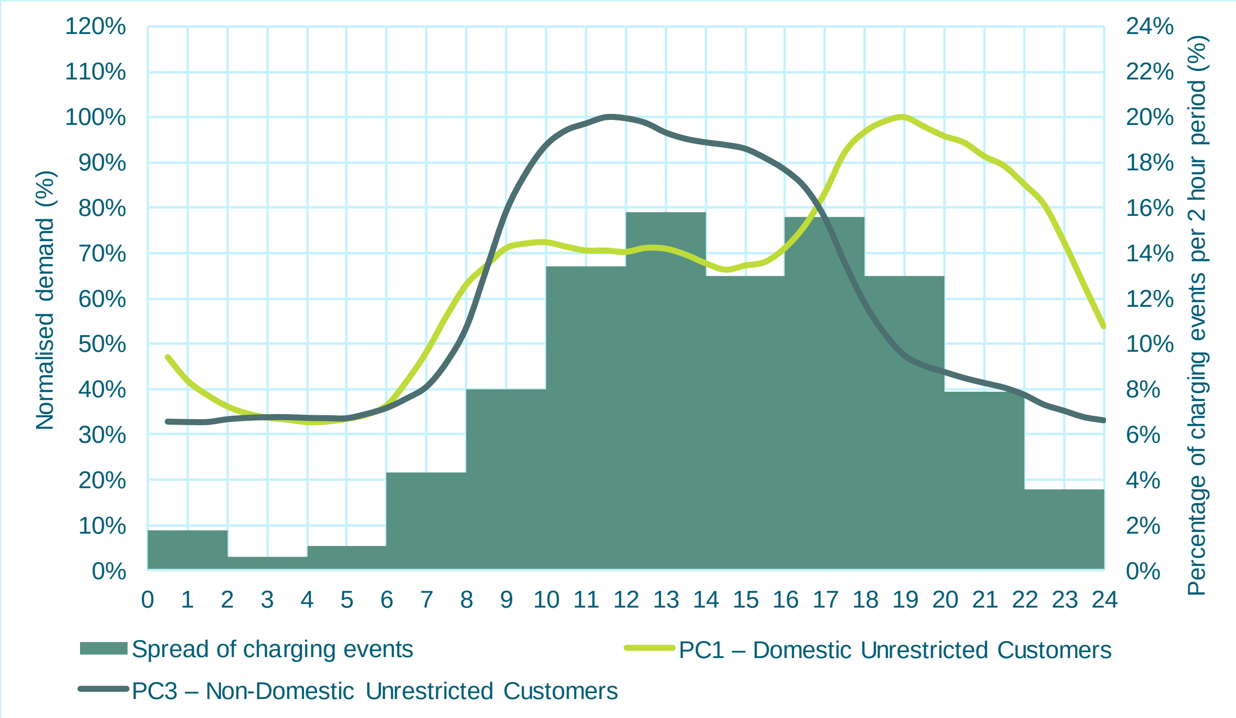


Figure 2-14 Comparison of normalised demand and spread of charging events

Figure 2-14 indicates that the domestic peak demand is typically observed in the early evening (18:00-19:00) and the non-domestic peak demand is typically observed in the middle of the day (11:00-12:00). In addition, the chart shows that the spread of charging events, taken from the research presented in section 2.5, appears to align more closely with the non-domestic profile of a bell-type curve during the day.

As such, if the particular section of network supplied by a primary substation is dominated by domestic consumption rather than non-domestic, then this may provide an opportunity to optimise plans for the development of the network in this area. It should be noted that specific demand management measures may be needed to address constraints that may arise. In particular, there may be a substantial number of EV charging events that coincide with the domestic evening peak period, albeit with the number expected to decline through the evening.

2.7 MSA infrastructure

There are fundamental requirements for rapid EV charging points in order to meet statutory obligations and meet the requirements of local authorities planning rules. In addition to these, there is a requirement for a commercial business case based on accurate costs and benefits for the particular location in question. The latter elements have been considered as part of the 'Site Selection Methodology' document and earlier work.

Whilst it is not appropriate to discuss the other requirements in this document, it is noted that many charging points are currently installed at conventional fuelling stations and MSAs, since these locations enable operators to meet the needs of their customers and other stakeholders.

Fundamentally, in order to implement EV rapid charging there is a requirement to have parking spaces available to be set aside for EVs to use for the duration of their charging. It is generally the case that MSAs have large parking areas for different types of vehicles in order to provide easy access to the other services that they provide. In addition, all MSAs are required to provide access to a conventional fuelling station, and these tend to be relatively large with approximately 18 sets of pumps offering petrol and diesel fuels. Currently, MSAs also have a number of EV charging points, generally in the range of 2 to 6 nos.

In addition, according to the guidance note in [27, 28], there is a requirement for 10% of parking spaces associated with new commercial/residential developments to be equipped with an EV charging point in the short term. This provides an indication of the amount of infrastructure that is expected to be needed in future, in light of the significant projected uptake of EVs discussed in section 2.2. It is likely that the majority of parking spaces at MSAs will be replaced for charging bays in the time horizon up to 2050.

2.8 Hardware

This section looks to build on the material presented in our 2020 EV Strategy [29], which provides an overview of the considerations relating to network planning and provision of connections, including connector types and charging unit capacities. That document covers use of existing network capacity and new infrastructure to support home charging, as well as street side and public charging. It also describes stakeholder engagement plans relating to provision of capacity for EV charging at public locations operated by EV charge point operators, motorway services and other refuelling and service locations. Take Charge is also referenced in the strategy to prove there is a smart solution to meet the OLEV capacity requirements at 33kV (7 MVA on average for each MSA). We believe that the solution developed in this project will be 'essential bearing in mind that electrical plant has a service life of fifty years that all criteria are taken into consideration and that it follows the Committee for Climate Change view of "touch it once till 2050"'.

In order to progress the development of a smart solution to provide the required capacity, we have considered each major element in the typical charging installation and associated distribution network equipment. It is clear that the capacity of the CCS will depend on the number and type of chargers at each individual charging point, as well as the total number of them.

It is well established that EV charging infrastructure introduces an additional load on the network and uncontrolled charging can cause significant issues on the electricity network. Hence, to reduce this risk, an early planning assessment of predicted EV charging demand has been carried out to ensure the suitability of network infrastructure.

2.8.1 Early planning assessment of predicted EV charging demand

The following assessment of EV demand considers the battery capacity and charging durations of EVs . The charging duration is critical to provision of rapid charging with minimal disruption to journeys, and is determined by the power rating of the EV supply equipment (EVSE) and, ultimately, the CCS that provides the supply to each unit.

At present, battery capacity for EVs varies between 35kWh (for small capacity cars, e.g. VW eGolf) and 100kWh (e.g. Tesla Model S/ X), which have longer ranges over 300 miles [25, 30]. In recent years, the evolution of Lithium-ion technologies for EV batteries has accelerated the reduction in EV costs and increases in battery capacity.

The trend of increasing battery capacities (along with increasing uptake of EVs) means that there is a critical need for higher capacity rapid charging technology in the future in order to ensure that drivers can fully charge their EVs in a suitable period of time to avoid disruption to their journeys. The most powerful chargers currently available commercially are the 350kW DC chargers. Table 2-1 outlines the main characteristics of three models of 350kW DC chargers currently on the market.

Table 2-1 Characteristics of three models for 350kW rapid chargers [31, 32, 33]

Feature	Tritium Veefil-PK	ABB Terra HP CE	Efacec HV350
Package	2 x 175kW power cabinets 1 x charging post 2 x charger outputs	2 x 175 kW power cabinets 1 x charging post 2 x charger outputs	2 x 175kW power cabinet 1 x charging post 2 x charger outputs
Input	2 x 480Vac 3ph	2 x 400Vac 3ph	2 x 400Vac 3ph
Efficiency	>98%	>95%	>95%
Output	2 x 950Vdc 350kW	150V-920Vdc 350kW	920Vdc 350kW

Although no EVs are currently capable of fully benefiting from 350kW high power charging rate, the next generation of EVs (for example Porsche Taycan) are likely to take advantage of charging times as low as 20 minutes by using 350kW chargers [34].

2.8.2 Configuration and flexibility of EVSE installation

Presently, EVs have their power input limited by their on-board DC chargers. For example, the Hyundai Kona with a 64 kWh battery has its charging capacity limited to 100kW and it would take 54 minutes for the battery to achieve 80% SOC [35]. Even though the current EVs have limited power input, a 350kW charger offers flexibility in charging arrangements through use of dynamic sharing of the power delivered as shown in Table 2-2. For instance, ABB Terra HP 350kW charger can be connected to charge one vehicle at up to 350kW or two vehicles simultaneously at up to 175kW.

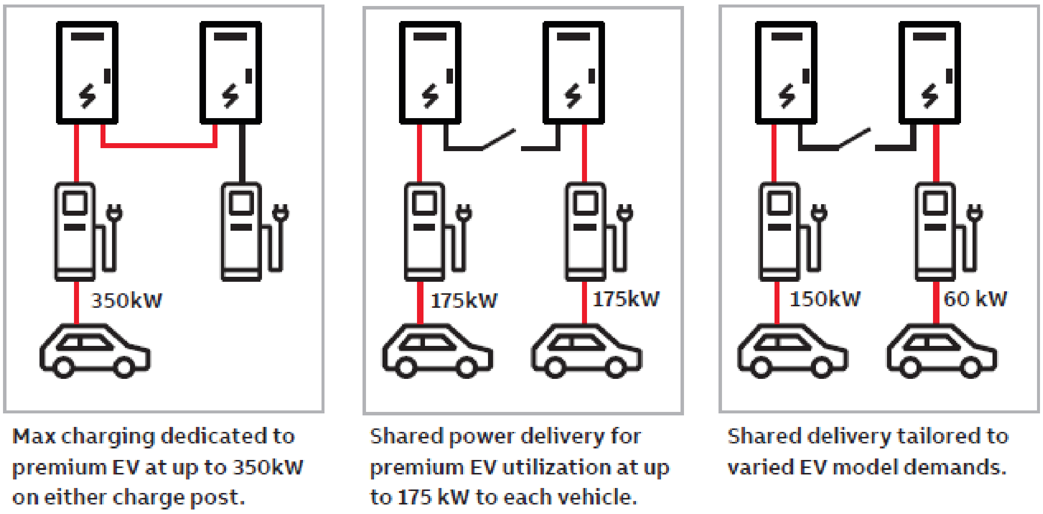


Figure 2-15 Dynamic DC power-sharing capabilities illustrated for ABB Terra HP 350kW charger [31]

This architecture enables higher utilisation of charging installation [31]. It should be noted that 350kW charging technology has already been implemented by the IONITY charging network in the UK.

As presented in Table 2-1, the Tritium Veefil PK charger requires a 480V input supply. Therefore, this charger would require the installation of an isolation transformer (400V/480V) to provide sufficient incoming supply, as presented in Figure 2-16. Isolation transformers also provide galvanic isolation and are used to protect against electric shock and to suppress electrical noise in sensitive devices like EV chargers.

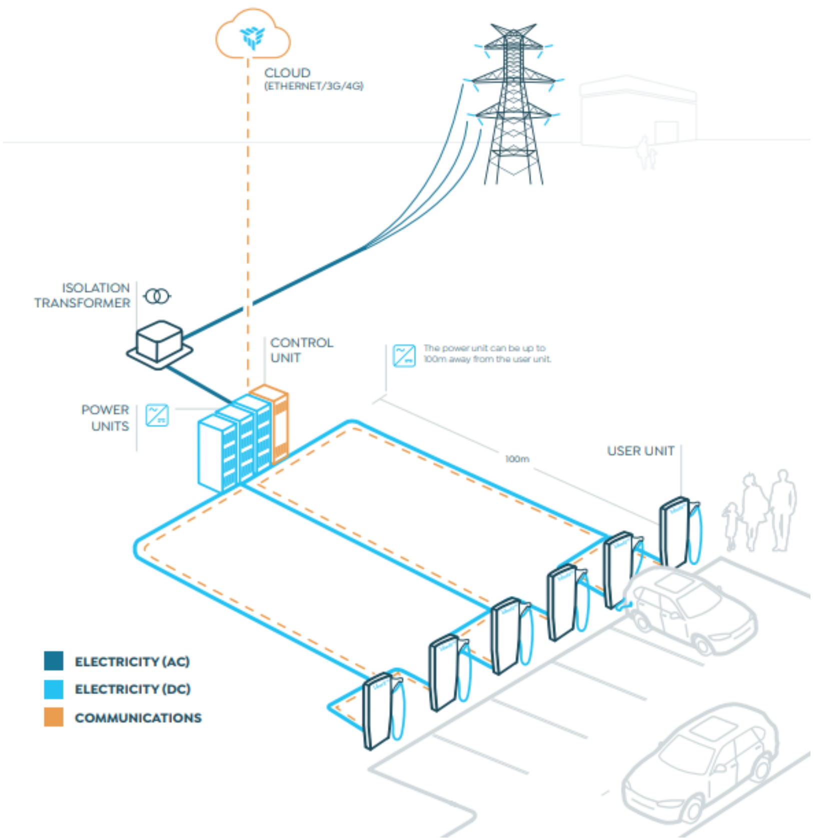


Figure 2-16 Example of system components for installation of Veefil PK 350kW chargers.

Moving forward, the maximum number of charging units connected to the distribution network system depends on the rated capacity of the distribution transformers (11kV/400V). To fully utilise the connection it is desirable to install the greatest possible number of chargers. However, there are also practical considerations that mean that there is a strong preference for using standardised transformer types and sizes to ensure that costs, spares-holdings and maintenance time are minimised. At present, the highest capacity distribution transformer that is typically installed on the 11kV network is 1 MVA (primarily to meet the Class A demand in Engineering Recommendation P2/7). Therefore, the total number of charging units that it is possible to connect without overloading is 2. However, by limiting power input and output to a little under 95% of the peak rating, it is possible to fully utilise the electrical equipment and safely provide 3 chargers. Details of the possible arrangement are shown in Figure 2-17.

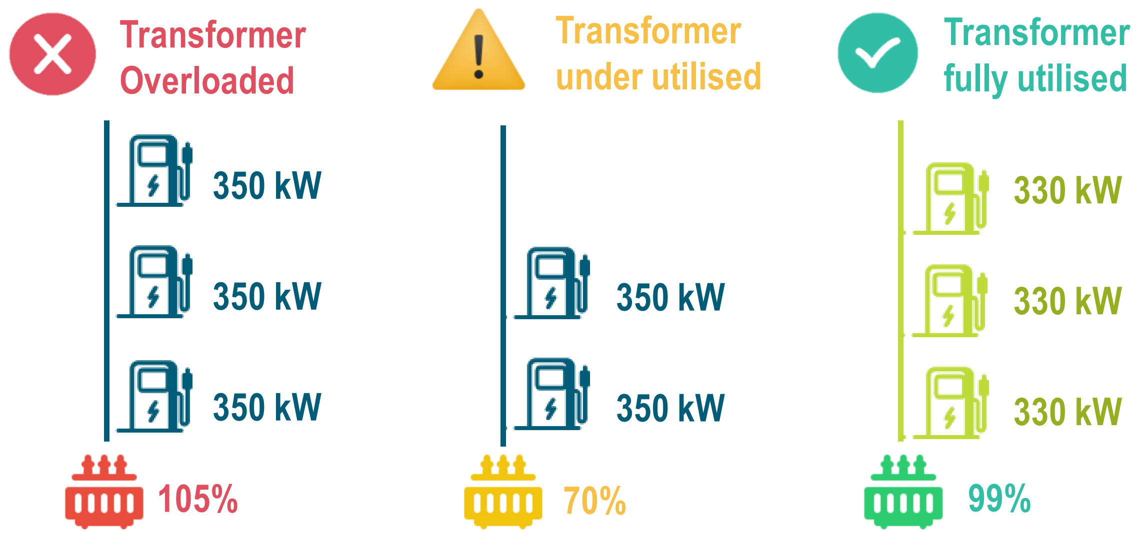


Figure 2-17 Illustration of different EV infrastructure arrangement

The brochure for the Tritium Veefil-PK high power charging system provides details of such a scheme using Dynamic Site Power Management [36].

2.8.3 High voltage supplies

A cluster of rapid chargers would require to have a dedicated connection from the high voltage distribution network. Depending on the size of the dedicated feed, several 3-charger installations could be installed on the LV side of a distribution substation and connected to the 11kV circuit with Ring Main Unit (RMU). The 11kV circuit would be supplied from local BSP via a dedicated primary transformer (33kV/11kV).

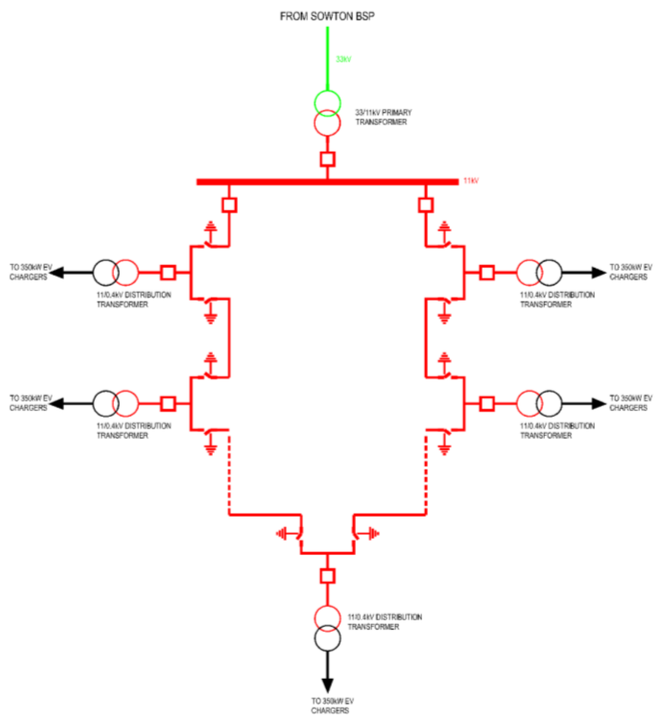


Figure 2-18 Example of network connection diagram for EV charging station

When the charging infrastructure is connected via a single primary transformer, the security of supply standards may not be fulfilled. As a DNO we have to comply with P2/7 Security of Supply Engineering Recommendation and the only option for charging infrastructure to be supplied by a single transformer above 1MW is to gain consent from the customer or obtain the site exemption approved by utility regulatory body - Ofgem. Table 2-2 provides the extract from P2/7 Security of Supply Engineering Recommendation document with minimum demand and time of repair requirements.

Table 2-2 Extract from ENA Engineering Recommendation P2 Issue 7 2019 Table 1

Class of supply	Range of Group Demand	Minimum demand to be met after*	
		First Circuit Outage	Second Circuit Outage
A	Up to 1MW	In repair time: Group Demand	Nil
B	Over 1MW and up to 12MW	(a) Within 3 hours: Group Demand minus 1MW (b) In repair time: Group Demand	Nil
C	Over 12MW and up to 60MW	(a) Within 15 minutes: Smaller of (Group Demand minus 12MW); and 2/3 of Group Demand (b) Within 3 hours: Group Demand	Nil

In order to comply with the Security of Supply standards for supply classes B and C, a second supply would need to be installed to share load during normal operation or to pick up the load during the outage of the normal incoming supply.. An example of the connection arrangement is presented in Figure 5-1 (in Appendix A). In this scenario a second CCS is installed at the site and is interconnected via the 11kV network to provide security of supply.

A second option to satisfy the security of supply standard is to provide a link to the local 11kV network via a normally open point as presented in Figure 5-2 (in Appendix A). During the potential outage of the transformer, a proportion of the charging load could be supplied from the 11kV local network. In this case, a fraction of the charging units would be out of service, which would impact EV charging customers negatively, but some level of supply would be maintained.

2.8.4 Potential combination with solar PV

There appears to be a strong move towards installing EV charging stations combined with solar PV that can provide clean electricity to charge the vehicle batteries. Significant cost reductions in solar PV technologies and improvement in solar efficiency, as well as the focus on EVs, appears to have prompted recent attention in the industry. Solar PV has been integrated into residential buildings extensively, including to support EV charging at home [37]. Usually, the domestic installations also include a home battery, which is charged during sunny hours and discharged as needed to smooth the variable output from the solar PV.

In the case of rapid charging infrastructure, the American vehicle manufacturer Tesla uses solar panels at their supercharging stations to offset energy use. Solar panels are installed in canopies above charging bays and, hence, provide shade and shelter against rain [38]. In the UK, Gridserve's EV charging station aims to supply the majority of power from roof-mounted solar panels, along with a separate ground-mounted solar farm and integrated battery energy storage system (BESS) [39].

However, to supply rapid charging points with a rated output of 350kW, roof-mounted solar panels would not be sufficient to support a reasonable fraction of the charging load. For example, a typical solar PV module (1.68m^2 panel) has a rating 400W [40]. To charge a single 100kWh battery, such as those in the Tesla X model, from 20% to 80% SOC using a 100kW rapid charger would require more than 300 panels to charge the battery in 30 minutes on a sunny afternoon. 300 solar panels correspond to 506 m^2 of solar PV surface (assuming 1.68m^2 per one panel), which could be compared to 44 standard parking spaces on the carpark (4.8 x 2.4m). This represents a significant investment, including in civil works associated with canopies over car parking spaces. In addition, weather conditions should also be considered. The full output from the panels will not be achieved at all times in view of the seasonal variations in the UK and, therefore, it is not deemed to be viable to combine solar PV technology with EV rapid charging at MSA locations.

2.8.5 Potential combination with battery storage

With regard to the possible combination of EV rapid charging with battery storage technologies, it is theoretically possible for batteries to be used to smooth the demand profile throughout the day or between seasons of the year. In either case, the ability to smooth the demand depends on the nature of the demand profile. As seen in section 2.5, the diurnal profile of EV rapid charging demand corresponds to a standard normal distribution covering most of the daytime hours.

In addition, the power demand for EV rapid charging is significant compared with the capacity of available battery energy storage solutions. An example of a large grid-scale battery connected to the distribution network is in Leighton Buzzard in Bedfordshire. The battery was installed by UKPN as part of its Smarter Network Storage project in 2014. The battery has a capacity of 6MW/10MWh, and represented a considerable capital investment. Based on the capacity of this battery, it could supply power to 17 nos. 350kW rapid chargers at a time, for a duration of 100 minutes. Installing battery storage solution of this magnitude would take considerable investment, and it is unclear whether sufficient benefits could be demonstrated to make a viable business case.

As such, it is deemed that there is no realistic prospect of storing sufficient energy to smooth the diurnal or seasonal profiles for EV rapid charging demand.

2.9 Summary

Table 2-3 Summary of the key factors in the assessment

Category of factors	Summary
EV uptake	Projections from the National Grid 2019 FES suggest that the uptake of EVs in 2050 would be between 88-98% of around 40m vehicles, compared with approximately 0.5% of 36m vehicles on the road in 2019. The figures for 2050 correspond to between 35.8-38.0m vehicles in total for the different scenarios.
Traffic	Traffic, or total journey length, is projected to increase in the South West and across England and Wales. The average CAGR over the 2015-2050 period is 1.25%, which corresponds to growth from 15.6 bvm in the South West region in 2015 to 24.1 bvm in 2050. This is deemed to be a reasonable forecast, which results in significant growth over 30 years, but avoids unmitigated growth in the period of greater uncertainty towards the end of analysis.
Customer behaviour	**Number of customers:** Annual footfall for MSAs across the UK varies between 1.0 and 5.7 million, based on data provided by Moto. In addition, the Motorway User Survey indicates that only 2% of survey participants declared that they visit MSAs to refuel or charge their vehicles. EV ownership in the South West region is expected to be broadly in line with that in GB as a whole. In addition, the region is a well known tourist destination and, as such, EVs owned in other regions undertaking long journeys to visit the region will need to be charged in addition to EVs owned locally. As such, it is expected that the number of EVs visiting MSAs would increase in the future in line with the trends in uptake, supporting the need to provide reliable rapid charging infrastructure for future EV owners. **Charging habits:** according to National Grid, 5% of charging demand is currently satisfied by rapid charging points. According to both the UKPN Charger Use Study report and the Zero Carbon Futures paper, the profile for EV rapid charging typically corresponds to a consistent number of charging events occurring through the day between about 10:00 and 20:00. This profile is consistent between weekdays and weekend days. The UKPN Charger Use Study report also indicates that charging habits are being observed that indicate greater reliance on BEVs with larger battery capacities for longer journeys. **Average dwell time:** At the moment, the average dwell time at MSAs is 20 minutes, according to Motorway User Survey [11]. According to the UKPN Charger Use Study report, 'plug-in durations at 50 kW rapid public charge points are found to be on average 35-40 minutes'. However, the trend towards higher capacity charging points (up to 350kW) is envisaged to support truly rapid charging of EVs with large battery capacities (with charge durations in the region of 10-15 minutes).

Category of factors	Summary
Charging demand/profile	The profile of plug-in events for rapid charging (with the bulk of events occurring evenly between 10:00-20:00) is deemed to provide a better representation of the power demand profile than the FES public charging demand profile, which covers all public charging locations.
Network demand	With regard to diurnal profiles, a daily peak demand for the GB system is observed in the early evening (18:00-19:00), with a relatively flat profile during the day and a slight secondary peak observed in the morning (08:00-09:00). Furthermore, typical profiles prepared by Elexon for different customer categories, indicate that the domestic peak demand is typically observed in the early evening (18:00-19:00) and the non-domestic peak demand is typically observed in the middle of the day (11:00-12:00). The spread of charging events appears to align more closely with the non-domestic profile of a bell-type curve during the day. As such, if the particular section of network supplied by a primary substation is dominated by domestic consumption rather than non-domestic, then this may provide an opportunity to optimise plans for the development of the network in this area.
MSA infrastructure	Many charging points are currently installed at conventional fuelling stations and MSAs, since these locations enable operators to meet the needs of their customers and other stakeholders. Fundamentally, in order to implement EV rapid charging there is a requirement to have parking spaces available to be set aside for EVs to use for the duration of their charging. This is the case at MSAs. In addition, for commercial/residential new developments, building regulations have been updated such that 10% of parking spaces must be provided with an Electric Vehicle charge points. This provides an indication of the amount of infrastructure that is expected to be needed in future, in light of the significant projected uptake of EVs. It is likely that the majority of parking spaces at MSAs will be replaced for charging bays in the time horizon up to 2050.

Hardware	**Early planning assessment of predicted EV charging demand:** At present, battery capacity for EVs varies between 35kWh (for small capacity cars, e.g. VW eGolf) and 100kWh (e.g. Tesla Model S/ X), which have longer ranges over 300 miles. To charge such large batteries, the most powerful chargers currently available commercially are 350kW DC chargers. Specifications for such units from three manufacturers have been reviewed as part of the project. Although no EVs are currently capable of fully benefiting from the 350kW high power charging rate, the next generation of EVs may take advantage of charging times as low as 10 minutes. **Configuration and flexibility of EVSE installation:** Presently, EVs have their power input limited by their on-board DC charger. However, a 350kW charger offers flexibility in charging arrangements through use of dynamic sharing of the power delivered, such that they can be connected to charge one vehicle at up to 350kW or two vehicles simultaneously at up to 175kW. At present, the highest capacity standard distribution transformer that is widely available is 1 MVA. Therefore, the total number of charging units that it is possible to connect without overloading is 2. However, by limiting power input and output to a little under 95% of the peak rating (330kW), it is possible to fully utilise the electrical equipment and safely provide 3 chargers. **High voltage supplies:** A cluster of rapid chargers would require to have a dedicated connection from the high voltage distribution network. Depending on the size of the dedicated feed, several 3-charger installations could be installed on the side and connected via 11kV circuit with Ring Main Units (RMUs). The 11kV circuit would be supplied from local BSP via a dedicated primary transformer (33kV/11kV). When the charging infrastructure is connected via a single primary transformer, the security of supply standards may not be fulfilled, but other options should be considered. **Potential combination with solar PV:** There appears to be a strong move towards installing EV charging stations combined with solar PV that can provide clean electricity to charge the vehicle batteries. However, to supply rapid charging points with a rated output of 350kW, roof-mounted solar panels would not be sufficient to support a reasonable fraction of the charging load. For example, to charge a single 100kWh battery from 20% to 80% SOC using a 100kW rapid charger would require more than 300 panels to charge the battery in 30 minutes on a sunny afternoon. As such, it is not deemed to be viable to combine solar PV technology with EV rapid charging at MSA locations. **Potential combination with battery storage:** With regard to the possible combination of EV rapid charging with battery storage technologies, it is theoretically possible for batteries to be used to smooth the demand profile throughout the day or between seasons of

Category of factors	Summary
	the year. The diurnal profile of EV rapid charging demand corresponds to a standard normal distribution covering most of the daytime hours. In addition, the power demand for EV rapid charging is significant compared with the capacity of available battery energy storage solutions. The largest grid-scale battery in the UK has a capacity of 6MW/10MWh, and represented a considerable capital investment. Based on the capacity of this battery, it could supply power to 17 nos. 350kW rapid chargers at a time, for a duration of 100 minutes. As such, it is deemed that there is no realistic prospect of storing sufficient energy to smooth the diurnal or seasonal profiles for EV rapid charging demand.

3 Assessment for Exeter MSA

3.1 Overview

This section presents the supporting analysis as well as the capacity assessment for the EV rapid charging system to be supplied via the CCS and installed at Exeter MSA.

Section 3.2 presents the analysis of the available data for the factors identified in the discussion of the approach to the assessment in section 2. The range of factors comprises:

- EV uptake as a proportion of vehicles on the road;
- Traffic (historic count of vehicle flow past Exeter MSA; and regional and national projections of total vehicle journey miles);
- Customer behaviour (vehicle turn-ins at Exeter MSA; dwell time of vehicles stopped; proportion of vehicles that stop to refuel);
- Charging demand/profile (comparison of approximate EV rapid charging demand profile with Exeter MSA demand to assess level of complementarity);
- Network demand (comparison of approximate EV rapid charging demand profile with local network demand profile to assess level of complementarity);
- MSA infrastructure (numbers of existing conventional fuel pumps, EV fast charging units and car parking spaces); and
- Hardware (EV rapid charging units, 33/11kV transformer sizes, and potential for sharing of electrical equipment between EV rapid charging and solar PV and/or battery storage technologies).

Section 3.3 presents the capacity assessment for the CCS, comprising a summary table of the assumptions and presentation of the assessment itself. The assessment uses two approaches to apply factors representing the projected increases in the number of vehicles on the road, future EV uptake and charging behaviour to:

1. The existing charging infrastructure; and
2. The number of conventional fuel filling pumps.

Figure 3-1 presents a step-by-step summary of the two assessment approaches.

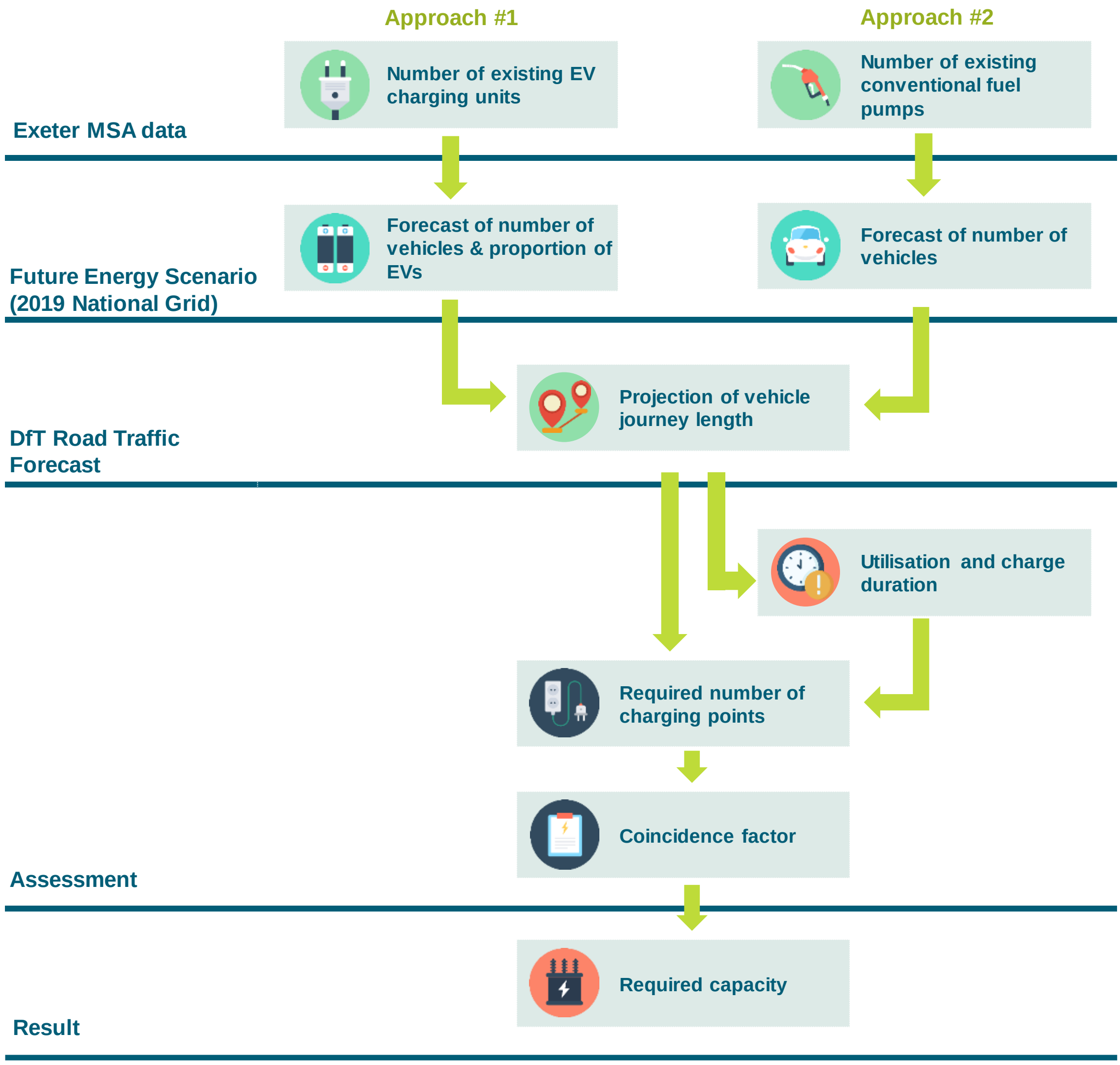


Figure 3-1 Approaches to assessment

3.2 Analysis

3.2.1 EV uptake

As stated in section 2.2, based on the assumptions from National Grid's 2019 FES document the uptake of EVs is assumed to increase from 0.5% of the 38.2 million vehicles in 2019 to 88.3% of the 41.0 million vehicles in 2050. This corresponds to the 'steady progression' scenario, which represents the most conservative projection for the proportion of EVs. This updated national projection was shown to be broadly consistent with the assumptions that were adopted in our DFES document for the South West region, across the range of scenarios.

According to the National Grid projection, the number of vehicles on the road is assumed to increase by 7.5% over the 2019-2050 period. The proportion of EVs is assumed to increase by more than 17,200% over the same period due to the low starting level and ambitious targets for electrification of transport, which is expected to be a key component of the plan for decarbonisation of the UK economy.

In this analysis it is assumed that the growth rates associated with these national projections are applicable to the number of vehicles travelling in the vicinity of Exeter MSA. The assumptions relating to the traffic and customer behaviour relating to EV charging are described in sections 3.2.2 and 3.2.3, respectively.

3.2.2 Traffic

As shown in section 2.3, journeys on motorways and principal A roads in the South West region are forecast to increase from 15.6 bvm in 2015 to 24.1 bvm in 2050, according to the DfT Road Traffic Forecasts 2018 (scenario 7 – shift to ZEVs). This corresponds to an average CAGR of 1.25%, and an estimated 16.4 bvm in 2019.

In addition, DfT traffic count data for manual count point 16023 (M5 J29-30 – immediately adjacent to Exeter MSA) [41] have been consulted. This annual average daily flow data presents a combination of actual count data (taken to represent a typical day) and estimated count data for traffic travelling in each direction. The data is recorded for each year in the period 2000-2018. Figure 3-2 presents the annual average daily flow of traffic on the M5 in either direction past the Exeter MSA.

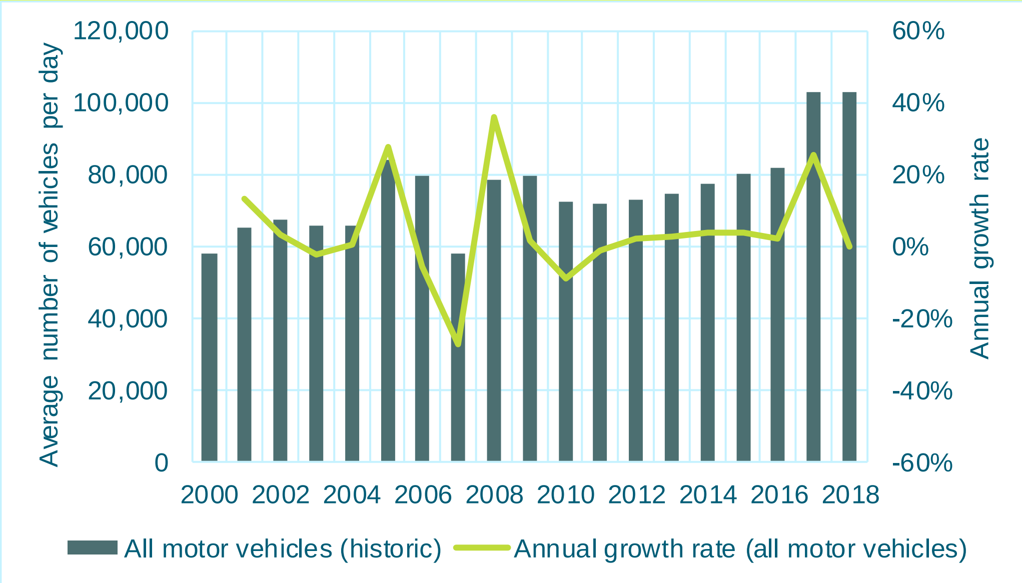


Figure 3-2 Annual average daily flow through M5 J29-30 (total of N- and S-bound traffic)

Figure 3-2 shows an overall trend of modest growth in traffic flow past the Exeter MSA. It should be noted that actual count data are presented for the following years: 2000-2001, 2005-2008, 2010, 2012 and 2017. The increase from 57,739 vehicles in a typical day in 2000 to 102,886 in 2018 corresponds to a CAGR of 3.26%. This is higher than the projected CAGR of 1.25% for the 2015-2050 period for scenario 7 in the DfT road traffic forecasts.

The lower CAGR figure of 1.25%, taken from the DfT traffic forecast, is used in the subsequent analysis to represent future growth at a more modest level than that observed since 2000. This corresponds to an increase of approximately 45% in traffic over the 30 year period to 2050. As such, an increase of 45% is applied to the existing refuelling capacity to account for the increased energy consumption for longer journeys.

As such, the estimated average daily traffic flow in the 2019 reference year for this analysis is 104,000, which corresponds to 38.0 million vehicles in the year.

In conjunction with the above data for traffic in the South West region generally and travelling on the M5 past Exeter MSA, further data are needed to support assumptions about the numbers of vehicles that turn-in to Exeter MSA and, ultimately, engage in rapid charging of an EV. Detailed data for anonymised vehicle visits, provided by Moto, are presented in section 3.2.3 to support this further analysis.

3.2.3 Customer behaviour

Vehicle turn-in data for Exeter MSA have been provided by Moto for the 2019 calendar year, which is considered as the base year for this analysis. Where necessary for comparison other figures have been adjusted to provide estimated equivalent figures for 2019 by application of the appropriate CAGR.

The data provided by Moto for turn-ins to Exeter MSA comprises detailed anonymised automatic number plate recognition (ANPR) data showing matched vehicle entry and exit timestamps for each individual visit. The data provided corresponded to a total of 1.68 million vehicle turn-ins during 2019, compared with annual footfall of 4.2 million visitors in 2018 based on data provided by Moto. The vehicles are categorised as 'no permit', 'guest', 'payment', 'visitor', 'account holder', 'staff', 'multivisit', 'coach', 'misread'.

Based on the data provided by Moto, along with the traffic flow of 38.0 million vehicles estimated from the DfT count data in section 3.2.2, it is calculated that approximately 4.4% of vehicles that travelled past Exeter MSA in 2019 turned in to the service station.

Figure 3-3 presents the breakdown of the total number of vehicles that arrived at Exeter MSA during 2019 by vehicle type category, based on anonymised detailed ANPR data provided by Moto.

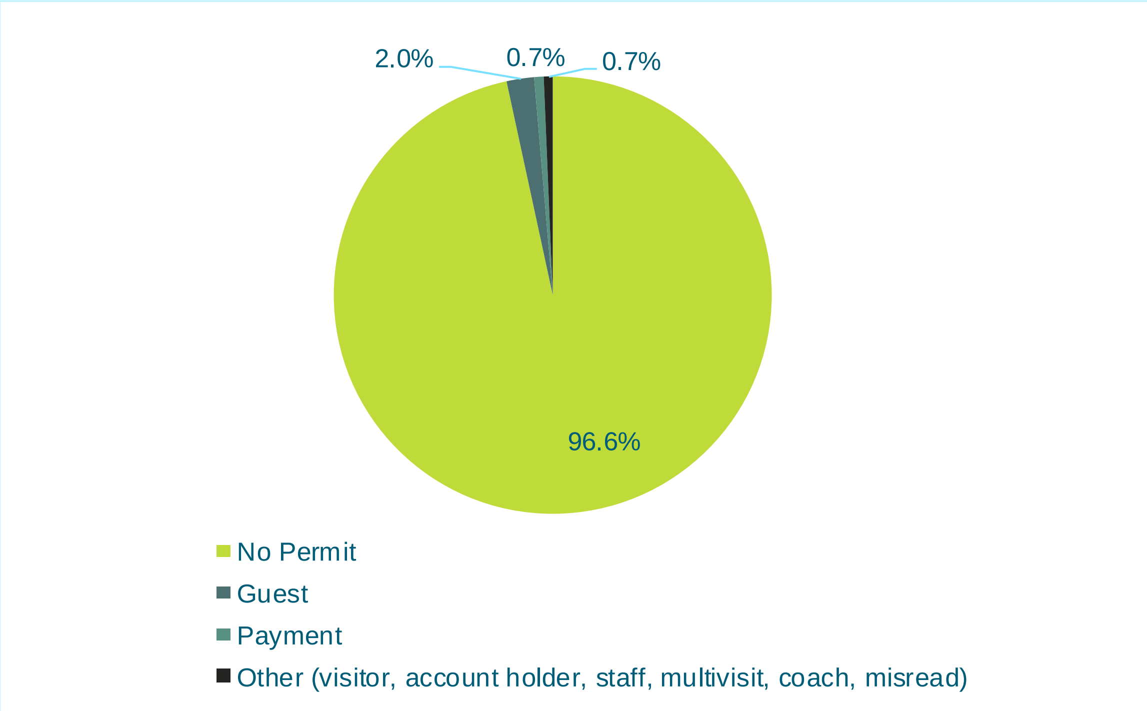


Figure 3-3 Moto 2019 breakdown of Exeter MSA arrivals by vehicle type, based on anonymised detailed ANPR data

Figure 3-3 shows that a significant majority (96.6%) of the vehicles turning-in were those with no permit, and thus eligible for up to 2 hours of free parking.

Figure 3-4 presents the total number of daily turn-ins and average number of turn-ins per week for Exeter MSA in 2019, based on the data provided by Moto. It also highlights the number of turn-ins on public holidays during the year.

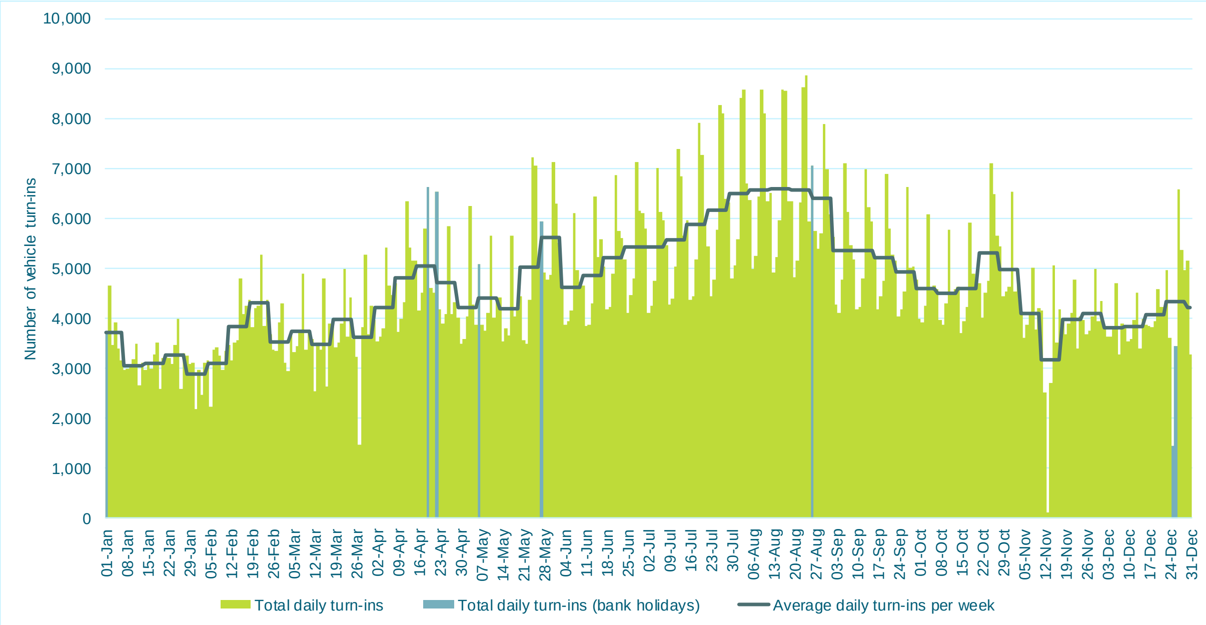


Figure 3-4 Moto 2019 daily turn-in data

Figure 3-4 shows a strong correlation between the number of turn-ins and the public holiday and school holiday periods. This indicates that the Exeter MSA principally serves leisure travel to and from the South West region. In addition, Exeter is located in mid-Devon near to the end of the M5 motorway. The A30 and A38 provide routes from M5 junction 31 (south of Exeter) to Cornwall and other parts of Devon to the west. Junction 29 of the M5 joins to the A30 eastbound, and in turn provides routes to Somerset to the north east and Dorset along the coast to the east via the A303 and A35, respectively.

To provide an indication, Figure 3-5 illustrates the limit of 100 miles range ("as the crow flies") from Exeter.

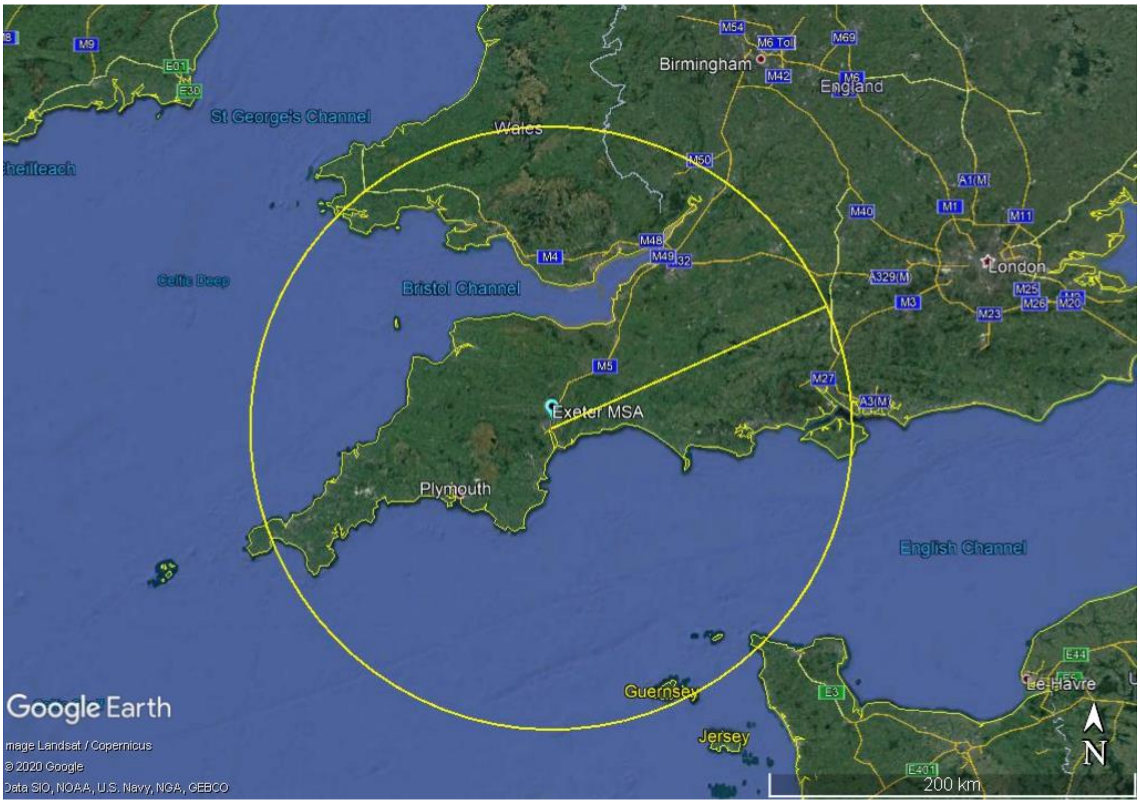


Figure 3-5 Illustration of 100 miles range from Exeter

Figure 3-5 shows that a range of approximately 100 miles from Exeter will enable travellers to complete a one-way journey to Penzance near the western point of Cornwall, to Gloucester, Swindon in Wiltshire, Winchester or Southampton in Hampshire.

The following figures have been prepared from the assessment of the detailed anonymised ANPR data provided by Moto for the Exeter MSA site. Figure 3-6 presents a comparison of the average number of turn-ins per hour on weekday and weekend days.

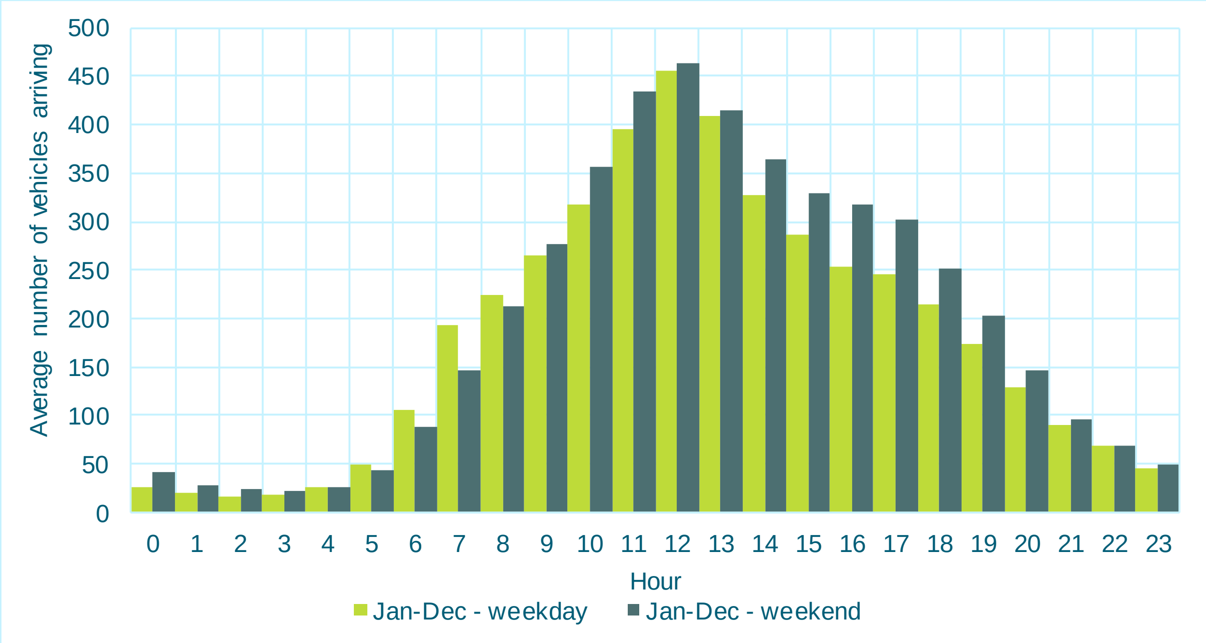


Figure 3-6 Exeter MSA average hourly turn-ins for weekday and weekend days ('no permit' category)

Figure 3-7 presents a comparison of the number of turn ins per hour on the peak day and the yearly average for each hour.

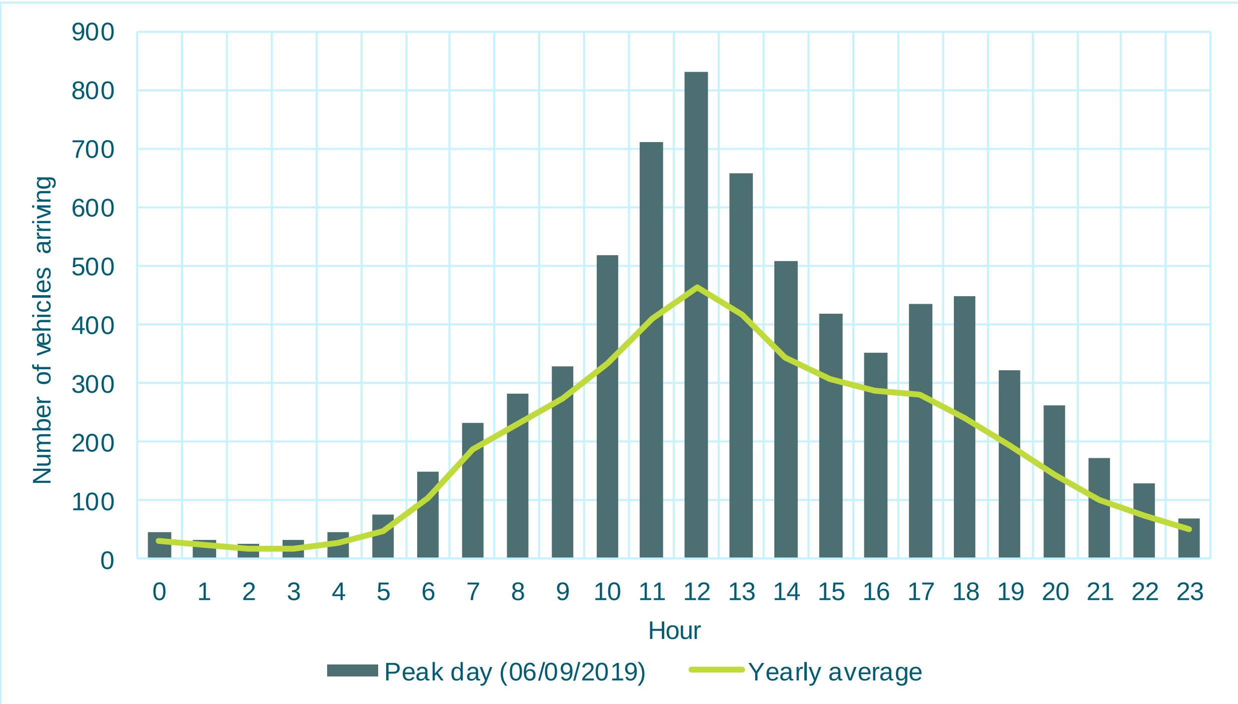


Figure 3-7 Exeter MSA hourly turn-ins on the peak day and yearly average (all categories)

Figure 3-8 presents the average number of turn-ins and corresponding average dwell times for vehicles arriving in each hour.

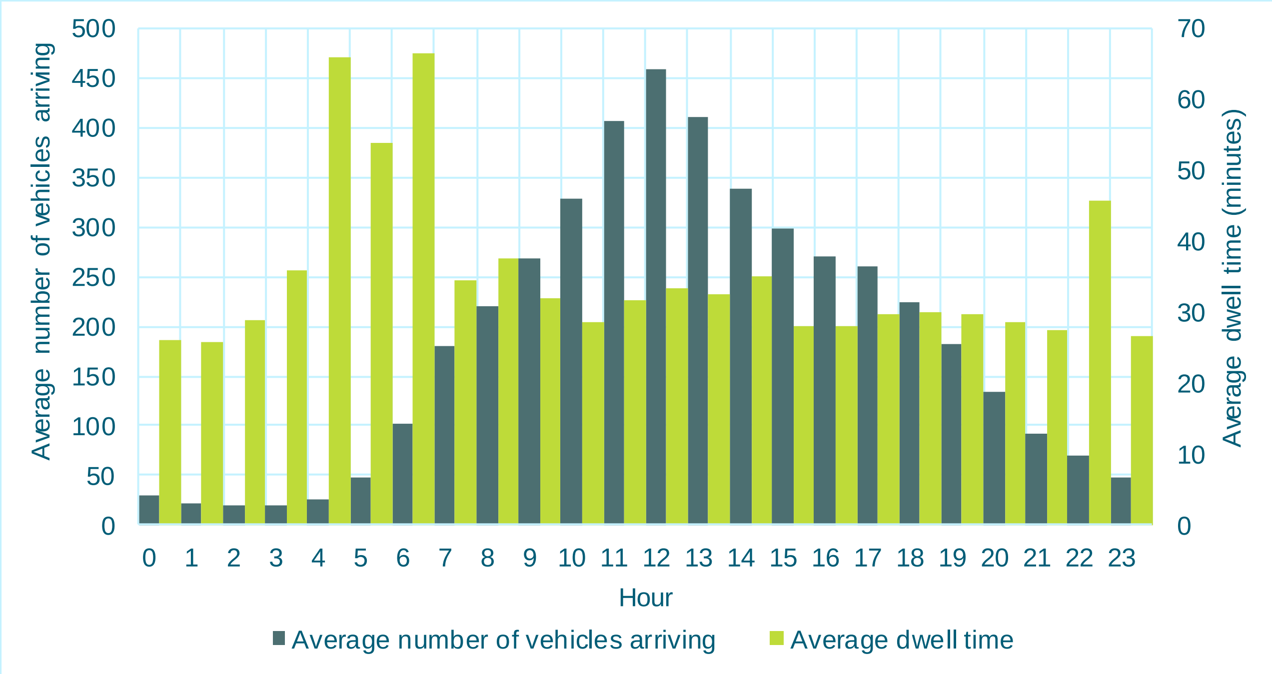


Figure 3-8 Exeter MSA average hourly turn-ins and hourly average dwell times for vehicles arriving ('no permit' category)

Based on the above figures from the detailed anonymised ANPR data for turn-ins at Exeter MSA in 2019, the following observations are made:

- Figure 3-6 shows that the profiles for the average number of turn-ins per hour are broadly the same for weekday and weekend days. Weekend days have a marginally higher average number of turn-ins per hour in all hours except 05:00-09:00. On both weekday and weekend days, the peak number of turn-ins per hour is observed during the 12:00-13:00 period;
- Figure 3-7 illustrates that the 'load factor' for turn-ins is 23%, i.e. the average hourly number is 23% of the peak hourly number of turn-ins, which corresponds to a relatively sharp drop off in the number of visits either side of the lunchtime peak;
- Figure 3-8 shows that average dwell time for 'no permit' category vehicles is well below the 2 hours of free car parking. The average dwell time for vehicles arriving at any time throughout the year is 31.5 minutes. It can be seen that the modest number of cars arriving between 04:00-07:00 and 22:00-23:00 appear to have a longer average dwell time in the range of 45-65 minutes. The average dwell time is consistent with the amount of time required to charge an EV battery to 80% using a rapid charger at present. As a result of this, it is assumed that each EV charging point is occupied for 40 minutes per charging event, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles.

In addition to the turn-in data provided by Moto, they also shared an information pack from February 2017 [42], which provides an overview of its operating model, locations, brands and assessment of behaviour and drivers based on current market segmentation and key user groups (KUGs). This document provides the following statistics:

- Estimated annual footfall for Exeter MSA of 4.20 million visitors (assumed to relate to 2016). Based on application of the CAGR of 1.25%, this corresponds to a footfall of 4.36 million visitors in 2019;
- Refuelling the vehicle is a driver of guest visits for 35% of guests, compared with other key drivers such as using the toilet (72%), taking a break from driving (55%), eating/drinking in a café/restaurant (46%), buying food to eat on-the-go (37%) and buying a drink to have on-the-go (35%). These survey responses are illustrated in Figure 3-9.

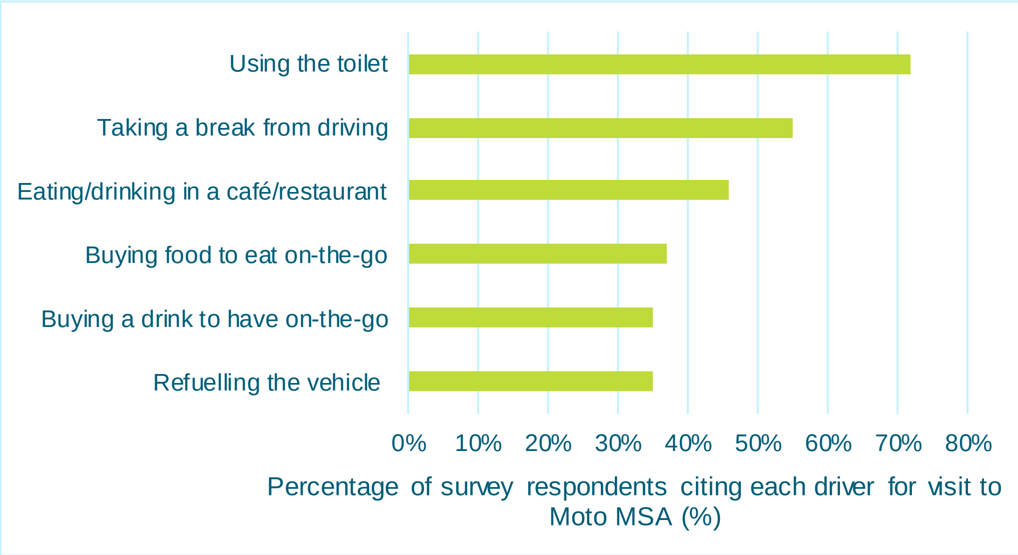


Figure 3-9 Drivers for guest visits to Moto MSAs

Based on a total number of 1.68m vehicle turn-ins in 2019, the average number of passengers per vehicle is calculated to be 2.59. Furthermore, taking the assumption of 35% of vehicles wishing to refuel, the number of vehicles that stopped to refuel in 2019 is estimated to be 0.59 million vehicles (an average of 1,600 per day).

The independent watchdog for transport users, Transport Focus, published a Motorway Services User Survey 2019 document and accompanying research agency report [43] in July 2019. This research agency report presents research of users of all MSAs in England, and states that the median journey characteristics from its sample are as follows:

- Time on road prior to stop: 90 minutes;
- Dwell time at service station: 20 minutes; and
- Total journey time (excluding MSA visit): 210 minutes.

In addition, the transport agency report states that only 2% of respondents said that their reason for visiting was ‘vehicle needed fuel, electric charge, or something else’. This appears to be significantly lower than the percentage recorded in the Moto information pack provided. The precise reasons for the difference are unclear, however, the results of such surveys are likely to have been impacted by the: formulation of survey questions; and locations at which surveys were carried out (MSAs selected and locations of surveyors within MSA sites).

The figure from the transport agency report of 2% of respondents visiting MSAs to refuel or recharge appears to be consistent with the finding that 78% of respondents felt that the cost of fuel at motorway services was less than 3 on a scale of 1 to 5 (where 1 is unreasonable and 5 is reasonable). With regard to current provision for electric vehicle charging, the agency report states that of the 1% of visitors who engaged in charging 58% felt that the number of charging bays available was ‘good’ or ‘very good’, 81% felt that the charging speed was ‘good’ or ‘very good’ and 79% felt that the value for money of charging was ‘good’ or ‘very good’.

Taking the revised assumption that 1% of vehicles engaged in charging, the number of vehicles that stopped to charge in 2019 is estimated to be 16,800 vehicles (an average of 46 vehicles per day). These figures have not been used directly in the assessment of the required capacity. However, they are used to contribute to the discussion of validation of the capacity requirements in section 3.3.5.

3.2.4 Charging demand/profile

Initial discussions with Ecotricity have revealed that existing charging patterns for EVs will not be reflective of future rapid charging. This is because most EV users charge their vehicles at home before embarking on a journey and hence don’t use public chargers on the motorway network very frequently. In addition, behaviour of users at MSAs may change as rapid charging will allow them to charge their vehicles in a fraction of the time compared with standard chargers. This could mean that users are more inclined to charge their vehicles whilst they use the facilities at MSAs.

In view of the above, a cautious approach has been adopted for consideration of rapid charging profiles. An approximate EV rapid charging hourly demand profile has been obtained from a confidential source to reflect current experience of rapid charging demand at service stations and similar locations. This means that the analysis does not rely on a profile for fast charging at a variety of public locations, which would not be representative of the specific profile of rapid charging at MSAs.

Figure 3-10 presents a comparison of the approximate EV rapid charging hourly demand profile with the Exeter MSA 2019 average half-hourly demand and charging events from the Zap project. The Exeter MSA 2019 half-hourly demand data have been retrieved from the WPD systems. The charging events data from the Zap project has been derived from data presented in the UKPN Recharge the Future project, described in section 2.5, and appears to align with the approximate demand profile adopted. All of the quantities in Figure 3-10 are presented on a normalised basis such that the sum of the hourly quantities corresponds to 100%, i.e. the total daily amount in each case.

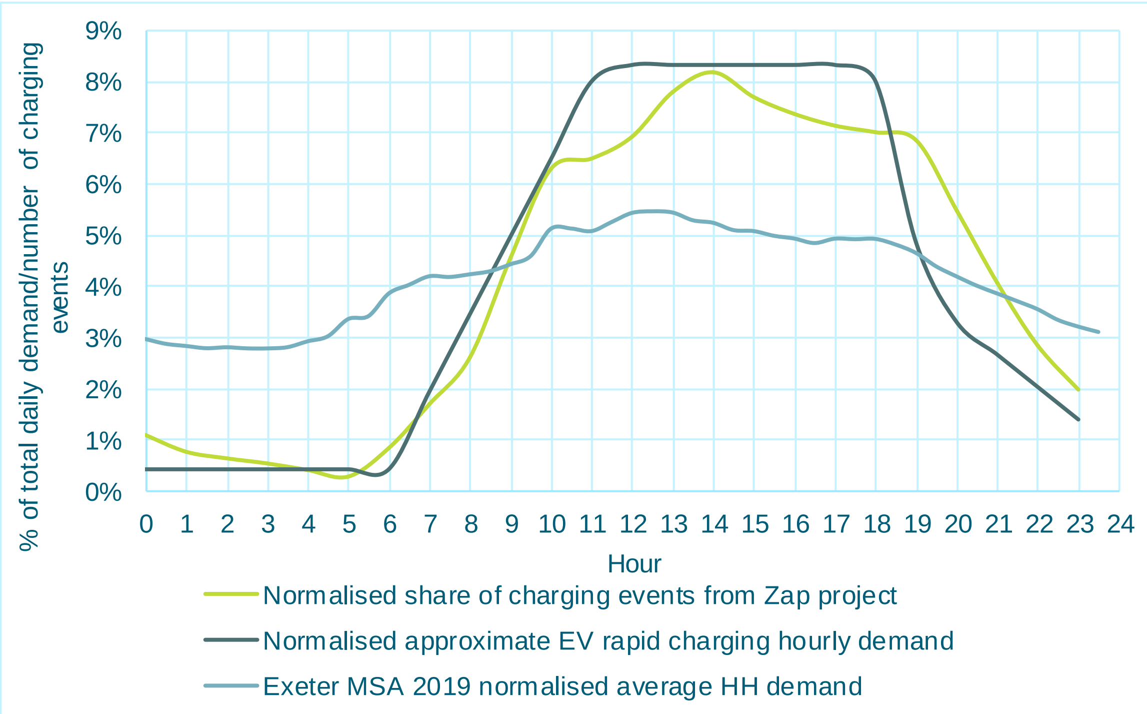


Figure 3-10 Comparison of normalised Exeter MSA demand, approximate EV rapid charging demand and charging events

Figure 3-10 is presented to enable a comparison to be made between Exeter MSA demand and the possible impact of charging events and associated EV rapid charging demand. The normalisation of the data means that the approximate EV rapid charging hourly demand profile is greater in peak magnitude than the 2019 Exeter MSA demand in the figure. However, this is not the case at present.

The figure shows that the approximate EV rapid charging hourly demand profile broadly correlates with the current Exeter MSA demand profile, i.e. the EV charging peak is likely to coincide with the MSA demand peak in the period 12:00-13:00. As the number of EV charging points increases to serve greater numbers of EVs in future, the peak magnitude of the EV charging demand will dominate the overall consumption of the site, and cause the peak period to be prolonged through the afternoon (11:00-18:00).

3.2.5 Network demand

The above comparison of the approximate EV rapid charging demand profile with the existing demand of the Exeter MSA site shows that new dedicated equipment will be needed to support the additional demand, which is likely to coincide with the peak demand of the site and exacerbate constraints that arise due to load growth on the existing supply connection.

As discussed in section 2.8, one or more dedicated primary transformers could be used to supply an 11kV ring circuit that serves clusters of EV rapid charging units. There are considerations relating to security of supply standards that have been discussed in that section, which include provision of a backup connection from a nearby 11kV circuit. In addition to the security of supply benefits, there is potential for the new EV rapid charging demand to have a profile that is complementary with that of the local network demand. In such a case, use of a permanent or intermittent/backup connection to the local 11kV network to supply the combined demand may have benefits in reducing the capacity of equipment required. This approach could be attractive if the demand profiles are observed to have peaks at different times, thus with potential to smooth the overall profile and make greater use of installed assets throughout the day.

Figure 3-11 presents a comparison of the normalised approximate EV rapid charging hourly demand profile and the normalised average half-hourly demand derived from measurements from Sowton BSP (the anticipated connection point for the CCS) during 2019. The approximate EV rapid charging profile is the same as that presented in section as presented in section 3.2.4, and the Sowton BSP average demand figures have been normalised in the same way for comparison.

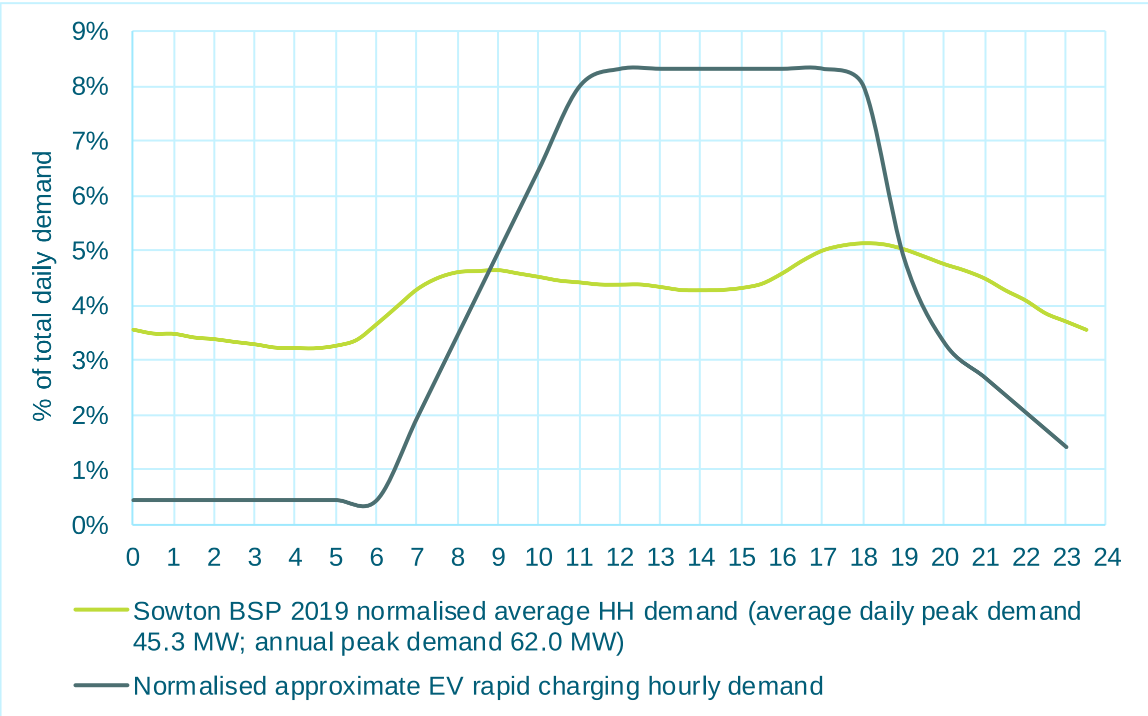


Figure 3-11 Comparison of normalised approximate EV rapid charging profile with Sowton BSP 2019 average half-hourly demand

Figure 3-11 shows that the Sowton BSP 2019 average demand has a notably flat profile, which corresponds to a load factor of 59%. This means that there is not much variation between the demand during the peak half-hour and that during the rest of the day, which is typical of an area that has a high proportion of industrial and commercial demand that persists throughout the day.

Figure 3-12 presents a comparison of the Sowton BSP 2019 average half-hourly demand profile in megawatts (MW) with the half-hourly demand on selected days. These selected days correspond to: the maximum half-hour peak demand day (i.e. the day on which the overall peak occurred, 4 March 2019); the maximum average half-hour demand day (i.e. the day when the demand was consistently high, 30 January 2019); and the minimum half-hour demand day (i.e. the overall minimum day, 13 April 2019).

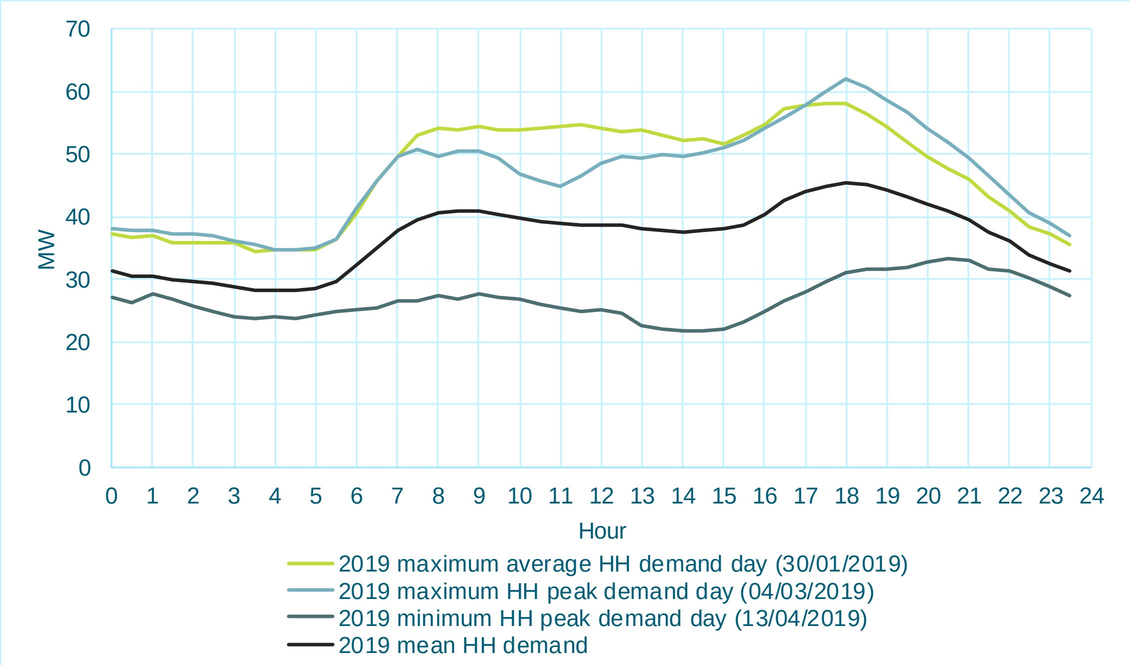


Figure 3-12 Comparison of Sowton BSP half-hourly demand for selected days

Figure 3-12 shows that the demand on the Sowton BSP varies through the year, but remains fairly flat. This means that there is little opportunity to smooth the overall demand profile by combining the EV rapid charge demand with that of the local network.

For comparison, Figure 3-13 presents a comparison of the normalised demand profiles presented earlier in Figure 3-11 along with the normalised demand profile that is used by Elexon in its settlement calculations relating to 'Profile Class 1' (PC1) customers. PC1 is corresponds to domestic unrestricted customers (single rate). The data is taken from the 'Default Period Profile Class Coefficient' table under the Market Domain Data (MDD) section of the Elexon Portal website [44]. Supporting material about application of demand profiles by Elexon in the settlement process is also provided on the website [45].

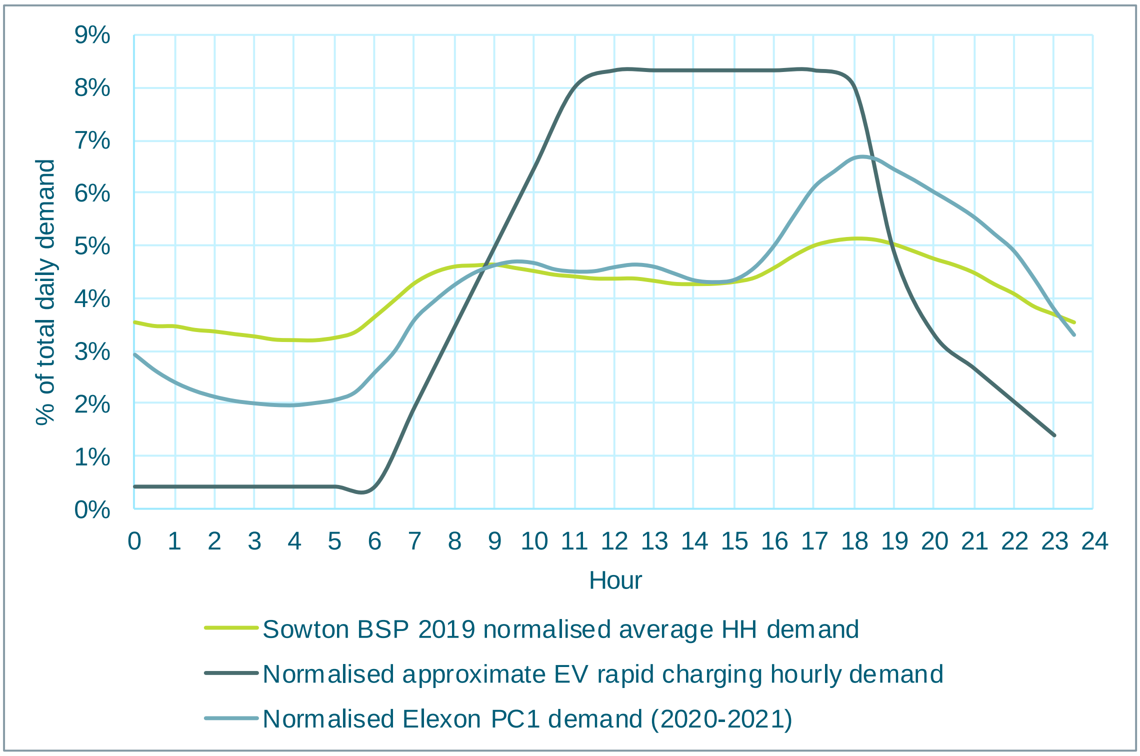


Figure 3-13 Comparison of normalised approximate EV rapid charging profile with Sowton BSP 2019 average half-hourly demand and Elexon PC1 profile

Figure 3-13 shows that if the profile of the local network demand aligned more closely with the domestic unrestricted profile (which has a load factor of 40%) then there might be opportunity to provide shared equipment to meet the combined demand, with a requirement for demand management during the 17:00-19:00 period when the peak demands coincide.

3.2.6 MSA infrastructure

Like other MSAs, Exeter MSA provides a maintained parking area for customers to access a range of services offered. According to parkopedia, Exeter MSA has 480 car parking spaces [46]. Currently, 5 of these appear to be adjacent to three existing EV fast charging units, as described in section 3.2.7.

In addition, Exeter MSA has a fuel forecourt operated by BP with 18 sets of pumps offering unleaded, diesel, ‘Ultimate unleaded’ and ‘Ultimate diesel’. It is assumed that conventional fuels pumps can service 6 users per hour at peak time (i.e. each user occupies the pump for 10 minutes, which includes pumping and payment).

Whilst the MSA is not subject to the regulations for a new development, in order to establish the reputation of being an EV charging “hub” it is assumed that at least 10% of the car parking spaces will be provided with an EV charge point in the medium-term in order to serve the demand that is anticipated by planning authorities. Furthermore, as for MSAs generally, it is likely that the majority of parking spaces at Exeter MSA will be replaced for charging bays in the time horizon up to 2050. This corresponds to 48 parking spaces and, assuming that each charging unit can support charging of two cars simultaneously, 24 EV rapid charging units.

3.2.7 Hardware

Ecotricity has three fast charging units installed at Exeter MSA, as shown in Figure 3-14. It is understood from Ecotricity that its current units each have a capacity of 50kW, and at Exeter there are five connectors available across the three units as indicated in Figure 3-15, which is taken from the Ecotricity website [47].

Figure 3-14 Exeter MSA existing EV fast charging infrastructure

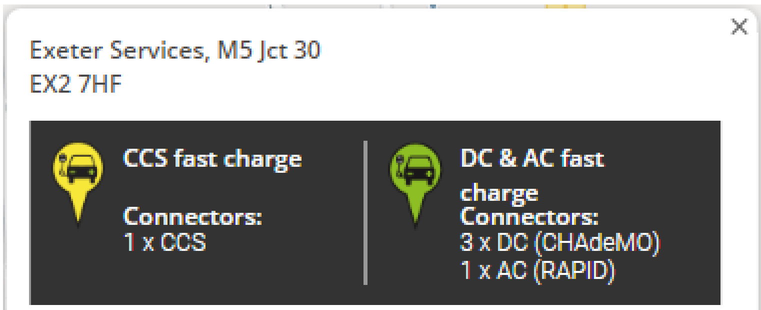


Figure 3-15 Exeter MSA existing EV fast charging connectors [47]

Based on the above, it appears that there are 5 parking spaces that could be used by vehicles to connect to the five connectors available from the three units. However, it is unclear whether the charging units can support simultaneous charging using different connectors at the same time with the necessary load management functionality.

It is assumed that the most powerful chargers currently available commercially (350kW DC chargers) will be used to provide the EV rapid charging service at Exeter MSA in future. As discussed in section 2.8, it is assumed that clusters with multiples of three nos. charging units will be supplied via LV transformers. In addition, standard 1MVA LV transformers will be used to supply each cluster, along with dynamic power sharing to operate within the transformer capacity.

Based on the demand profiles observed, there is no rationale for installing equipment that would be shared between the EV rapid charging units and Exeter MSA or the local network. As such, and as discussed in section 2.8, it is assumed that the clusters of 350kW charging units will be supplied via an 11kV ring circuit with dedicated primary transformer(s) and the CCS providing the connection from the 33kV network.

It should be noted that standard sizes for continuous rated 33/11kV power transformers operated by WPD are: 7.5, 12, 15 and 20 MVA. It is recommended that the civil works is prepared for the largest foreseeable transformer size at the outset in order to facilitate efficient replacement at a later date. However, smaller capacity transformers may be installed at the outset on the basis that they can be transferred to a different location if they require to be swapped for a larger capacity unit at a later date. Security of supply regulations should also be considered such that a solution using 2 smaller transformers is likely to be preferable to a single larger unit.

3.2.8 Potential combination with other technologies

Furthermore, as discussed in section 2.8, consideration has been given to pairing the EV rapid charging units at MSAs with solar PV and/or battery storage technologies. Consideration of this issue is complex, and would merit further work. However, it is not proposed to incorporate pairing of the EV rapid charging units with either of these technologies in the development of the dedicated compact solution as part of this project. This conclusion has been made principally based on the level of investment required and limited space availability at MSA sites.

With regard to solar PV technology, whilst the output of solar PV would work to offset the EV rapid charging demand during the day, the energy requirement for charging vehicles is expected to be dramatically higher than could be reasonably achieved through onsite solar PV generation. These technologies are not deemed to naturally complement each other since the area that would need to be covered in solar PV panels (either ground mounted, or on canopies above car parks) to provide the energy requirement for charging vehicle batteries is substantial. In addition, installation of canopies above car parks would incur significant capital costs for civil works.

For example, a high level assessment of Exeter MSA suggests that installation of solar PV panels over an area of approximately 3,700m^2 could be reasonably achieved. This corresponds to 1,762kWh generated per day or 17.5 full charges for a car battery of 100kWh.

With regard to battery storage, similarly, the level of capacity required to provide a solution that is complementary to the EV charging demand is significant. The approximate EV charging demand profile indicates that there could be value in using battery storage to smooth the sharp ramps up and down through the morning and early evening, respectively. However, this implies that the battery storage solution would need to have capacity to store approximately half of the daily energy requirement for EV charging. This would necessitate a grid utility- or industrial-scale battery storage solution. Such a solution is not deemed to be suitable for an MSA site based on the following considerations:

- Limited space availability;
- Requirement for significant additional investment; and
- Unknown benefits depending on commercial electricity tariffs and EV charging business model (complex use case and customer tariff arrangements).

As such, it is assumed that the CCS and associated transformer(s) developed in this project will be dedicated to the EV charging units.

3.3 Capacity assessment

3.3.1 Summary of assumptions

Item	Findings	GHD assumption
	EV Uptake	
Number of vehicles and proportion of EV	According to FES 2019, the number of vehicles on the road nationally is forecast to increase from 38.2 to 41.0 million. The proportion of EVs is forecast to rise from 0.5% to 88.3%. This updated national projection was shown to be broadly consistent with the assumptions that were adopted in our DFES document for the South West region, across the range of scenarios.	The total number of vehicles is forecast to increase by approximately 7.5%. The number of EVs nationally will rise by a factor of approximately 172.
	Traffic	
Traffic levels	According to the DfT road traffic forecast, the level of traffic (total length of vehicle journeys) is set to increase with a CAGR of 1.25% up to 2050. This is lower than the CAGR of 3.26% based on the annual traffic count data for 2000-2018. However, the lower figure is used to represent future growth at a more modest level than that observed since 2000.	Traffic growth is assumed to increase with a CAGR of 1.25% up to 2050, i.e. an increase of approximately 45% over the 30 year period up to 2050 (about 35% per vehicle, assuming 7.5% increase in the number of vehicles).
	Customer Behaviour	
Turn-in numbers	4.4% of vehicles that travelled past Exeter MSA turned in to the service station, with a strong correlation between the number of turn-ins and the public holiday and school holiday periods.	Not used directly in the GHD assessment, but included in the discussion to validate the calculated capacity requirements in section 3.3.5.
Turn-in profiles	The profiles for the average number of turn-ins per hour are broadly the same for weekday	Not used directly in the GHD assessment, but provided for

Item	Findings	GHD assumption
	and weekend days. The 'load factor' for turn-ins to Exeter MSA is 23%, which corresponds to a relatively sharp drop off in the number of visits either side of the lunchtime peak.	comparison with the subsequent EV rapid charging demand profile.
Dwell time	The average dwell time for 'no permit' customers at Exeter MSA is 31.5 minutes, which is consistent with the amount of time required to charge an EV battery to 80% using a rapid charger.	It is assumed that each EV charging point is occupied for 40 minutes per charging event, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles.
MSA visits to refuel or charge	Based on information provided by Moto, refuelling the vehicle is a driver of visits for 35% of guests. Based on the Motorway Services User Survey 2019, only 2% of respondents said that their reason for visiting was 'vehicle needed fuel, electric charge, or something else' and 1% of visitors engaged in EV charging.	Not used directly in the GHD assessment, but included in the discussion to validate the calculated capacity requirements in section 3.3.5.
	Charging demand/profile	
Charging profile from rapid chargers during the day	Based on information obtained from a confidential source to reflect current experience of rapid charging demand at service stations and similar locations, an approximate EV rapid charging hourly demand profile has been adopted. This is in line with the information presented in the UKPN Recharge the Future project for charging events from the Zap project.	An approximate EV rapid charging hourly demand profile has been adopted, which remains constant between 11:00-18:00. The profile ramps up between 06:00-11:00, and ramps down rapidly between 18:00-20:00.
	Network Demand	
Matching between EV rapid charging demand and Exeter MSA demand	Comparison of the approximate EV rapid charging demand profile with the existing demand of the Exeter MSA site shows that the additional demand is likely to coincide with the peak demand of the site rather than provide an	The CCS equipment and transformers should be dedicated to the EV charging units rather than being shared to support the demand of the existing Exeter MSA.

Item	Findings	GHD assumption
	opportunity for smoothing the overall demand profile.	
Matching between EV rapid charging demand and local network demand	Based on the demand profiles observed, there is little opportunity to smooth the overall demand profile by combining the EV rapid charge demand with that of the local network.	The CCS equipment and transformers should be dedicated to the EV charging units rather than being shared to support the demand of the local network.
	MSA Infrastructure	
Conventional fuel pumps	Exeter MSA has a fuel forecourt operated by BP with 18 sets of pumps.	It is assumed that conventional fuels pumps can service 6 users per hour at peak time (i.e. each user occupies the pump for 10 minutes, which includes pumping and payment).
EV parking bays	Currently out of 480 parking bays 5 are set aside for EV charging from 3 charging units (each 50kW).	As for MSAs generally, it is likely that the majority of parking spaces at Exeter MSA will be replaced for charging bays in the time horizon up to 2050.
	Hardware	
Capacity of EV rapid charging units	It is assumed that the most powerful chargers currently available commercially (350kW DC chargers) will be used to provide the EV rapid charging service at Exeter MSA in future. It is assumed that clusters with multiples of three nos. charging units will be supplied via LV transformers. In addition, standard 1MVA LV transformers will be used to supply each cluster, along with dynamic power sharing to operate within the transformer capacity.	Clusters of 3 nos. 350kW EV rapid charging units will be installed along with a standard 1MVA LV transformer. The output of the charging units will be managed through dynamic power sharing, such that each will be limited to 330kW when all are in use in order to operate within the transformer capacity.
High voltage supplies	Based on the demand profiles observed, there is no rationale for installing equipment that would be shared between the EV rapid charging units and Exeter MSA or the local network. As such, it is	Dedicated primary transformer(s) and the CCS will provide the connection from the 33kV network to the 11kV ring circuit to support all of the charging unit clusters.

Item	Findings	GHD assumption
	assumed that the clusters of 350kW charging units will be supplied via an 11kV ring circuit with dedicated primary transformer(s) and the CCS providing the connection from the 33kV network.	
Potential combination with other technologies	Based on considerations of space availability, capacity and investment requirements neither solar PV or battery storage solutions are deemed to be suitable to be developed in combination with EV rapid charging equipment at MSAs.	The CCS and associated transformers developed in this project will be dedicated to the EV rapid charging units.

3.3.2 2050 EV rapid charging capacity requirement

As illustrated in Figure 2-1 in section 3.1, two approaches have been adopted for the calculation of the capacity requirement for EV rapid charging units. The results of the assessment are presented in Figure 3-16 (updated version of Figure 2-1 with details provided in dark green boxes).

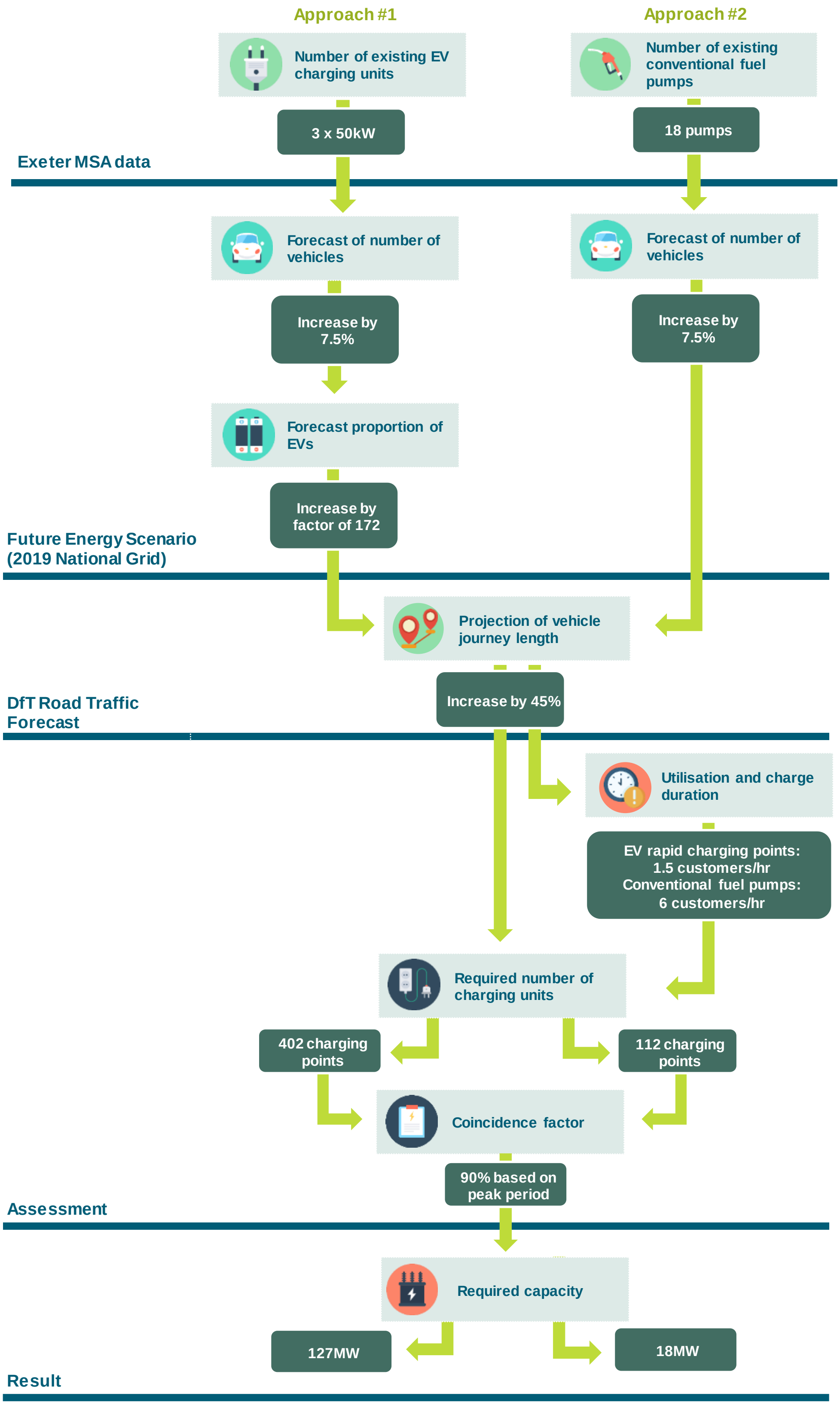


Figure 3-16 Capacity assessment results

The rationale for the assumptions adopted in each of the approaches (detailed in the dark green boxes) are described as follows:

1. The first approach is to take the existing number of EV rapid chargers installed at Exeter MSA and multiply this by the factors representing the projected increases in the number of vehicles on the road, proportion of EVs and traffic (total vehicle journey lengths) between 2019 and 2050:
    a. The number of existing EV charging units at Exeter MSA is 3 nos. 50kW units;
    b. Based on the FES document, as described in section 3.2.1, the number of vehicles is forecast to increase by 7.5%;
    c. The proportion of EVs is projected to increase by a factor 172;
    d. In addition, based on the DfT Road Traffic Forecasts described in section 3.2.2, the total vehicle journey length is projected to increase by 45%;
    e. Therefore, the required number of EV rapid charging points is calculated to be 804. However, if it is assumed that each charging unit can support charging of two vehicles then this corresponds to 402 nos. charging units and a capacity of 141MW based on a unit capacity of 350kW.
    f. Furthermore, a coincidence factor should be applied to reflect the fact that all of the charging points will not be in use at peak time. Whilst the data in this area is not robust, an assumption of 90% is proposed based on the relatively sharp peak of vehicle turn-in numbers during the 12:00-13:00 peak period.
    g. As a result, the calculation of the required capacity from approach 1 is **127 MW**.
2. The second approach is to take the existing number of conventional fuel filling pumps, multiply this by the factors representing the projected increases in the number of vehicles on the road and traffic (total vehicle journey lengths) between 2019 and 2050, and finally multiply this by a factor representing the difference in the utilisation of EV rapid charging points compared with conventional fuel pumps:
    a. The number of existing conventional fuel pumps for cars at Exeter MSA is 18;
    b. Based on the FES document, as described in section 3.2.1, the number of vehicles is forecast to increase by 7.5%;
    c. In addition, based on the DfT Road Traffic Forecasts described in section 3.2.2, the total vehicle journey length is projected to increase by 45%;
    d. In terms of utilisation, it is assumed that conventional fuels pumps can service 6 users per hour at peak time (i.e. each user occupies the pump for 10 minutes, which includes pumping and payment). By contrast, it is assumed that EV rapid charging points are able to service 1.5 customers per hour (i.e. 40 minutes, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles). Therefore, a factor of 4 is applied for the number of EV rapid charging points as compared with conventional fuel pumps;
    e. Therefore, the required number of EV rapid charging points is calculated to be 112. However, if it is assumed that each charging unit can support charging of two vehicles then this corresponds to 56 nos. charging units and a capacity of 20MW based on a unit capacity of 350kW.
    f. Furthermore, a coincidence factor should be applied to reflect the fact that all of the charging points will not be in use at peak time. Whilst the data in this area is not robust, an assumption of 90% is proposed based on the relatively sharp peak of vehicle turn-in numbers during the 12:00-13:00 peak period.
    g. As a result, the calculation of the required capacity from approach 2 is **18 MW**.

3.3.3 Impact of revisions from FES 2019 to FES 2020

A comparison of the key parameters for 2019 and 2050, taken from the FES 2019 and FES 2020 analyses, is presented in Table 3-1.

Table 3-1 Comparison between FES 2019 and FES 2020

Steady Progression		2019	2050	Factor increase (2019-2050)	% increase (2019-2050)
FES 2019	# Vehicles	38,179,668	41,030,267		7.5%
FES 2019	# EVs	195,473	36,235,306	185	
FES 2019	% EVs	0.5%	88.3%	172	
FES 2020	# Vehicles	37,704,942	40,671,424		7.9%
FES 2020	# EVs	112,701	37,628,371	334	
FES 2020	% EVs	0.3%	92.5%	310	

A significant change (in percentage terms) has been applied to the number of EVs in 2019. This figure is used as the reference point for our analyses. The revised parameters lead to changes to two key factors used in our calculations in one or both of approach 1 and approach 2:

- Percentage increase in the overall number of vehicles over the period (7.9%, increased from 7.5%); and
- Multiplication factor for the increase in the percentage of EVs (310, increased from 172).

The impact of these revised parameters on the calculated capacity requirement is summarised below:

- The required capacity from approach 1 is **230 MW** (increased from 127 MW); and
- The required capacity from approach 2 is **18 MW** (unchanged).

3.3.4 Incremental capacity requirement

Whilst the above figures indicate the projected endpoint for EV rapid charging peak demand in 2050, the uptake of EVs is not anticipated to occur linearly over that period. The “S-curve” adopted by National Grid for the uptake of EVs can be used to provide an estimate of the intermediate capacity requirements corresponding to the peak EV rapid charging demand. Figure 3-17 presents the cumulative growth in the proportion of EVs, i.e. the “S-curve” mentioned above from the FES document, for the steady progression scenario.

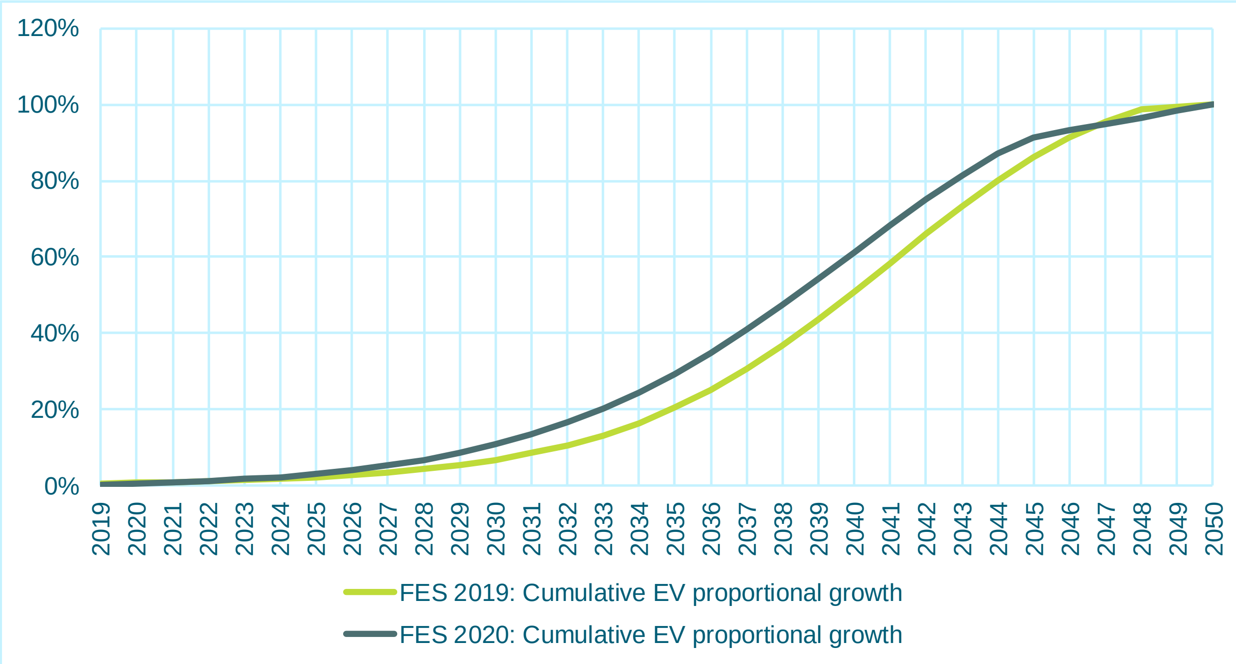


Figure 3-17 Cumulative growth in the proportion of EV uptake in the FES steady progression scenario

Table 3-2 presents the incremental EV rapid charging capacity requirement for approaches 1 and 2, based on the above "S-curve".

Table 3-2 Incremental EV rapid charging capacity requirement

FES	Approach	2025	2030	2035	2040	2045	2050
2019	Approach 1 (127 MW)	2.8	8.6	25.9	64.6	109.2	127.0
2019	Approach 2 (18 MW)	0.4	1.2	3.7	9.2	15.5	18.0
2020	Approach 1 (230 MW)	7.0	24.8	67.2	141.1	210.5	230.0
2020	Approach 2 (18 MW)	0.6	1.9	5.3	11.0	16.5	18.0

In both approaches there is an implicit assumption that the existing number of EV rapid charging points and conventional fuel pumps, respectively, is well matched to the peak demand for them. It may be argued that the number EVs is very small and the behavioural patterns associated with this relatively new technology are not yet well understood. As such, approach 2 (using the number of conventional fuel pumps as the starting point) is deemed to be more accurate.

In addition, the results from approach 2 appear to align better with forecasts from other sources. For example, for Phase 1 of OLEV's Project Rapid WPD provided pricing for provision average 7MVA supplies [29]. The precise timescales for the phases of the project are unclear, however, the Government policy paper published in May 2020 [48] indicates that the initial deployment will occur by 2023, followed by an 'extensive' network ('around 2,500 high powered chargepoints across England's motorways and major A roads') by 2030; and 6,000 by 2035. It is assumed that the average 7MVA capacity is anticipated to support the demand in 2035, and that Exeter MSA demand is likely to be higher than average since it has a higher than average footfall.

Figure 3-18 provides an illustration of the EV rapid charging capacity by Moto MSA location based on the 7 MVA average pro-rated by footfall numbers compared with the average.

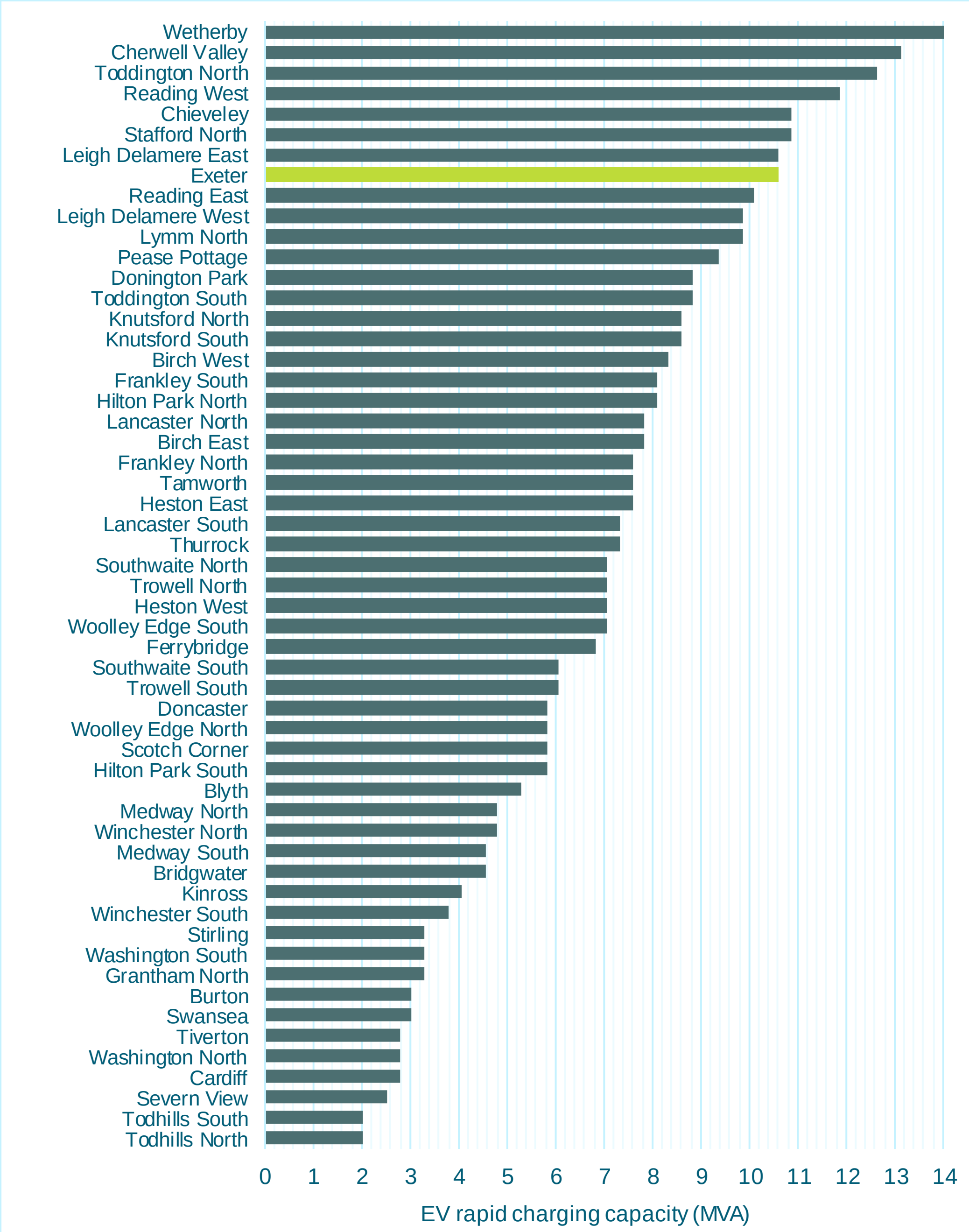


Figure 3-18 7 MVA average EV rapid charging capacity pro-rated by footfall numbers

Based on the simple analysis presented in Figure 3-18, Exeter MSA is expected to have a rapid charging demand of 10.6 MVA in 2035, which exceeds the demand calculated in approach 2 and using the FES uptake curve (3.7 MW). There is considerable uncertainty around the precise rate of uptake of EVs and utilisation of rapid charging points. However, this illustrates that the required capacity calculated in approach 2 is in line with expectations from other sources in the 2035-2040 period, and represents a pragmatic selection for the CCS to support future demand (with the possibility that the demand may exceed the selected capacity under some forecasts).

In view of the limited incremental steps in the EV rapid charging capacity requirement presented in Table 3-2 up to 2035/2040, it is recommended that 12 MVA transformer sizes be selected as part of the development of the modular compact substation. It should be noted that 12 MW aligns with the upper limit of the definition of Group B demand in the P2/7 Security of Supply standard, for which the restoration requirements are presented in section 2.8.3. The civil works should be prepared at the outset for the largest foreseeable transformer size in order to facilitate efficient replacement at a later date.

Security of supply regulations should also be considered such that a solution using 2 nos. 12 MVA transformers is likely to be preferable than a single 24 MVA unit.

Figure 3-19 illustrates the required capacity of the compact substation/transformer to meet the demand calculated using approach 2.

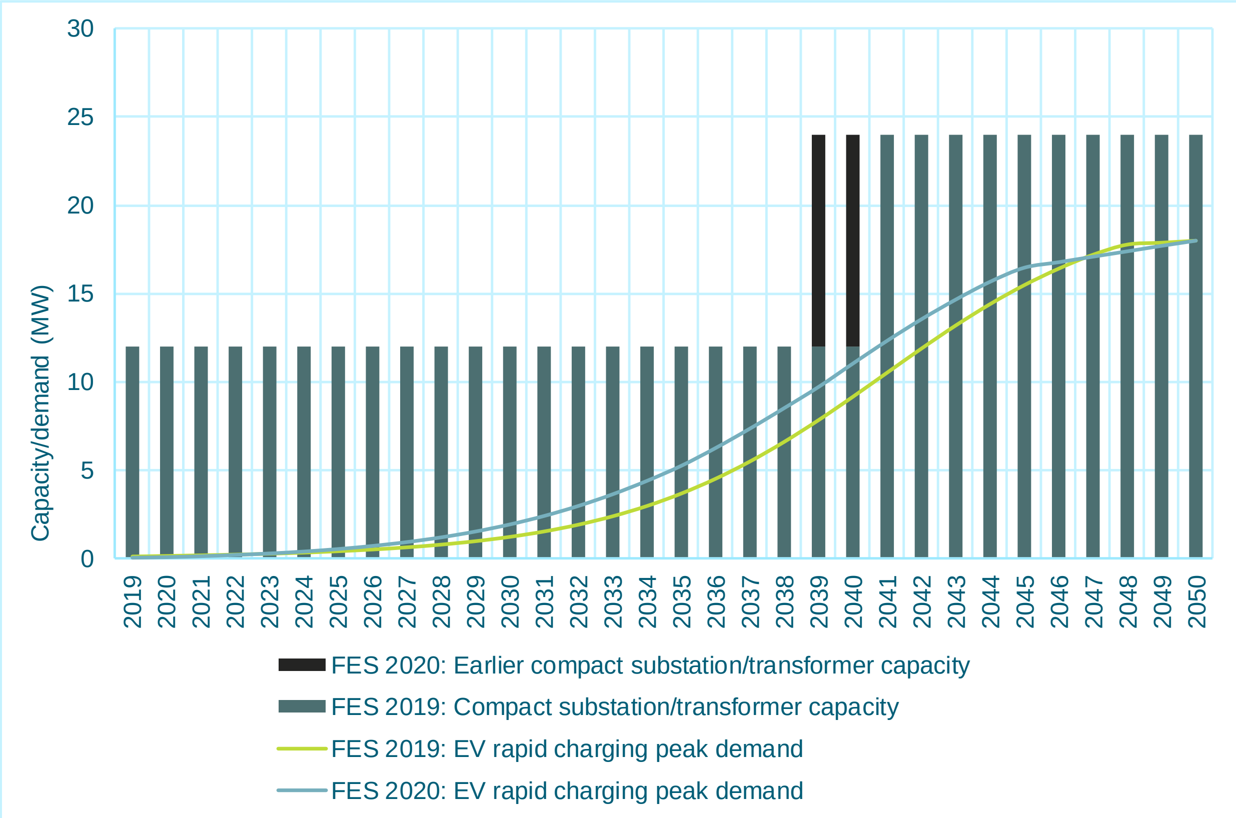


Figure 3-19 Compact substation/transformer capacity requirement to meet demand calculated using approach 2

The required capacity to meet the demand calculated using approach 2, is presented in Figure 3-19 based on a 12 MVA unit size and a requirement that the EV rapid charging peak demand should not exceed 80% of the installed capacity. As such, the required capacity of the transformer and compact substation is 12 MVA at the outset (2019). Following this, the required capacity increases to 24 MVA in 2041 (based on FES 2019) or 2039 (based on FES 2020), which is suitable to meet the demand that rises to 18 MW in 2050.

3.3.5 Discussion of validation of assessment results

In both approaches there is an implicit assumption that the existing number of EV rapid charging points and conventional fuel pumps, respectively, is well matched to the peak demand for them. It may be argued that the number EVs is very small and the behavioural patterns associated with this relatively new technology are not yet well understood. As such, approach 2 (using the number of conventional fuel pumps as the starting point) is deemed to be more accurate.

Furthermore, in practical terms, it is estimated that 38.0 million vehicles passing Exeter MSA in 2019 corresponds to approximately 59.2 million in 2050, based on projected increases in the number of vehicles (7.5%) and miles travelled (45%). The data provided in sections 3.2.2 and 3.2.3 indicated that 4.4% of the 38.0 million vehicles passing Exeter MSA in 2019 turned-in to use the services provided, and that 1% of these engaged in rapid charging. However, it may be expected that the proportion of vehicles that engage in EV rapid charging will rise to 35%, based on survey results. Assuming that 4.4% turn-in and 35% of those engage in rapid charging, then this means that on average approximately 2,500 EV rapid charging events can be expected to occur each day in 2050. For each approach, respectively, this corresponds to:

- Approach 1: 402 charging points each supporting 6.2 charging events per day on average; and
- Approach 2: 56 charging points each supporting 44.6 charging events per day on average.

Given that each charging point can support two charging events simultaneously, on average each connector is used 3.1 and 22.3 times per day, respectively, which corresponds to between 1.9 and 13.4 hours based on 40 minute charging events. As such, the capacity calculated through approach 2 is deemed to be reasonable in comparison with this basic assessment of the expected demand for EV rapid charging in 2050. Whilst each connector is assumed to be in use for 13.4 hours per day on average (load factor of 56%), it is noted that in busy periods, such as around lunchtime on peak summer days, the demand maybe greater. The load factor for vehicle turn-ins at Exeter MSA in 2019 was observed to be 23% due to the spike observed at lunchtime. This may result in queues to use the EV rapid charging services during such periods, or customers choosing to charge elsewhere when their SOC means that they have this option.

4 Results and summary

4.1 Overview

This report presents the results of our research for the general approach and specific analyses of the required EV rapid charging capacity at Exeter MSA.

The assessment has been undertaken using two approaches, to apply factors representing the projected increases in the number of vehicles on the road, future EV uptake and charging behaviour to:

1. The existing charging infrastructure; and
2. The number of conventional fuel filling pumps.

The second approach, to use the number of conventional fuel filling pumps as the starting point, is deemed to provide a more accurate assessment the power demand for EV rapid charging at Exeter MSA. Based on this, the required capacity of the transformer and compact substation at the outset of the assessment (2019) corresponds to a standard 12 MVA primary transformer size. Following this, the required capacity increases to 24 MVA in 2041, which is suitable to meet the demand that is projected to rise to 18 MW in 2050. In addition to the transformer unit size of 12 MVA, the assessment has assumed a requirement that the peak EV rapid charging demand should not exceed 80% of the installed capacity.

The demand of 18 MW in 2050 corresponds to 56 nos. 350kW rapid charging units that can each support up to two vehicles charging. It is assumed that the maximum output of each unit may be reduced to 330 kW at times of high demand.

4.2 Discussion of findings

The research carried out covers the general approach and specific analyses for Exeter MSA, comprising investigation of information relating to the following categories:

- EV uptake as a proportion of vehicles on the road;
- Traffic (historic count of vehicle flow past Exeter MSA; and regional and national projections of total vehicle journey miles);
- Customer behaviour (vehicle turn-ins at Exeter MSA; dwell time of vehicles stopped; proportion of vehicle that stop to refuel);
- Charging demand/profile (comparison of approximate EV rapid charging demand profile with Exeter MSA demand to assess level of complementarity);
- Network demand (comparison of approximate EV rapid charging demand profile with local network demand profile to assess level of complementarity);
- MSA infrastructure (numbers of existing conventional fuel pumps, EV fast charging units and car parking spaces); and
- Hardware (EV rapid charging units, 33/11kV transformer sizes, and potential for sharing of electrical equipment between EV rapid charging and solar PV and/or battery storage technologies).

The nature of information available in each of the above categories is limited, due to the fact that the uptake of EVs is still relatively low. The key findings that have been used in our assessment are summarised below:

- According to National Grid FES, the number of EVs will rise by a factor of approximately 172;
- According to the DfT, the level of traffic (total length of vehicle journeys) is projected to increase with a CAGR of 1.25% up to 2050, i.e. an increase of approximately 45% over the 30 year period up to 2050;

- It is assumed that each EV charging point is occupied for 40 minutes per charging event, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles;
- An approximate EV rapid charging hourly demand profile has been adopted, which remains constant between 11:00-18:00. The profile ramps up between 06:00-11:00, and ramps down between 18:00-20:00;
- Based on the demand profiles observed, the EV rapid charging demand does not appear to complement the Exeter MSA or local network demand profiles such that they would provide a smooth combined profile. As such, it is concluded that the primary transformer(s) and CCS should be developed to be dedicated to the EV charging units;
- Exeter MSA has a fuel forecourt operated by BP with 18 sets of pumps. It is assumed that conventional fuels pumps can service 6 users per hour at peak time (i.e. each user occupies the pump for 10 minutes, which includes pumping and payment).
- Exeter MSA has 5 dedicated parking bays for EVs with 3 charging units (each 50kW). It is assumed that EV rapid charging points are able to service 1.5 customers per hour (i.e. occupied for 40 minutes, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles).
- Clusters of 3 nos. 350kW EV rapid charging units will be installed along with a 1 MVA LV transformer. It is proposed that the output of the charging units will be managed such that each will be limited to 330kW when all are in use in order to operate within the transformer capacity; and
- Based on considerations of space availability, capacity and investment requirements neither solar PV or battery storage solutions are deemed to be suitable to be developed in combination with EV rapid charging equipment at MSAs. The compact substation and associated transformers developed in this project will, thus, be dedicated to the EV rapid charging units.

4.3 Future considerations

The EV sector is constantly growing around the world and with accelerated support for batteries, the cost of owning an EV has decreased. While EVs currently dominate the market for low-emission vehicles, hydrogen-based cars offer another option for decarbonisation of transport, assuming that hydrogen would be produced with no CO_2 emissions. Hydrogen vehicles are powered by fuel cells that generate electricity from hydrogen and oxygen.

Importantly, fuel cell vehicles fuel up relatively quickly – approximately 15 times faster than a battery EV using fast-charging technology [49]. Furthermore, fuel cells provide advantages for heavier vehicles travelling over longer distances. In addition, hydrogen also has potential to contribute to decarbonising rail transport or shipping in the longer term [50]. However, the principal obstacle to global adoption of fuel cell vehicles is the need for substantial investment for development of re-fuelling infrastructure. The National Grid FES document envisages that EVs will be the technology of choice, with 88% of vehicles being EVs in 2050 compared with 0.3% being hydrogen vehicles in the steady progression scenario.

It is important to consider electrification of trucks and other heavy goods vehicles in the future. Currently, heavy goods vehicle drivers use MSAs as a point to make necessary breaks from driving (including to meet statutory requirements) or to stay overnight. If electric heavy goods vehicles will become available in the future, MSAs should be able to provide charging points for those types of vehicle, either fast/rapid chargers or slow, overnight chargers. Either way, in the future MSAs would require larger network connections to accommodate charging of heavy goods vehicles and dedicated charging points for longer vehicles with possible overnight stays.

Last, but not least, consideration should be given to autonomous vehicles. In the future, autonomous vehicle technology together with new business models to provide mobility as a service could potentially result in improvements to road safety and traffic management. Some researchers predict that costs of autonomous vehicles would reduce and use of land for parking would decrease. Policies are in place to ensure that future autonomous cars will be strictly battery-powered. However, the impact of on-demand mobility services with autonomous vehicles on the existing transport sector is still unclear. It is conceivable that, even though they are battery-powered, autonomous vehicles will not necessarily save energy or emissions because autonomous on-demand services may replace trips that could be taken by more sustainable modes of transport like walking or cycling [51]. There are currently uncertainties relating to the regulatory framework, successful business models and technological challenges for the deployment of autonomous vehicles. From a technical point of view, the key challenges include: remote oversight of operations; and robust communications.

4.4 Conclusions and learning

EV uptake is the factor that has the biggest impact on the calculation of required EV charging capacity. Projections of EV uptake have been taken from the National Grid FES 2019 document, which have been determined with reference to the Government policy initiatives described in the Road to Zero. However, these projections reflect significant ambition that has not yet materialised, i.e. the proportion of EVs is projected to increase by a factor of approximately 172 from 0.5% in 2019 to 88.3% in 2050.

According to the DfT road traffic forecast, the level of traffic (total length of vehicle journeys) is set to increase with a CAGR of 1.25% up to 2050. This corresponds to an increase of approximately 45% over the 30 year period up to 2050. The National Grid FES document forecasts the total number of vehicles to increase by approximately 7.5% from 38.2 to 41.0 million. As such, the length of journeys covered by each vehicle is forecast to increase by about 35%.

Initial discussions with Ecotricity have revealed that existing charging patterns for EVs will not be reflective of future rapid charging. This is because most EV users charge their vehicles at home before embarking on a journey and hence do not use public chargers on the motorway network very frequently. In addition, behaviour of users at MSAs may change as rapid charging will allow them to charge their vehicles in a fraction of the time compared with standard chargers. This could mean that users are more inclined to charge their vehicles whilst they use the facilities at MSAs.

EV charging profiles at MSAs are generally expected to follow the same trend as shown from experience of public, rapid EV charging. These profiles also align with traffic visiting MSAs and, therefore, can be used as the basis to calculate the capacity required for EV charging requirements in the future. An approximate EV rapid charging hourly demand profile has been adopted, based on information obtained from a confidential source to reflect current experience of rapid charging demand at service stations and similar locations. This profile remains constant between 11:00-18:00, reflecting a uniform demand for EV rapid charging throughout the day. The profile ramps up between 06:00-11:00, and ramps down rapidly between 18:00-20:00.

Based on our assessment of customer behaviour, it is assumed that each EV charging point is occupied for 40 minutes per charging event, which includes 25-30 minutes charging time plus buffer time to account for delays in returning to vehicles. This is compared with an assumption that conventional fuels pumps can service 6 users per hour at peak time (i.e. each user occupies the pump for 10 minutes, which includes pumping and payment).

The configuration of rapid charging infrastructure on site is limited by interfacing with existing WPD standard assets (such as distribution transformers). For example, 350kW rapid chargers are currently connected at LV and, therefore, only a maximum of three can be connected to one distribution substation. There are possibilities to connect more, however, control systems would be required to limit the output from chargers at peak times.

5 References

[1] HM Government, Industrial Strategy, “The Road to Zero,” July 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf.

[2] National Grid, “Future Energy Scenarios,” July 2019. [Online]. Available: http://fes.nationalgrid.com/media/1409/fes-2019.pdf.

[3] HM Government, DfT, “Consulting on ending the sale of new petrol, diesel and hybrid cars and vans,” 20 February 2020. [Online]. Available: https://www.gov.uk/government/consultations/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans. [Accessed 8 July 2020].

[4] UK Petroleum Industry Association, “2019 Statistical Review,” 1 August 2019. [Online]. Available: https://www.ukpia.com/media/2237/ukpia-statistical-review-2019.pdf. [Accessed 8 July 2020].

[5] d, “Reformed Plug-In Car Grant extended into next decade,” 11 10 2018. [Online]. Available: https://www.gov.uk/government/news/reformed-plug-in-car-grant-extended-into-next-decade.

[6] House of Commons Library, “Electric Vehicles and infrastructure,” Briefing paper 7480, 25 March 2020. [Online].

[7] HM Government, “Consulting on ending the sale of new petrol, diesel and hybrid cars and vans,” 9 April 2020. [Online]. Available: https://www.gov.uk/government/consultations/consulting-on- ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans.

[8] Western Power Distribution, “Distribution Energy Future Scenario,” WPD, 2017.

[9] HM Government (DfT), “Road Traffic Forecasts 2018,” 14 September 2018. [Online]. Available: https://www.gov.uk/government/publications/road-traffic-forecasts-2018. [Accessed 12 May 2020].

[10] MOTO, “Information Pack,” Moto, 2017.

[11] BVA BDRC, Transport Focus, “Motorway Services User Survey,” Transport Focus, 2019.

[12] Element Energy Limited, “Electric Vehicle Charging Behaviour Study,” Element Energy Limited, Cambridge, 2019.

[13] UK Power Networks, Element Energy, “Recharge the Future Project: Charger Use Study,” UKPN, London, 2018.

[14] SSE Networks, “My Electric Avenue Project,” 2020. [Online]. Available: http://myelectricavenue.info/. [Accessed 8 July 2020].

[15] OLEV, “Plugged In Places programme,” 12 Feb 2013. [Online]. Available: https://www.gov.uk/government/publications/plugged-in-places. [Accessed 29 June 2020].

[16] ESB, “ESB ecars,” 2020. [Online]. Available: https://www.esb.ie/ecars/ecars. [Accessed 29 Jun 2020].

[17] Colin Herron, Shirley Coleman, “Methodology to determine the number of rapid chargers needed for electric vehicles in the UK,” 30 Dec 2017. [Online]. Available: https://www.zerocarbonfutures.co.uk/number-of-charge-points/. [Accessed 2020].

[18] European Commission, “2012-EU-13066-S: Accelerating the introduction of Electric Vehicle Rapid Charging by studying adoption and use along PP axes 13 and 26 in the UK and Ireland,” March 2018. [Online]. Available: https://ec.europa.eu/inea/en/ten-t/ten-t-projects/projects-by-country/multi-country/2012-eu-13066-s. [Accessed 8 July 2020].

[19] RAF Foundation, “Development of UK Public Chargepoint Network,” RAF Foundation, London, 2018.

[20] T. Carpenter, “Measuring & Mitigating Electric Vehicle Adoption Barriers,” University of Waterloo, Ontario, 2015.

[21] EA Technology, Scottish & Southern Electricity Network, Ricardo, “An Assessment of the Public Acceptance of Demand-Side Response of EV Charging using Esprit,” EA Technology, 2015.

[22] BMW, “Technical specifications BMW i3,” BMW Media Information, 2018.

[23] Nissan, “Technical Specification Nissan Leaf,” Nissan, 2019.

[24] Hyundai, “Ioniq Technical Specification,” Hyundai, 2019.

[25] Tesla, “Tesla S Technical Specification,” Tesla, 2020.

[26] Gridwatch Templar, “G.B. National Grid Status,” 2020. [Online]. Available: http://www.gridwatch.templar.co.uk/. [Accessed 29 June 2020].

[27] Thanet District Council, “Electric Vehicle Charging Points for New Development. Guidance Note for Applicants,” Thanet District Council, 2018.

[28] Bracknell Forest Coucil, “Parking Standards Supplementary Planning Document,” 2016.

[29] WPD, “2020 EV Strategy,” Apr 2020. [Online]. Available: https://www.westernpower.co.uk/downloads-view/114340. [Accessed 18 Jun 2020].

[30] Energy System Catapult, “Preparing UK Electricity Networks for Electric Vehicles Report,” Energy System Catapult, 2018.

[31] ABB, “Product Leaflet: ABB Terra HP high power charging,” ABB, 2019.

[32] Efaces, “HV350 Product Technical Information,” Efaces, 2019.

[33] Tritium, “Veefil PK: High Power Charging System,” Tritium, 2019.

[34] J. Voelcker, “Porsche Claims It Can Double Tesla’s Fast-Charging Rate,” IEEE Spectrum, 2019.

[35] Hyundai, “Hyundai Kona Electric brochure,” 2020. [Online]. Available: https://www.hyundai.co.uk/brochures/brochure_kona-electric.pdf. [Accessed 8 Jul 2020].

[36] Tritium, “VEEFIL-PK HIGH POWER CHARGING SYSTEM Brochure,” 2020. [Online]. Available: https://www.tritium.com.au/products/veefil-pk-high-power-charging-system/. [Accessed 24 Jun 2020].

[37] Drive Green, “Solar Charging,” Drive Green, Emborough, 2020.

[38] Renewable Energy World, “Tesla Doubles Its Superchargers With Massive Solar Station,” Bloomberg News Editors, 2017.

[39] Gridserve, “EV Charging,” 2020. [Online]. Available: https://www.gridserve.com/electric-vehicle-charging. [Accessed 8 Jul 2020].

[40] Solaris, “Solar Panels Rating,” Solaris, 2018.

[41] HM Government (DfT), “Road Traffic Statistics - Manual Count Points, site number: 16023,” 2020. [Online]. Available: https://roadtraffic.dft.gov.uk/manualcountpoints/16023. [Accessed 19 May 2020].

[42] Moto, “Information pack 2017,” 2017.

[43] Transport Focus, “Motorway Service User Survey 2019 - research agency report,” 31 July 2019. [Online]. Available: https://www.transportfocus.org.uk/research-publications/ publications/motorway-services-user-survey-2019/. [Accessed 17 June 2020].

[44] Elexon Portal, “Market Domain Data (MDD),” 2020. [Online]. Available: https://www.elexonportal.co.uk/mddviewer/view?cachebust=r3r5nyrrbk. [Accessed 9 June 2020].

[45] Elexon, “Profiling,” 2020. [Online]. Available: https://www.elexon.co.uk/operations-settlement/profiling/. [Accessed 9 June 2020].

[46] Parkopedia, “Exeter services,” 2020. [Online]. Available: https://en.parkopedia.co.uk/parking/carpark/exeter_motorway_service_station/ ex2/exeter/?arriving=202006241730&leaving=202006241930. [Accessed 24 June 2020].

[47] Ecotricity, “Our car charging stations,” 2020. [Online]. Available: https://www.ecotricity.co.uk/for-the-road/our-electric-highway. [Accessed 24 June 2020].

[48] HM Government, “Policy Paper: Government vision for the rapid chargepoint network in England,” 14 May 2020. [Online]. Available: https://www.gov.uk/government/publications/government-vision-for-the-rapid-chargepoint-network-in-england/government-vision-for-the-rapid-chargepoint-network-in-england. [Accessed 8 Jul 2020].

[49] McKinsey & Company, “The future of mobility is at our doorstep,” McKinsey Center for Future Mobility, 2019.

[50] IRENA, “Hydrogen from Renewable Power. Technology outlook for the energy transition,” IRENA, 2018.

[51] MIT Energy Initiative, “Insights into Future Mobility,” Massachusetts Institute of Technology, 2019.

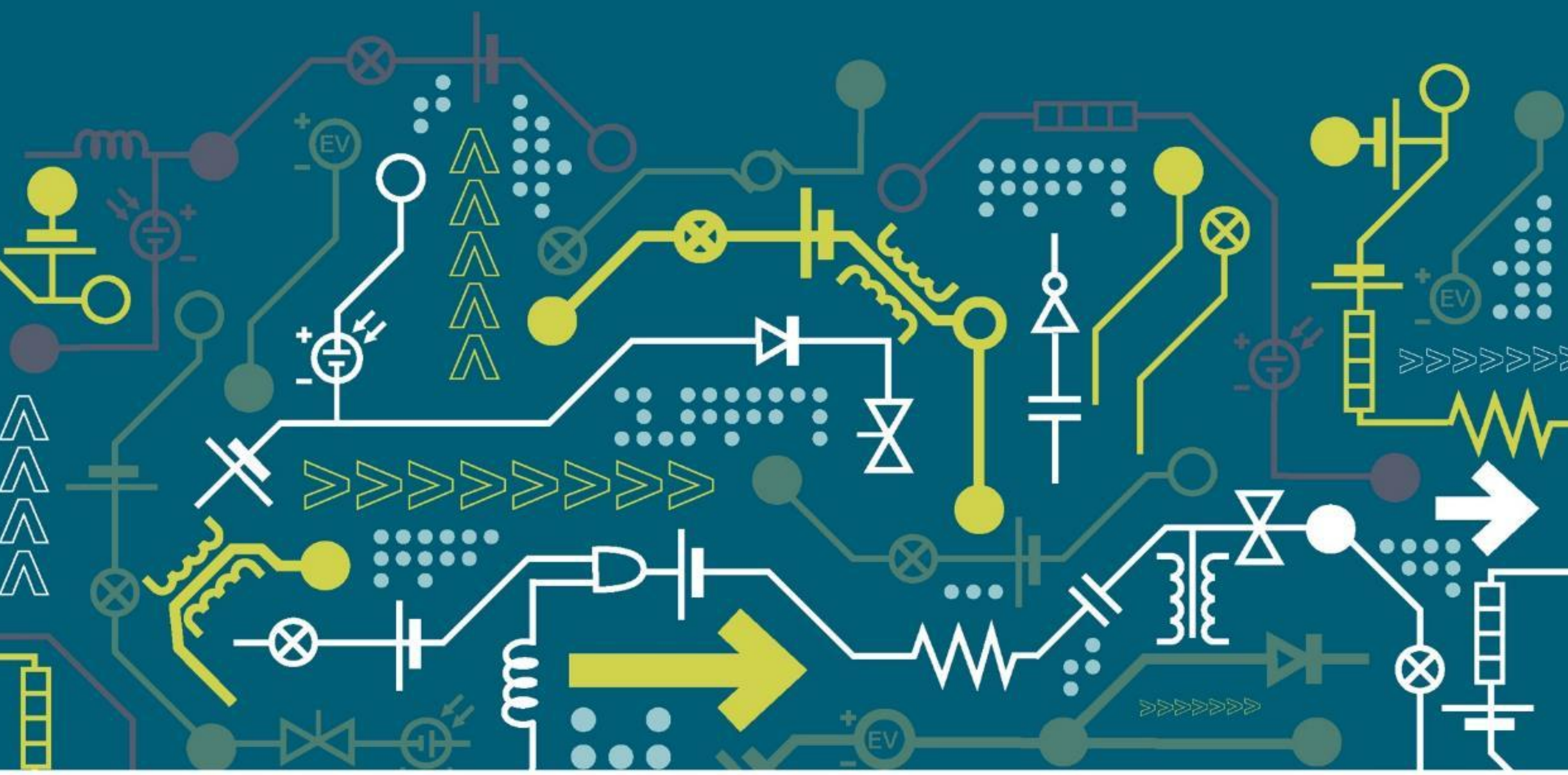
[52] Accenture Strategy , “Utilities: Lead the Charge in eMobility,” [Online]. Available: https://www.accenture.com/_acnmedia/PDF-97/Accenture-Utilities-Lead-Charge-eMobility.pdf#zoom=50.

[53] Emu Analytics, “A sustainable Future, Preparing for Electric Vehicles,” White Paper, May 2018. [Online]. Available: https://www.emu-analytics.com/whitepapers/electric_vehicles.

[54] Transport Laboratory Research, “Turning flow at Motorway Service Area,” TRL, 2020.

[55] Production Engineering Solutions, “UK now has more electric car charging points than fuel stations,” 15 Aug 2019. [Online]. Available: https://www.pesmedia.com/electric-vehicles-charging-points-uk/. [Accessed 29 June 2020].

Appendix



WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

A. Network Connection Diagrams

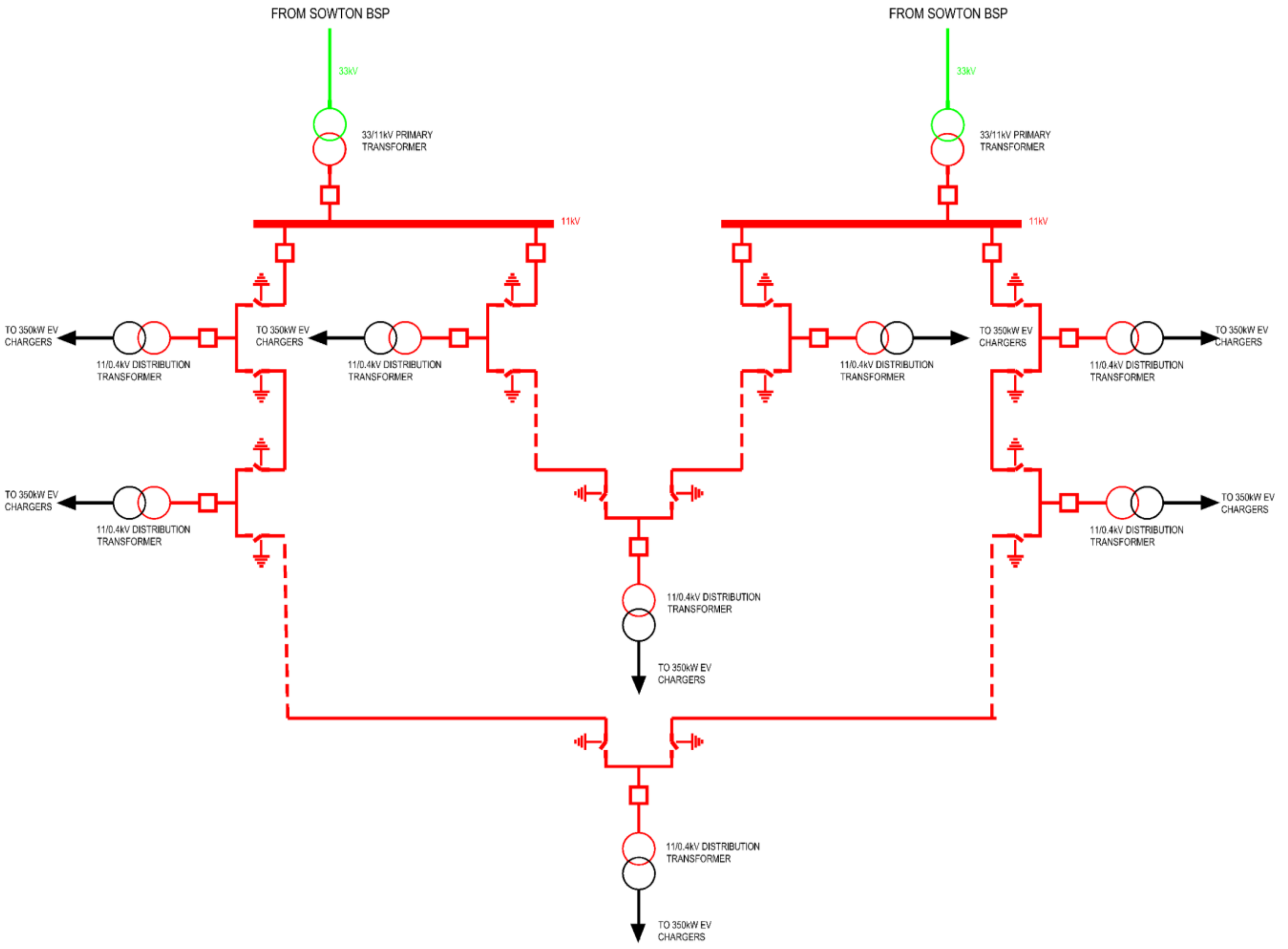


Figure 5-1 Example of network connection by two primary transformers for charging station

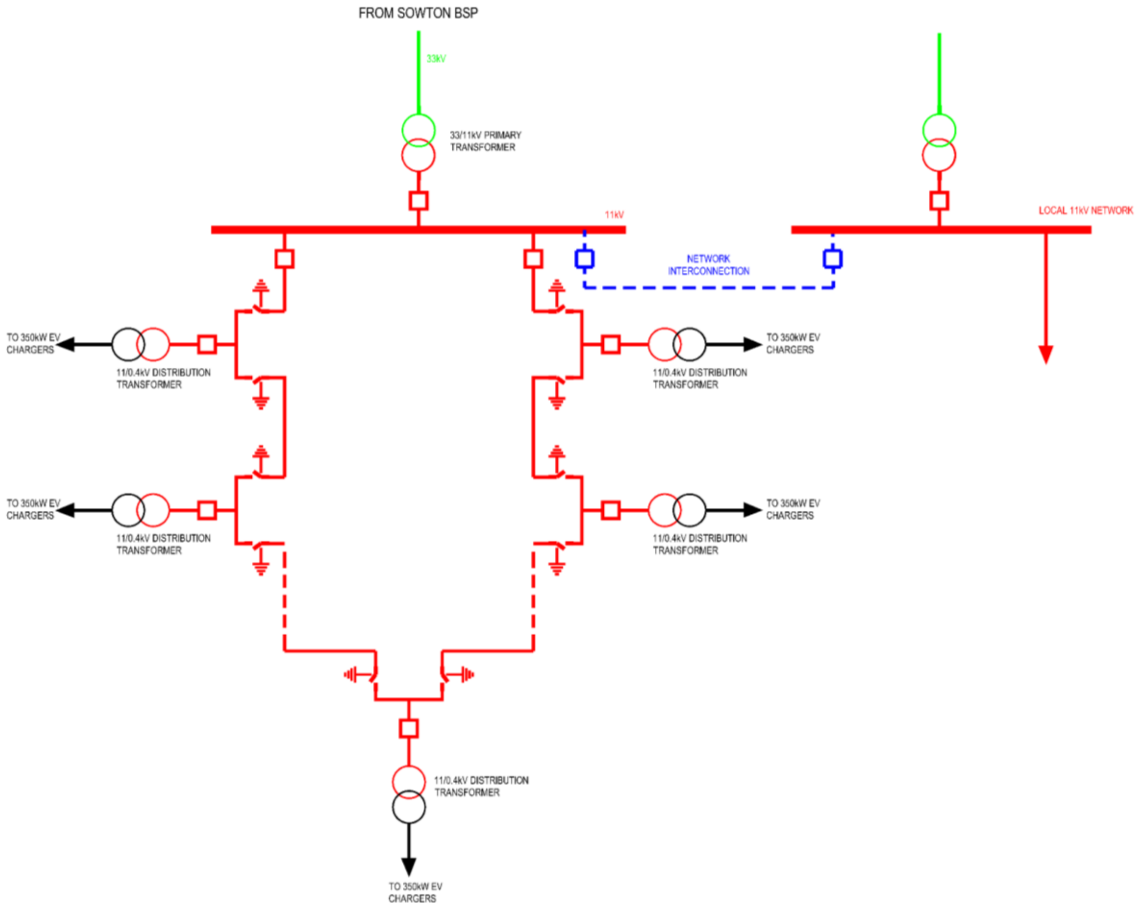


Figure 5-2 Example of network connection by single primary transformer and interconnection to local 11kV network for charging station

Western Power Distribution (East Midlands) plc, No2366923
Western Power Distribution (West Midlands) plc, No3600574
Western Power Distribution (South West) plc, No2366894

Western Power Distribution (South Wales) plc, No2366985

Registered in England and Wales
Registered Office: Avonbank, Feeder Road, Bristol BS2 0TB

wpdinnovation@westernpower.co.uk
www.westernpower.co.uk/innovation

@wpduk