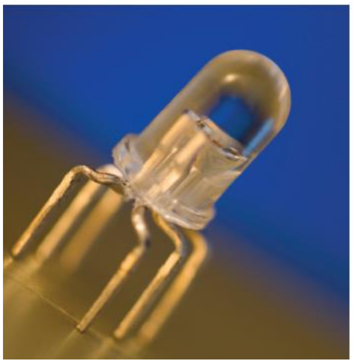

Overview of the Electric Vehicle market and the potential of charge points for demand response

10 March 2016

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A report submitted by ICF Consulting Services

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Contents

1 Executive summary

The purpose of this report is to provide an overview of the electric vehicle (EV) market in the UK along with the charging infrastructure and to examine the potential for demand response management of charging points drawing on the results of trials carried out in the UK.

Since 2010 the electrification of transport has been in the spotlight with market deployment envisaged to grow rapidly over the next years. However, the roll-out of EVs requires access to charging infrastructure. Trials carried out by the "My Electric Avenue" project show that the uptake of EVs, especially when clustered, can lead to stresses on local low voltage distribution networks as most people charge at home after work. Demand response solutions can resolve localised problems with network voltage and thermal capacity by shifting demand later into the night, without compromising the users' travelling requirements.

A literature review of major UK trials and studies pertaining to EVs, charging infrastructure and demand response was carried out and a summary of key findings is provided below:

- Based on evidence from an Electricity Infrastructure Roadmap to 2050 for transport:
  - **20 to 25 million EV passenger cars** on the roads envisaged by 2050 across the UK compared to nearly 50,000 in 2015.
  - **10 to 15 million residential** off-street and shared on-street **charge points** envisaged by 2050 compared to 60,000 in 2015.
  - **80% of electricity for transport** could be delivered **via residential charging infrastructure**.
- **66% of EV owners charge at home between 4pm and 10pm** as they tend to plug in after work. This actually **coincides with the domestic peak demand**.
- A **3.5 kW Nissan Leaf** currently has energy consumption roughly equivalent to that of **a kettle operating at a continuous rate for several hours**.
- **Domestic charge points** can operate at **3.7kW or 7.4kW**. Higher power rating of up to 50 kW (or higher based on type of vehicle) are observed in public and commercial areas.
- More than **65% of EVs** are charged until the battery is full.
- **EV uptake** could lead to a **domestic peak demand of nearly 2kW** per household, which is **double the domestic peak demand observed without EV deployment**.
- **Without** any **demand response** action **32% of the low voltage feeders** (i.e 312,000 circuits) **will require reinforcement by 2050** to cope with clustered EV uptake (based on 40-70% of customers having an EV charging at 3.5kW). With new EVs having higher power capacities of 7.5kW the impact to the low voltage network might be even higher.
- **With demand response solutions,** domestic feeders are likely to experience **curtailment during the evening peak** and this is expected to be more **prominent in winter**.
- **EV charging demand** occurring during system peak hours can be **shifted towards the late evening and night hours** providing the same volume of energy during the same stationary periods.
- "**My Electric Avenue**" project, the **largest network-related trial in the UK** and potentially in **Europe** has proven that **load curtailment** with Esprit technology can **be beneficial for all major EV stakeholders** (i.e. Distribution Network Operators (DNOs), EV manufacturers and EV owners). Evidence shows that **demand response can work with**:
  - ***the network***: thermal headroom[1] benefits of up to 46% at the highest levels of EV uptake using the curtailment technology whereas voltage headroom[2] could be equivalent to an additional 10% of customers connecting EV charge points.
  - ***the vehicle***: curtailment has no impact on battery life
  - ***the consumer***: the majority of consumers accepted the controlled curtailment and were comfortable with the Esprit technology being able to control their charging.

[1] Thermal capacity of an electricity network is determined by the continuous and short term rating of transformers, circuit conductors and switchgear. Thermal headroom is the amount remaining before the capacity limit is reached.
[2] Voltage capacity of an electricity network is restricted by statutory voltage limits which are imposed on distribution networks at all nominal voltages. Voltage headroom is the amount remaining before the voltage limit is reached.

2 Demand response potential for charge points

2.1 Hypothesis

High power chargers, including those suitable for use with electric vehicles (EV), have the potential to present a substantial and growing load on the electricity network, which is suitable for demand response. More specifically:

- The take up forecasts and government ambition for EVs are large.
- There is emerging evidence of a preference to home-charge at peak network load times.
- Technical potential exists to shift these loads and provide frequency response.

2.2 Summary of relevant evidence

2.2.1 International outlook for EVs uptake

In the last 10 years vehicle electrification has gained global attention in light of increasing and volatile oil prices, deteriorating urban air quality, and climate change. After the mass production of EVs began in 2010, stock levels globally have amounted to over 665,000 vehicles (as of end of 2014) representing 0.08% of total passenger cars[3] [1]. The Electric Vehicle Initiative[4] seeks to facilitate the global deployment of at least 20 million passenger car EVs, including plug-in hybrid and fuel cell electric vehicles, by 2020 [2].

The electric vehicle market at present is heavily dependent on “early adopters” keen to try out new technology or reduce their emissions, and on government incentives offered in markets such as China, Netherlands and Norway. The US currently has the highest proportion of EV stock accounting for 39% in 2014, followed by Japan with 16% and China with 12% [1].

Box 2.1 EV uptake and DSR in selected countries

USA – California

In the U.S., a federal tax credit for EV purchases offers buyers up to $7,500 toward the cost of a new vehicle[5]. California also provides vouchers up to $45,000 for EV fleet purchases, and rebates up to $2,500 for individual EV purchases, subject to programme funding limits. The Californian energy supplier Pacific Gas & Electric provides EV owners the option of taking a tiered residential rate or a special time of use rate, based on whether or not they have a separately metered charging station. Southern California Edison offers flat-rate, time-of-use (TOU) pricing for separately-metered charging stations. In the city of San Diego specifically, which has a fleet of 3,300 EVs in use and 400 public charging stations, the TOU tariffs provided by the local energy supplier have caused more than 80 percent of electric vehicle charging to be scheduled between midnight and 5 a.m. This has led to more efficient use of generating capacity.

China

China is expected to become the world's biggest electric car market this year, with sales estimated at 220,000 to 250,000 vehicles, based on the Chinese Association of Automobile Manufacturers surpassing the US[6]. The market is growing quickly because of generous subsidies and incentive programmes (including tax incentives and exemptions from restrictions designed to reduce traffic

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3 Statistics based on 16 key countries participating in the Electric Vehicle Initiative

4 The Electric Vehicles Initiative (EVI) is a multi-government policy forum dedicated to accelerating the introduction and adoption of electric vehicles worldwide. EVI is one of several initiatives launched in 2010 under the Clean Energy Ministerial, a high-level dialogue among energy ministers from the world’s major economies. EVI currently includes 15 member governments from Africa, Asia, Europe, and North America, as well as participation from the International Energy Agency (IEA).

5 http://www.theicct.org/sites/default/files/publications/EVpolicies_final_July11.pdf

6 http://www.reuters.com/article/us-autos-china-idUSKBN0TP0IQ20151206

congestion). These policies are part of a drive to put 5 million new energy vehicles (NEVs) on Chinese roads by 2020[7]. The country is also implementing a small number of demand response pilot programmes which will pave the way to more policy reforms in the short-term. In March 2015, the government also introduced power sector reforms addressing issues that will affect demand response: pricing reforms, ancillary services markets, and the opening up of wholesale electricity markets.

Japan

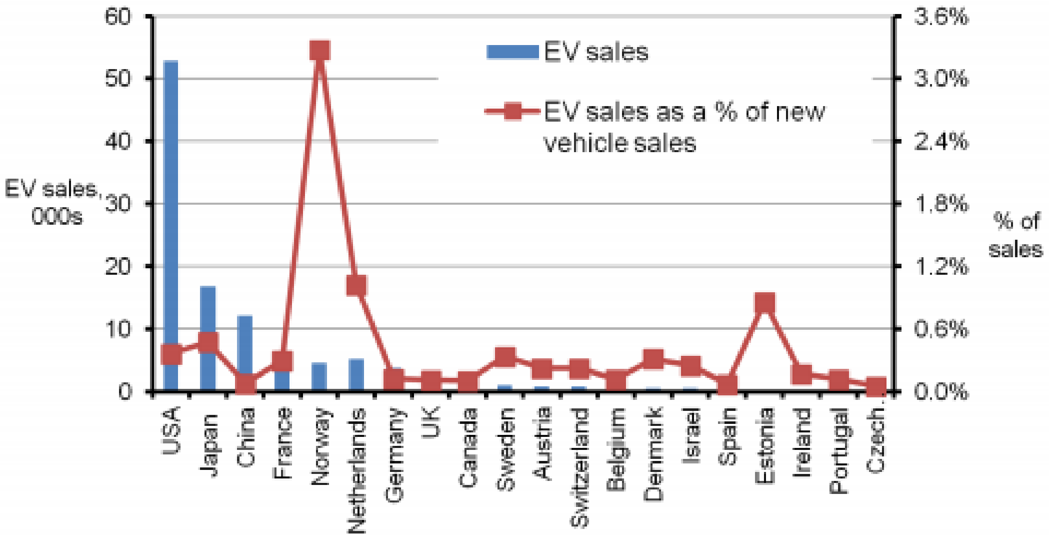
Demand response as an overall strategy has been making Japanese grids more efficient by giving incentives to consumers to modify their power consumption during times of peak usage[8]. Japan has introduced the LEAF to Home system which is part of a larger Vehicle to Home (V2H) initiative to expand the use of electric vehicles in both emergencies and to support the overall electrical grid operation during daily use. The new system is being tested for demand response capability and involves several Nissan LEAF sales outlets in Japan and ENERES Co, an energy management company. The LEAF-To-Home system enables EVs to discharge power to the home, supporting peak reduction, emergency power supply, and reducing the cost of electricity[9].

Norway

In 2015 Norway achieved its goal of reaching 50,000 zero emission vehicles by 2018. Among the existing incentives, all-electric cars are exempt in Norway from all non-recurring vehicle fees, including purchase taxes, which are extremely high for ordinary cars, and 25% VAT on purchase, together making electric car purchase price competitive with conventional cars. Electric vehicles are also exempt from the annual road tax, all public parking fees, and toll payments, as well as being able to use bus lanes. These incentives are in effect until the end of 2017[10].

Although Europe is the smallest regional market, it hosts six of the top 10 countries in the world for absolute EV sales as indicated in the figure below [3]:

Figure 2.1 New Vehicle sales of EVs in leading countries in absolute terms and as a % of total vehicles sold (2012)



Source: The Climate Change Committee

[7] http://en.cnesa.org/featured-stories/2015/11/27/chinas-grid-and-the-electric-car

[8] http://www.torquenews.com/1080/nissan-begins-leaf-home-grid-demand-response-testing

[9] https://www.veic.org/documents/default-source/resources/reports/evt-rd-electric-vehicles-grid-resource-final-report.pdf

[10] https://en.wikipedia.org/wiki/Plug-in_electric_vehicles_in_Norway, http://www.globalsmartgridfederation.org/2014/03/31/smart-grid-developments-in-norway/

An overview of incentives and infrastructure in place for a selected pool of countries is provided in the table below:

Figure 2.2 Financial incentives for EV purchase and charging infrastructure

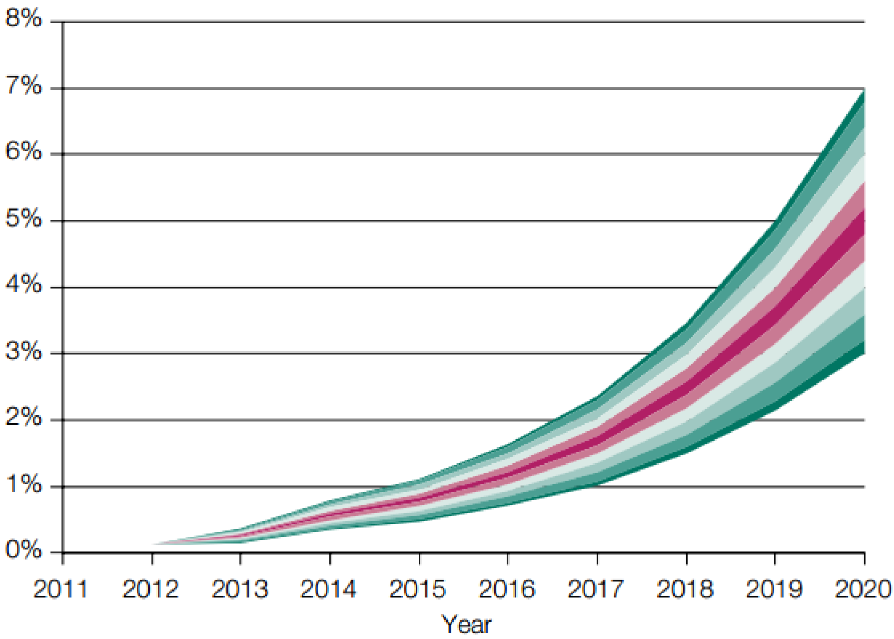
	Norway	Netherlands	Japan	United States	Sweden	Denmark	France	Ireland	Germany	UK
Capital cost incentives[75] (either grant or tax break)	£12,200 (BEVs only)	£4,200 – £6,800 for private purchase	Up to £6,700	£1,590 - £4,770 Federal tax credit	£3,900	Up to £35,000 depending on segment (BEVs only)	£5,900	£5,650	Up to £8,500 (corporate purchase only)	Up to £5,000 for cars, £8,000 for vans
Running cost incentives	Annual tax exemption, Free parking, Exempt from road tolls.	Annual tax exemption, Exempt from income tax for lease vehicles, Some free parking.		State – specific incentives inc. insurance and parking charge exemptions	Annual tax exemption, Free parking in places, exempt from congestion charge in Stockholm	Annual tax exemption, Free parking	Annual tax exemption, Free parking in some places		Annual tax exemption	Reduced annual tax, Exemption from congestion charge in London
Charging infrastructure*	c. 4,000 public CP, and 127 fast chargers	c. 4,500 public and semi-public CP, and 89 fast chargers	Emphasis on fast charging, with 1,400 fast CP and c,4,000 slow CP	c. 14,000 slow CP and 200 fast CPs	c. 280 slow CP (although most people have access at home or work)	c. 1,080 slow CPs and c. 100 fast CPs	c. 1,600 slow CPs and 100 fast CPs	640 slow CPs	c. 2,000 slow CPs	C 8,500 public CP, <100 50kW chargers
2012 EV sales, %	**3.28%**	**1.02%**	**0.47%**	**0.36%**	**0.34%**	**0.31%**	**0.30%**	**0.17%**	**0.12%**	**0.11%**

Going forward the sales of electric vehicles are expected to reach 41 million by 2040 representing 35% of new light duty vehicle sales. This would be almost 90 times the equivalent figure for 2015, when EV sales are estimated to have been 462,000, some 60% up on 2014. At the core of these projections is that cost of batteries which make up one third of the cost of an electric vehicle will continue to fall and thus demand for EVs will rise [4].

2.2.2 UK landscape

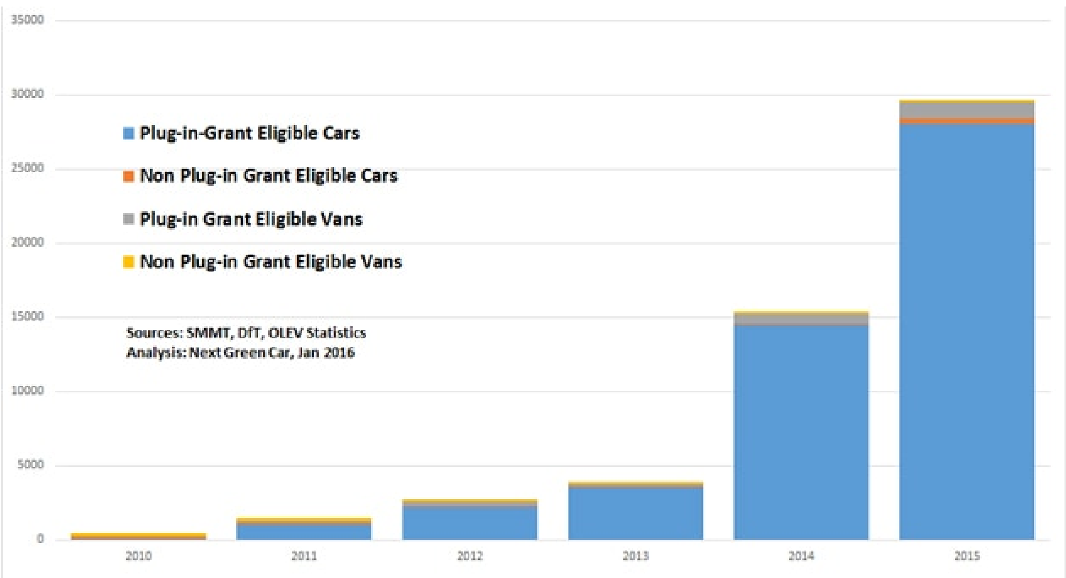
The last three years have seen a remarkable surge in demand for electric vehicles in the UK. More specifically, new registrations of plug-in cars increased from 3,500 in 2013 to approximately 48,000 by the end of 2015 (based on claims made through the Plug-in Car and Van Grant schemes). Statistics show that annual electric car sales in the UK have risen by 121% during the past 12 months (from 13,556 units in 2014 to 29,894 in 2015) with sales of electric cars expected to account for 3% to 8% of all car sales by 2020 [5,6].

Figure 2.3 Projected EV car sales as proportion of all car sales (2011-2020)



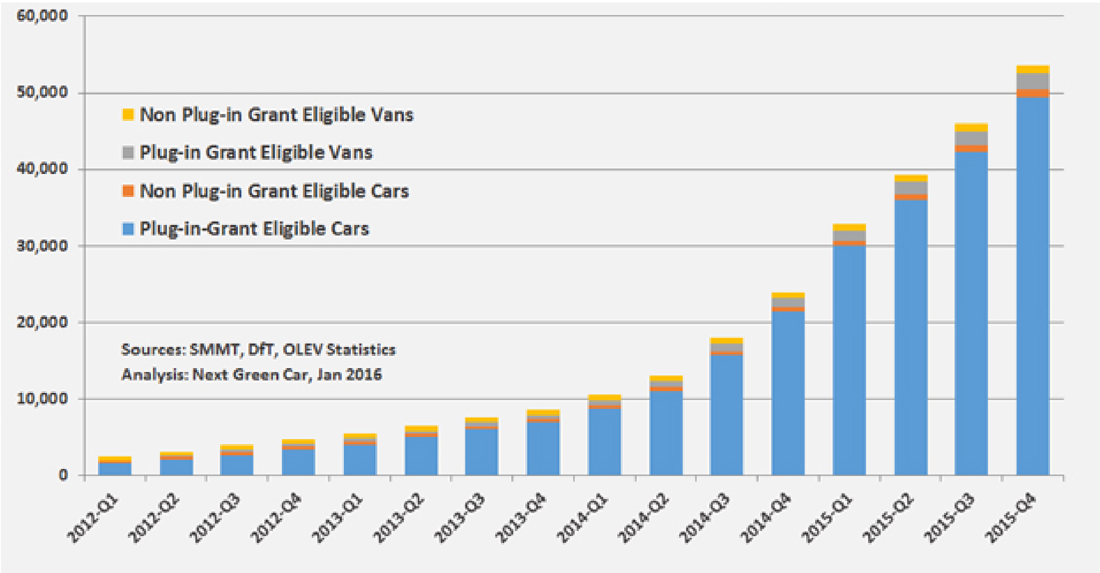
Source: Department for Transport modelling

Figure 2.4 Annual electric vehicle sales in the UK (2010-2015)



The figure below shows that the total registrations of EV cars after taking into account registrations that refer to cars not eligible under the grant schemes, account for over 50,000 electric vehicles in 2015.

Figure 2.5 Cumulative electric vehicle registrations 2012-2015



Source: Next Green Car

The uptake of EVs remains difficult to predict particularly beyond 2020. To give an idea of scale, 2.63 million new cars of all types were registered in the UK in 2015, a 6% rise on 2014. So EVs are expected quickly to take a significant share of a growing market. Evidence shows that the total number of EVs up to 2030 will range from 1.8 million to over 5 million EVs with forecasted energy usage varying from 4TWh to 14 TWh based on the following three scenarios developed [7]:

- High uptake: this is based on the base case scenario developed by Element Energy for the Low Carbon Vehicle Partnership Project (LowCVP);
- Medium uptake: National Grid's "Gone Green" scenario based on 2015 Future Energy Scenarios (FES); and
- Low uptake: National Grid's "Slow Progression" scenario based on 2015 Future Energy Scenarios (FES).

Figure 2.6 Projected number of EVs by 2030

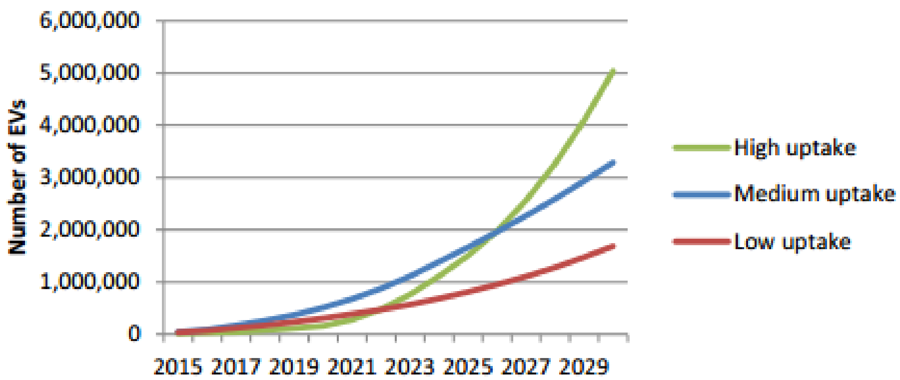
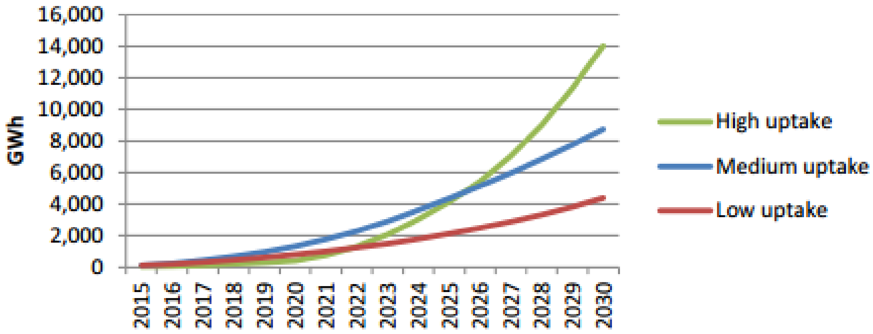
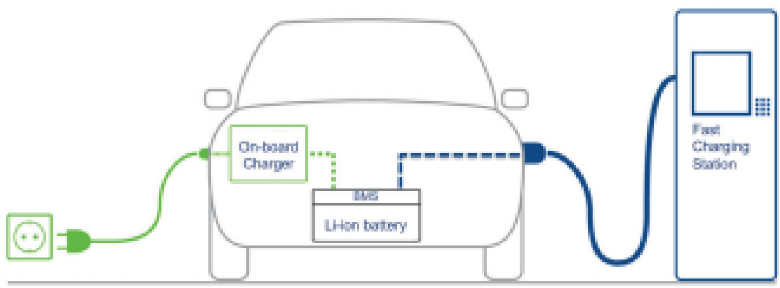


Figure 2.7 Projected annual electricity demand by 2030



Other reports from the Low Carbon Vehicle Partnership (LCVP) project show even higher stock levels with 4.7 to 9.3 million EVs estimated to be on the road in 2030 rising to 23.5 to 29 million by 2050 (with more than 86% accounting for passenger cars and the remaining 14% covering vans and heavy duty vehicles) [8].

However, high uptake of EVs needs to be facilitated by easy access to charging infrastructure. More specifically, today's technology supports two charging methods through either on-board AC charger (slow/fast charging) or an immobile off-board DC charger (rapid charging) [9].



The primary EU standard governing electric vehicle charging is IEC 62196 (with charging communication interface in Europe dictated by ISO 15118) and defines four charging 'modes' as follows [7, 8]:

- Mode 1 – Household socket and extension cord

  Connection of the EV to a standard AC mains socket outlet. This mode is not recommended in the UK because residual-current device (RCD) protection, which is necessary to ensure protection against electric shock, is not guaranteed for all socket outlets. In this case, the AC/DC conversion and charging equipment is on the car.

- Mode 2 – Household socket and cable with a protection device

  Connection of the EV to a standard AC mains socket outlet, but with a charge controller fitted on the connection cable to inform the EV of the charge power that can be drawn and to provide RCD protection (located within the cable). The power is limited to 3kW for domestic socket-outlets and to 7.4kW for industrial socket-outlets. In this case, the AC/DC conversion and charging equipment is split between cable and car.

- Mode 3 – Specific socket on a dedicated circuit

  Connection of the EV to a charge point or EVSE[11] (Electric Vehicle Supply Equipment) supplying AC power. The charge point is able to communicate with the EV to inform it of

[11] EVSE delivers electrical energy from an electricity source to charge an EV's battery and communicates with the EV to ensure that an appropriate and safe flow of electricity is supplied [1]. Based on the IEC 61851-1 standard EVSE is defined as "conductors, including the phase, neutral an protective earth conductors, the EV couplers, attachment plugs, and all other accessories, devices, power outlets or apparatuses installed specifically for the

the available power, and there is safety interlocking between the EV and charge point. A single phase Mode 3 system usually operates at 3.7kW or 7.4kW (applicable to home charging), while a three phase system may operate at a higher power rating (typically 11, 22 or 43kW applicable to workplace and public charging). In this case the charging equipment is split between the immobile infrastructure (controlling the AC supply) and the AC/DC conversion equipment which is on the car. As Mode 3 includes data connection, Mode 3 enables full vehicle isolation and ‘smart’ charging capability.

- Mode 4 - DC connection for fast recharging

  Connection of the EV to a charge point supplying DC power. There is communication between the EV and the charge point to establish safety and define the appropriate charge current. These have a wide range of charging capabilities up to over 100kW which is more suited to public and industrial/commercial applications where the time available for charging is limited. Currently, the most common Mode 4 charge point power is in the 20-50kW range with higher power to become available in the medium term. In this case the charger is part of the immobile infrastructure off the car, providing controlled amounts of direct current to the battery. Mode 4 includes a full ‘handshake’ so enabling ‘smart’ charging capability.

- Inductive charging – (emerging technology)

  A way of charging a battery without connecting it to a charging station is by inductive charging. With this technology, electrical energy is transferred by a process of induction in which magnetic forces are used to transfer electrical power from a transmitter to a receiver, without the use of cables or connections. In this instance the charging equipment is split between an immobile source and a receiver on the car.

A list of EVSEs along with their charging time and service capabilities is presented in the following figures [6]:

Figure 2.8 Example of mode 2 charging

purpose of delivering energy form the premises wiring to the EV and allowing communication between them if required ”.

Figure 2.9 Indicative list of available mode 3 and 4

Market Segments	Equipment		Charge Time / Service Capability
Office/Home (Work/Sleep & Charge)		AC Wallbox	4 - 8 hours 1 - 2 vehicles/day
Public (e.g., Parking Lot)		AC Charge Post	4 - 8 hours 1 - 2 vehicles/day
Commercial/Office (Park & Charge)		Convenient Fast Charger DC 20 kW AC 22 kW	30 - 120 minutes 10 - 15 vehicles/day
Highway (Charge & Go)		Fast Charger DC 50 kW AC 43 kW	15 - 30 minutes 12 - 24 vehicles/day

Example of Mode 3 charging

Example of Mode 4 charging

At the time of writing, 5,704 public charging devices have been installed across the UK based on information obtained from a public charging infrastructure database [10]. However, there is no obligation to report installations of charging points to the national charge point registry so the aforementioned figures might be a fraction of the actual installed charging base.

With regards to the residential charging infrastructure, it is estimated that around 60,000 charging points are currently installed. However, a breakdown of mode 1, 2 and 3 charge points is not available.

Moreover, evidence from the Electricity Infrastructure Roadmap developed for the LowCVP project shows that ambitious uptake-scenarios and unbalanced access to off street parking in urban/rural areas means that many households will need new solutions for access to regular charging [8]. To this end, Westminster City Council in London has introduced a rule for new builds and retrofit to be “socket-ready”.

Another conclusion of the Electricity Infrastructure Roadmap is that by 2050, over 80% of electricity for transport could be delivered via residential charging infrastructure as approximately 19 million households (c.70%) have a garage or off-street parking in the UK (although this can be as low as 10% in certain urban areas). Thus, the study suggests that domestic charging must be prioritised due to >95% lower cost relative to on-street charging. However, drivers without off-street parking (30% of households) must also be supported [8].

Evidence shows that millions of charge points (especially in the residential sector) will be needed to support widespread EV deployment with a degree of uncertainty over charging technologies. In particular, based on the Electricity Infrastructure Roadmap for the LowCVP project it is estimated that the following charging infrastructure will be required in the long term [8]:

Table 2.1 Charging Infrastructure (up to 2050) based on the Electricity Infrastructure Roadmap developed for the LCVP project

Charging infrastructure network	Vehicle types	2020	2025	2030	2050
Residential	Cars/Vans (3-7 kW off street or shared on-street)	300,000-370,000		3,900,000-7,200,000	10,000,000 - 15,000,000
Public network (total sites with variable number of CPs)	Various	500	1,100 (c. 10 CPs per site)	2,200	Dependant on BEV/ PHEV split and charging rates
Depot/workplaces	Cars/vans (3/7/22kW)	8,000-10,000		100,000-200,000	400,000-550,000
	buses/HGVs (>40kW plug and wireless)	Installed with concurrent trials of alternative power delivery systems		4,000-5,000	20,000-25,000

Note: based on new sales car/van EVs scenarios

Evidence from the National Travel Survey (a database of 1.25 million car journeys from 23,589 households covering period 2007-2010) has shown that the most frequently visited location is the home followed by the workplace. This reinforces arguments that home charging infrastructure should be prioritised to facilitate e-mobility, with commercial depots also playing a pivotal role as the second most important location for recharging points [11]. Based on this survey the electrical installation in most domestic dwellings could support two 3kW charge points or one 7kW with some older properties with lower capacity supplies requiring an upgrade.

Most private EV owners are currently middle-aged, male, well-educated, affluent, and live in urban areas with households containing two or more cars and with the ability to charge at home. The majority of EV owners in 2013 were based in urban areas (63%) with the remaining 37% in rural areas. Looking ahead to the next 3-5 years, and based on insights from more developed EV markets, the basic socio-demographic profile of EV owners in the UK is not likely to change significantly. For instance, in Norway 90% of EV drivers live in metropolis, cities or densely populated areas [12].

2.2.3 Residential EVs and charging patterns – findings from major UK trials

The results of the Low Carbon London (LCL) trials on a sample of 54 residential EVs showed that most of the monitored EVs were charged at 3.7 kW (i.e. 16 A[12]), although both higher (up to 7.5kW) and lower (1.7kW) maximum charging powers were witnessed [13]. This is in line with the 3.5 kW charging power observed in the “My Electrical Avenue” trials (sample of 220 EVs) although new EVs can charge at double that rate [14].

A typical profile of a charging event for an individual EV with respect to time and power involved is presented in Figure 2.10 below. The event lasts for 2.5 hours during which 6.6 kWh is consumed from the grid [13].

[12] Household mains wiring typically has 32A rated ring circuits, 32A dedicated cooker connections, 20A radial circuits and 6A lighting circuits. Hence a charger of 16A is too large a load for a standard 13A socket, and so should be wired with a dedicated circuit that can be switched independently of other household circuits.

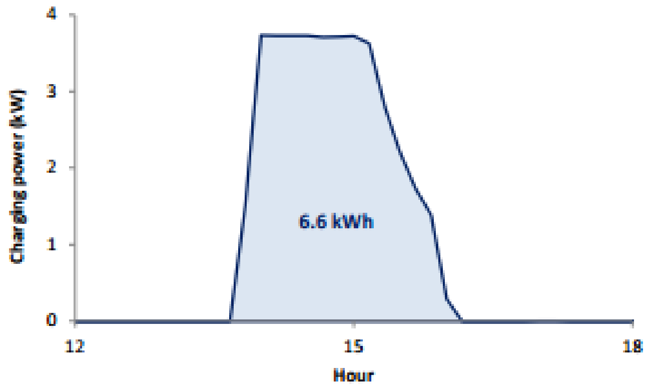
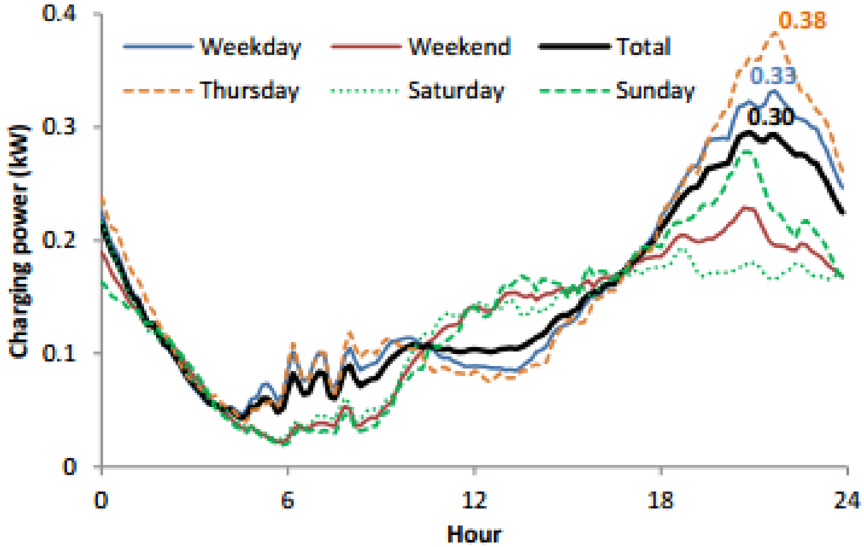


Figure 2.10 Demand profile for a typical charging event (charged to full capacity)

Source: LCL trials, Report B1

Based on the charging patterns of the LCL sample, most of the charging energy requirements are observed between 6 pm and midnight with the peak demand occurring at around 9 pm in the evening. The energy charging requirement for an average workday is 3.68 kWh leading to an average peak demand of 0.33 kW (Figure 2.11). This decreases to 3.09 kWh for an average weekday where the peak value for average demand per EV is around 0.23 kW [13].

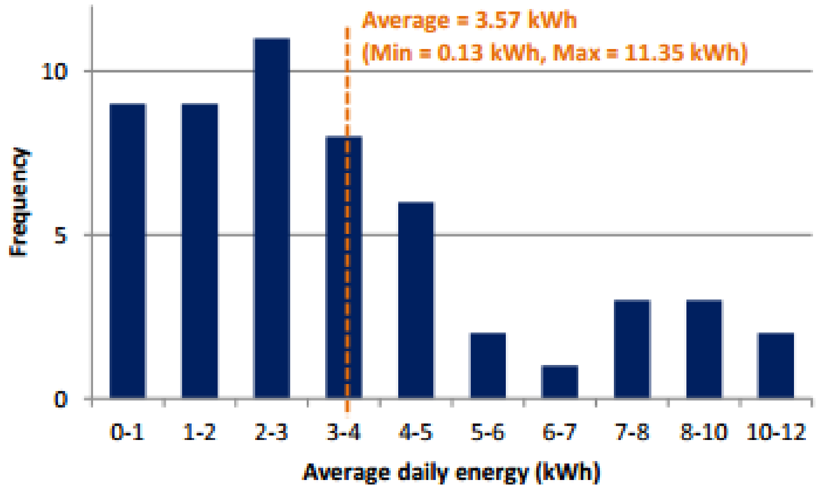


Day type	Energy requirement for charging (kWh)	Peak average demand (kW)
Workdays	3.68	0.33
Weekend	3.09	0.23
Monday	3.33	0.34
Tuesday	3.84	0.35
Wednesday	3.57	0.30
Thursday	3.80	0.38
Friday	3.88	0.30
Saturday	2.96	0.22
Sunday	3.22	0.28

Figure 2.11 Average charging profiles per EV for different days of week

Significant variations have also been observed in the charging energy required to support the EVs journeys. More specifically, the charging demand per day varied from 0.13 kWh to 11.35 kWh with the average being 3.57 kWh.

Figure 2.12 Distribution of daily energy requirements for the residential EV sample



According to the LCL trials, residential vehicles spend on average around 7.8% of their time (i.e. almost less than 2hrs per day) charging although this varies from 10 minutes to 11.5 hours. This is significantly longer than any other existing non-heating loads in the home, such as power showers, tumble driers and vacuum cleaners. Although this does not mean that the vehicles are available for demand shifting for the rest of the time, there seems to be considerable potential for demand shifting from residential smart EV chargers.

The trials have showed that 84% of the logging sample comprising 22 residential EVs charge their vehicles at home. Evidence shows that a great majority of charging events are terminated when the state of charge (SoC) reaches about 90-98%.

Evidence from the Customer-Led network Revolution (CLNR) trials showed that from 88 participants, 61% (i.e. 54 responders) reported that they charge their EVs in the evenings, with the second most popular answer being charging anytime/when needed (14%). Other interesting observations are that 67% of the responders in the EV survey reported that they charge their batteries when they are lower than half or lower than a quarter charge (34 and 24 responders respectively from 88 EV users).

The findings of the “My Electric Avenue” project also support the aforementioned evidence. More specifically, the trials showed that 66% of EV users charge electric vehicles at home (out of a sample of 279 responders) with the second preference being public charging (excluding rapid charging points) with 18% followed by 11% reported at workplace. In terms of the frequency, evidence from the Electric Avenue project show that most of the participants (over 70%) charged their EVs once per day [14].

Evidence from the trials also suggest that a great majority of charging events can be rather easily performed during the night, which implies there is a significant scope for deploying flexible charging schemes i.e. shifting charging demand towards the late evening and night hours.

2.2.4 Load shifting potential

2.2.4.1 “My Electric Avenue” project - Esprit curtailment technology

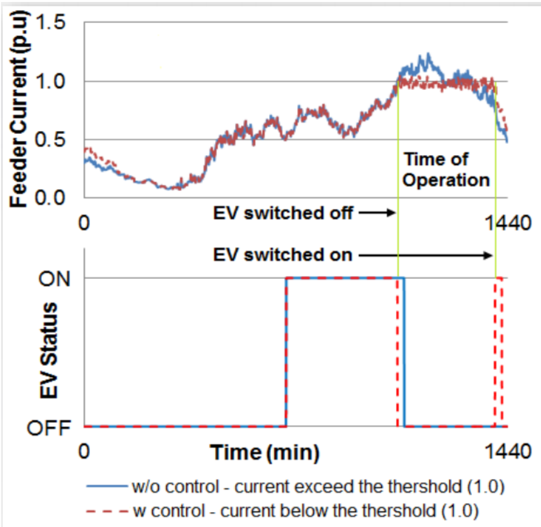
The EV market deployment requires significant roll-out infrastructure. In turn, this can lead to stresses on the local low voltage distribution networks, especially when EV uptake is clustered.

Thus, the “My Electric Avenue” project aimed to assess the potential impact of a cluster of EVs may have in a local area served by one electricity substation. Given the anticipated increase in EV uptake, if users charge their EVs at the same time then the load on the local electricity network may exceed the substation capacity.

The 3-year project was completed in December 2015 and examined ten "electric avenue" groups or clusters (nine residential areas and one business location) of ten or more people around Britain (a number of 100 drivers participated in the technical trials). The trial participants were driving a Nissan Leaf for 18 months to trial a new technology, "Esprit", which would monitor and control the electricity used when the car was being charged. This technology has been designed to avoid any potential power outages and damage to network infrastructure by temporarily curtailing high load devices (typically in this trial for 30 minutes) to reduce the overall load on a single feeder or transformer.

Figure 2.13 shows the load curtailment with Esprit technology whereby an EV which is plugged in for charging can be switched off at peak demand so that charging is delayed and the EV is switched back on during the off-peak period where there is no pressure on the feeder [15].

Figure 2.13 Esprit – conceptual approach

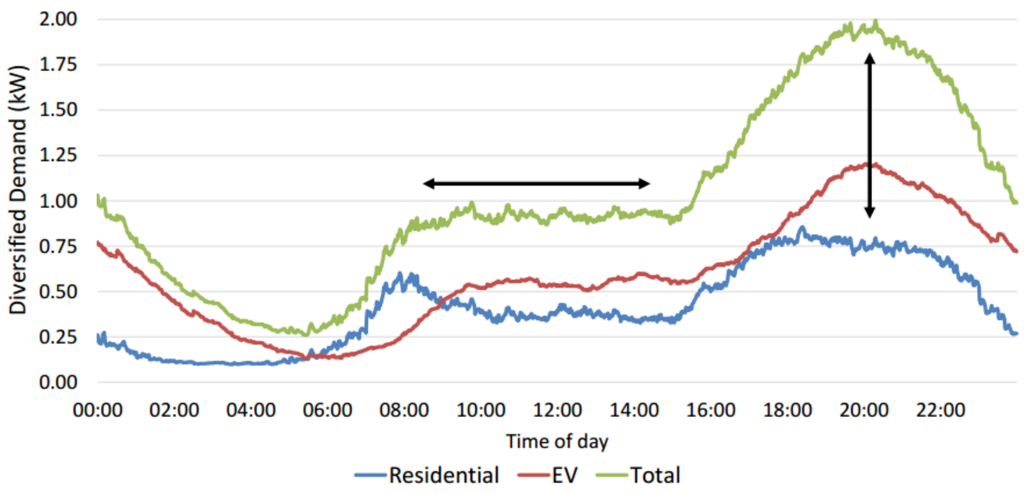


Social trials were also conducted in parallel with the technical trials and were mainly designed to provide a comparison with the participants who had their EV charging directly controlled (a further 120 drivers of Nissan Leaf were recruited without being in a cluster or having the curtailing technology fitted). In total 220 3.5kW Nissan LEAF EVs were monitored throughout the UK over the course of the project representing the largest network-related EV trial in the UK and potentially in Europe.

The project showed that the power drawn by a Nissan LEAF is currently roughly equivalent to that of a kettle operating at a continuous rate for several hours. The EV demand also coincides with domestic peak demand in the evening as users plug in EVs after returning home. Figure 2.14 shows that with the inclusion of EVs:

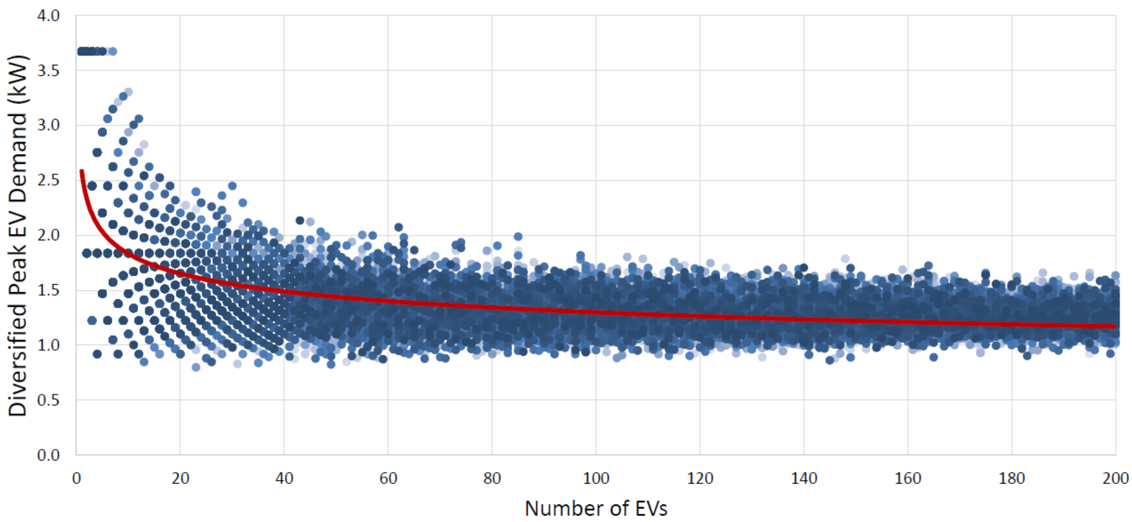
- demand from 8am to 3pm is even higher than the residential peak demand without EVs and
- peak demand doubles to nearly 2kW

Figure 2.14 After-diversity maximum demand with and without EV uptake (weekday)



With the ever growing uptake of EVs in the future the peak demand on the network is expected to rise further with the effect of clusters expected to increase the likelihood of localised problems with network voltage or thermal capacity. The networks in the UK are characterised by an available capacity of less than 1.5 kW per customer. As such, adding 3.5kW demand from EVs on top of the 1.5 kW average on the network will push things up and upgrades will be required (the trials concluded that the 220 EVs monitored during the project could have an impact of 1.2 kW to the network).

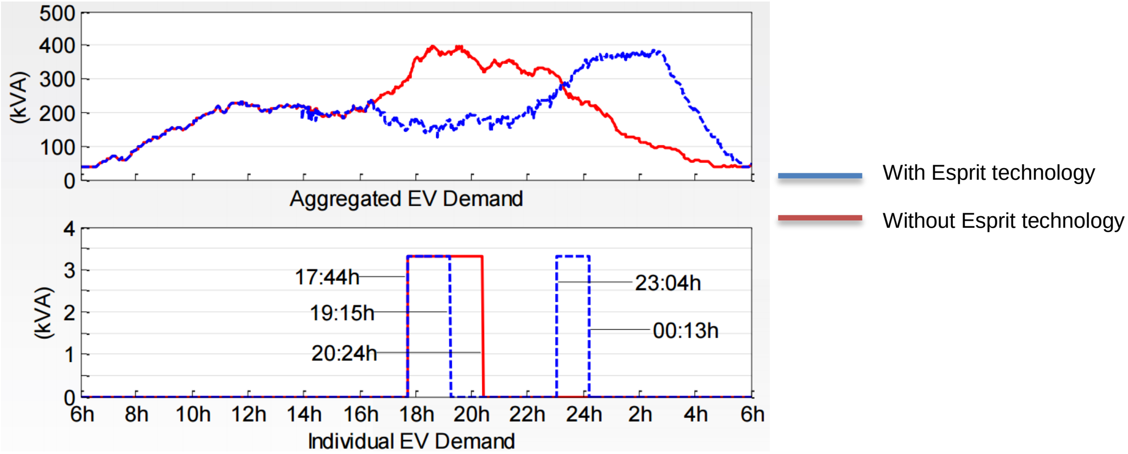
Figure 2.15 Diversified average EV demand



Industry trends towards higher power charging for vehicles with increasing battery capacities may further exacerbate this issue (it is worth noting that new EVs can charge at 7.5kW which is double the rate of the 3.5 kW Nissan Leaf used in the trials).

More specifically, trials have shown that 32% of the low voltage feeders (i.e. 312,000 circuits) will require reinforcement by 2050 to cope with clustered EV uptake (based on 40-70% of customers having an EV charging at 3.5kW) [14]. However, demand response management solutions such as curtailment can resolve these issues and can be more effective in a residential setting than at workplace based on findings from the “My Electric Avenue” project. Figure 2.16 below shows an example of the impact from the introduction of Esprit technology [15]:

Figure 2.16 Esprit-like control - EV demand



Modelling of the trial feeders to assess the likely loadings for different EV penetration levels showed that:

- Domestic feeders are likely to experience curtailment during the evening peak and this is timely to be more prominent in winter.
- Although the load differs for different phases of the feeder, two of the phases that required controlled charging could experience curtailment for a period of approximately three hours during the evening peak.
- Patterns for the curtailed and non-curtailed participants were broadly similar to each other with both groups most likely to start charging between 4 pm and 10 pm.
- None of the participants mentioned financial incentives as a way of making curtailment more acceptable [16].

Additionally, curtailment was a major concern for participants from the workplace cluster. The trials have found that most of the participants opted to charge at home due to the unreliability of receiving enough charge and the importance of leaving the charging points to those who had to charge at work due to the length of their commutes.

Other interesting outcomes from the trials showed that approximately 70% of the EVs are charged only once per day and 65% of EVs are charged until the battery is full. Moreover, 66% of the participants tend to charge their vehicles at home even if charging is controlled. The trials also evaluated the EV drivers' acceptability of a DNO being able to curtail charging and results showed that the Esprit technology didn't cause any insignificant inconvenience or unacceptable loss of service to EV users. Instead, the majority of participants reported that they were comfortable or very comfortable with curtailing charging.

The project has also provided conclusive evidence that demand response technologies can work with the vehicle. More specifically, trials showed that switching on and off the charging of EVs doesn't damage the vehicle battery, doesn't affect the relay life of the charger and doesn't have a negative impact on the market uptake as this has already started and the EV deployment has already risen significantly.

In terms of the benefits to the network, the project concluded that they vary based on the type of the network and feeder. For the four networks where EV uptake caused technical issues, the impact of Esprit technology varied from 25% to 115% as indicated in the table below:

Table 2.2 Impact of ESPRIT technology to the four networks affected by EV uptake

	Number of Residential Customers	Number of EVs before problems	Number of EVs with Esprit	% Increase in EVs
Feeder 2	102	71	153	115%
Feeder 4	101	40	50	25%
Feeder 6	76	30	38	27%
Feeder 7	167	117	167	43%

The trials showed that thermal headroom benefits up to 46% at the highest levels of EV uptake using the curtailment technology (Figure 2.17) whereas the voltage headroom could be equivalent to an additional 10% of customers connecting EV charge points (Figure 2.18).

Figure 2.17 Modelled impact of Esprit on thermal capacity (Phase C) – winter weekday (100% uptake)

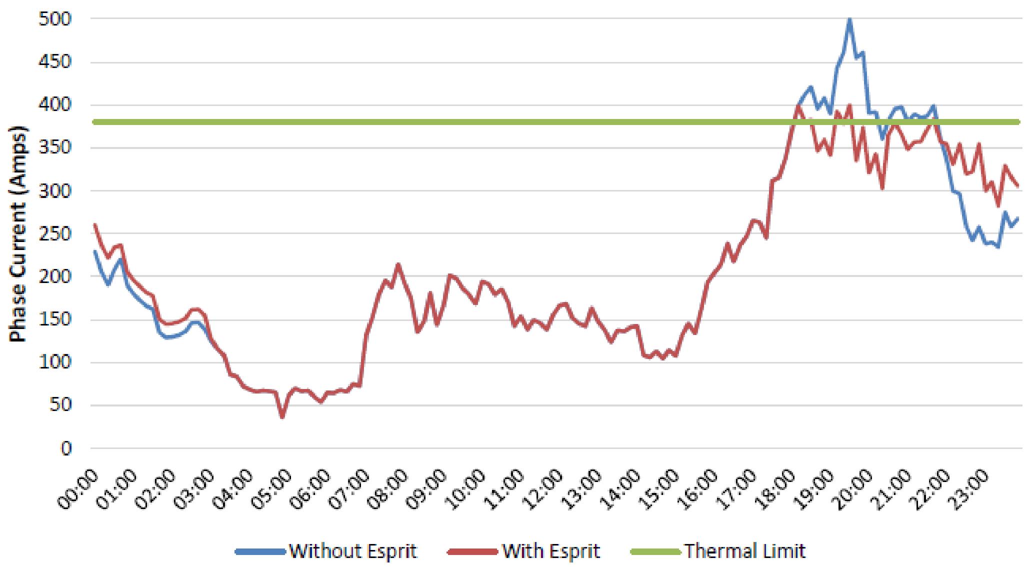
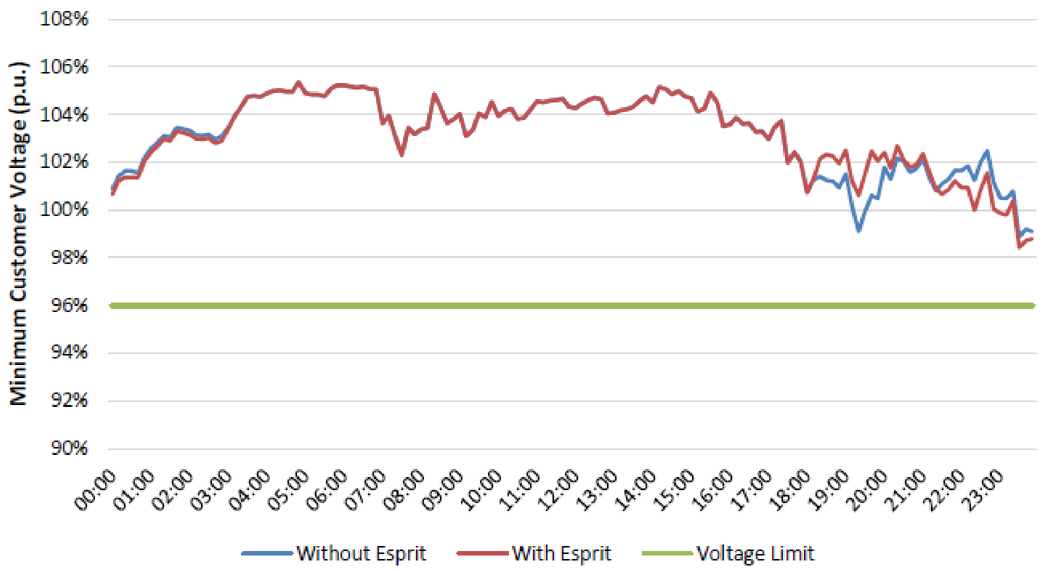


Figure 2.18 Modelled impact of Esprit on Voltage (Phase C) – winter weekday



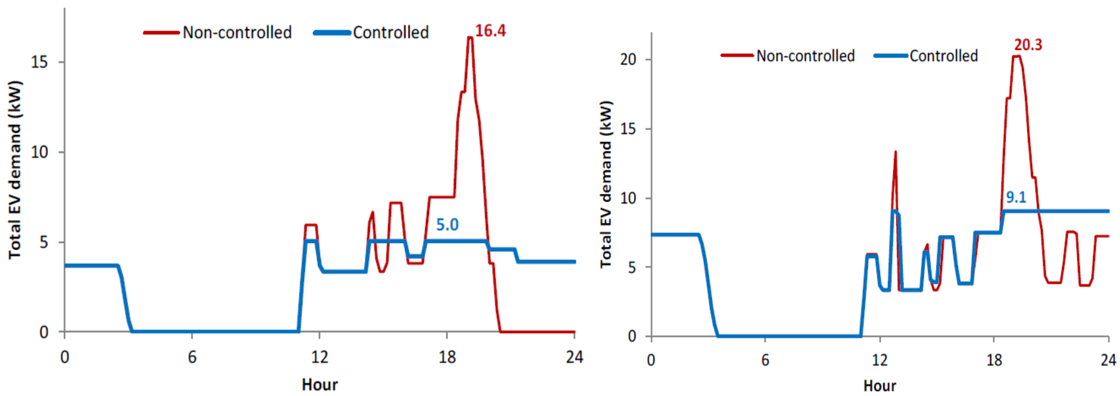
Thus, the project has proven that demand response solutions can work with DNOs, vehicles and consumers. However, a roll-out in the long-term will need a mechanism to educate consumers and help them understand the benefits of such solutions (either through incentives or standards with the latter to be further examined in a follow-up project by EA Technology who led the “My Electric Avenue” Project).

2.2.4.2 Low Carbon London (LCL) trials

The LCL trials have showed that there is significant potential for demand response with EVs without compromising the users' travelling requirements. Two residential case studies[13] indicate that most EV demand occurring during system peak hours can be shifted towards late evening and night hours, while still providing the same volume of energy during the same stationary periods [13].

More specifically, a peak demand managemeent tool was deployed[14] to shift EV charging demand only within the stationary periods immediately following charging events i.e. before the following journey begins. The resulting charging profiles before and after intervention are presented below for both cases (i.e. 10 and 22 EVs respectively):

Figure 2.19 Aggregated demand for 10 EVs (case 1 - left) and 22 EVs (case 2 - right) – without baseline



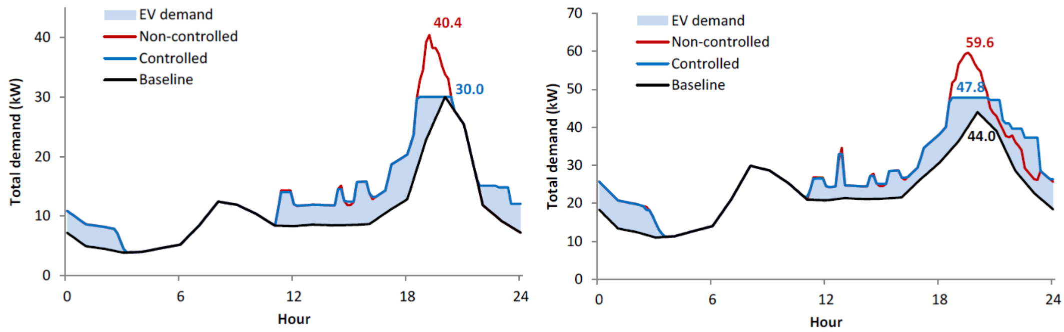
The peak of the aggregated demand for the 10 EVs reduced by 70% (from 16.4 kW to 5 kW) with demand of the smart charging events shifted from the peak time (i.e. 6-8pm) towards the late evening hours. In the case of the 22 EVs, the minimized peak of the sample was reduced by 55% from 20.3kW to 9.1 KW with both peaks observed successfully resolved with demand shifting.

The figure below also illustrates that in the case of 10 EVs, the smart charging has in effect reduced the total peak to the levels before the EVs introduction (the reduction observed is in the order of 10.4kW). The reduction to zero levels of the EV consumption during peak hours is a testament of the high flexibility of the EVs to demand response. Although the results of the second case study show that bigger reduction of 11.8kW has been achieved in the sample of 22 EVs, a vehicle charging between 7-8pm hindered the reduction of the peak demand to zero levels (for a fraction of 3.8kW which is equal to its assumed charging power).

[13] The EV sample participating in the data logging activity included 22 residential vehicles 10 of which had been monitored for their charging profiles as well. The key input into the model is the information on charging, driving and parking events, which was taken for a selected day in March 2014 that had an adequate coverage of EV events.

[14] The peak minimization model was implemented as a linear programming model using the FICO Xpress platform.

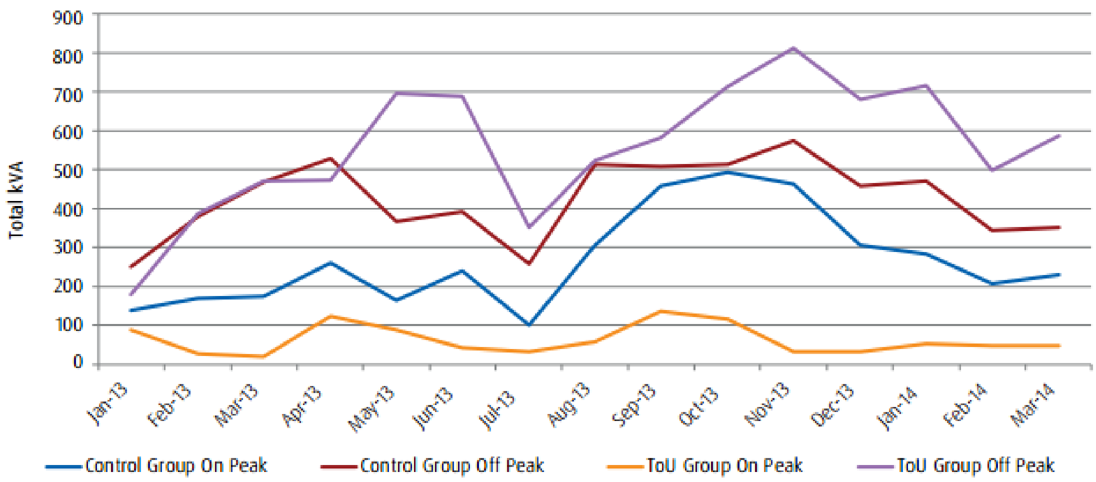
Figure 2.20 Aggregated demand for 10 EVs (case 1 - left) and 22 EVs (case 2 -right) – with baseline



Moreover, a control charging trial using the behavioural mechanism of a ToU tariff was also carried out to investigate the impact on domestic customers' recharging behaviour at home. The main hypothesis investigated was whether EV charging patterns coincided with early evening peak demand and whether offering consumers an attractive price for off-peak power would see a switch from this peak period to off-peak.

A sample of 10 EV users signed up to the EDF ECO 20:20 tariff[15] was compared against a control group of users of a flat tariff rate[16]. The trial showed that 70% of domestic EV users modified their charging behaviours to predominately charge their vehicle at off-peak times, despite the monetary incentive being small. By comparing the control group to those consumers that took part in the ToU trial, it can be seen that participants tend to modify their behaviour if they believe they are getting a better rate off-peak. Without any incentive, participants tend to plug in when it is convenient to them.

Figure 2.21 Average On/Off Peak[17] Charging for ToU and Control group



One could consider that this change in charging patterns might be due to the users being monitored by the project. However, the consistent manner in which participants charged off-

[15] The ECO 20:20 tariff by EDF provides a discount of 20% on electricity between 21:00 and 07:00 and all day at weekends.

[16] It is worth noticing that participants in the control group were served by various Suppliers and it is not known whether they were offered any incentives for off-peak charging.

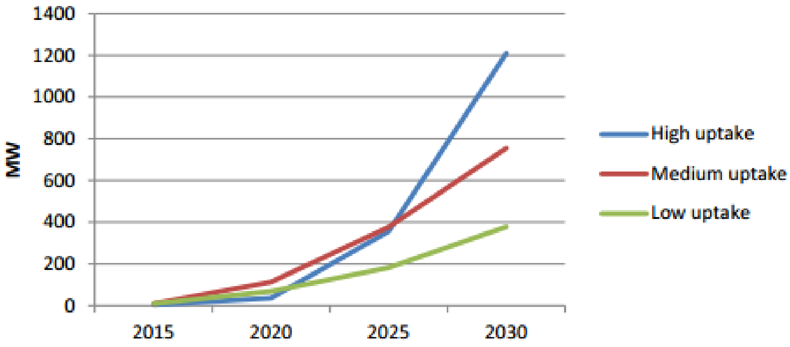
[17] The off-peak period is the period between 21:00 and 07:00, when the 20% discount on the nominal cost is applied.

peak indicates that the time of use tariff acted as a useful mechanism to shift load from time of peak demand.

2.2.4.3 National grid – frequency control evidence

Electric cars will be more commonplace by 2030 and there are likely to be more people recharging at the same time. Thus, evidence shows that there is significant potential to provide frequency response (which is controlled variation of electrical load in order to stabilize network frequency when large supply changes are experienced) via interrupted charging because electric vehicles are projected to typically be available for charging for 8 hours per day, but only require charging for 3 hours (for the home charging archetype in the analysis). Evidence from National Grid on the potential for frequency response from EVs shows a remarkable increase after 2020 as indicated in the figure below [7]:

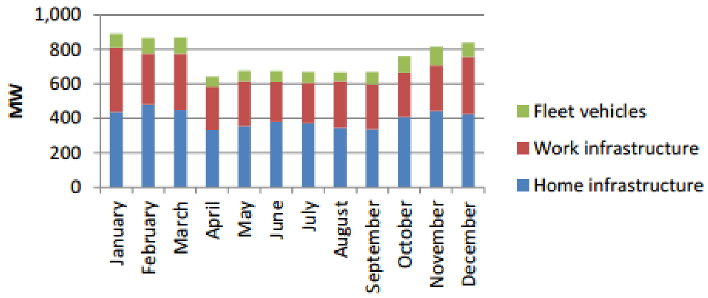
Figure 2.22 Average low frequency response from EVs



By 2030, EVs could contribute an average low frequency response (i.e. adding load to increase frequency) of 754MW in the medium uptake scenario, 52% of the projected average 2030 requirement. This could rise to 1210MW, 83% of the projected requirement, in case of high EV uptake, and could reduce to 377MW, 26% of the projected requirement, if EV uptake is low (achieved by switching off charging or reducing the charge power). For comparison, the 2014 average power consumption in the UK was around 35 GW.

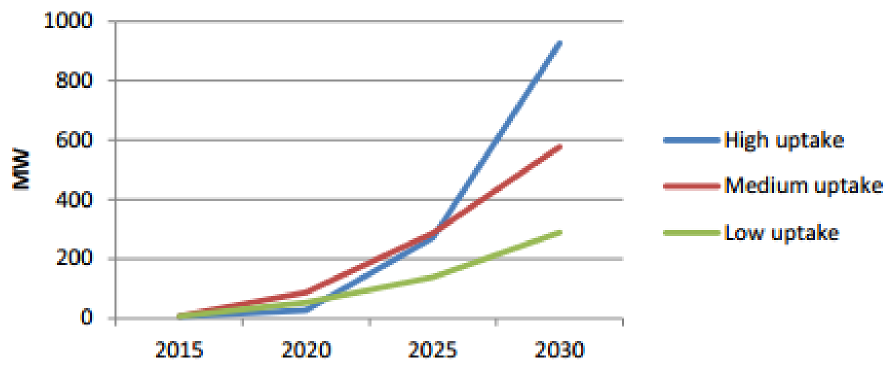
Taking into account the medium uptake scenario, most of the response is provided by home and work charging (representing 53% and 37% respectively). Although fleet vehicles have very predictable use patterns, they are less flexible as they tend to have higher energy requirements and less time for charging [7].

Figure 2.23 Seasonal variation in average low frequency response from EVs, 2030 medium scenario



The estimated potential for high frequency response (i.e. shedding load to reduce the frequency) is slightly lower than that observed for low frequency response. By 2030, it could contribute 577MW in the medium uptake scenario, rising to 926MW in the high uptake scenario, and reducing to 289MW in the low uptake scenario (achieved by switching on charging or increasing charge power).

Figure 2.24 Average high frequency response from EVs to 2030



2.2.5 Design changes for enabling DR

Evidence shows that EVs with mode 3 and 4 charging already encompass many of the required functionalities to enable frequency response provision. However, additional hardware will be required for EVs to fully enable such capabilities. The necessary interventions pertain to frequency sensing, control, metering and telemetry components [7]. We understand that some charge point operators have DSR capability built into their systems (meaning they can remotely control charge points, and could curtail charging).

2.3 Conclusions and areas for further work

Based on the Electricity Infrastructure Roadmap under the LCVP project, domestic power peak demand can increase from 60GW in 2015 to 72kW by 2050 on the assumption of 3kW EV charge points. Given the technological advancement leading to higher battery capacities, peak demand could increase up to 89GW with the use of 7kW charge points putting extra pressure to the local networks [8]. Thus, demand response solutions could play a pivotal role.

Acknowledging the market potential of EVs in the UK, energy suppliers have developed packages to cover not only electricity needs of EVs but also charging infrastructure [19]. Some of the UK utilities currently offering or interested in offering such services for EV owners include British Gas and OVO.

Standardisation will also be instrumental in allowing all electric vehicles to be charged and communicate with the electricity grid anywhere in Europe[18]. To this end, the Commission delivered in 2010 a mandate (M468)[19] to the European Standardisation Organisations (ESOs) to issue new standards or review existing standards with the aim of:

- Ensuring interoperability and connectivity between the electricity supply point and the EV charger, including the charger of their removable batteries so that this charger can be connected and be interoperable in all EU States;
- Ensure interoperability and connectivity between the charger of EV – if the charger is not on board - and the EV and its removable battery, so that a charger can be connected, can be interoperable and re-charge all types of EVS and their batteries;
- Appropriately consider any smart-charging issue with respect to the charging of EVs;

[18] http://www.cencenelec.eu/standards/Sectors/Transport/ElectricVehicles/Pages/default.aspx

[19] ftp://ftp.cen.eu/CEN/Sectors/List/Transport/Automobile/ElectricVehiclesMandate.pdf

- Appropriately consider safety risks and electromagnetic compatibility of the charger of EVs in the field of Directive 2006/95/EC[20] and directive 2004/108/EC (electromagnetic compatibility)[21];

In 2012 a standards working group, CEN-CENELEC eMobility Coordination Group, was set up to answer this mandate.

As smart charging[22] is deemed necessary for optimisation of electro-mobility and energy use, a specific working group consisting of the CEN -CENELEC eMobility Coordination Group (M468) and the CEN-CENELEC-ETSI Smart Grid Coordination Group (M490) was created in June 2012 and in May 2015 they published a report on Smart charging[23]. The report indicates the following gaps:

- A standard for data communication between the EVSE and the EVSE Operator.
- A standard for data communication between the EVSE Operators and E-Mobility Service Providers for standardised business transactions and roaming issues.

A list of relevant standards for charging EVs (as of November 2015) is provided in Annex 1.

Another standardisation request was issued in March 2015 (M/533) in support of Directive 2014/94/EU[24] on the deployment of alternative fuels infrastructure and specifically Article 4 “Electricity Supply for Transport” and Point 1 of Annex II “Technical specifications of charging points”. In essence, this request complements M/468 on all aspects pertaining to interoperability as the ESOs could not deliver single harmonised specifications from an interoperability point of view.

Under the new mandate ESOs are requested to develop standards based on the following Work plan:

Table 2.3 Requested work programme for EU standards on electricity supply

Reference information	Publication
1. A European standard containing technical specifications with a single solution for wireless recharging for passenger cars and light duty vehicles interoperable with the specification contained in IEC/TS 61980-3 Ed. 1.0 or its later edition	31/12/2019
2. A European standard containing technical specifications with a single solution for battery swapping for electric vehicles	31/12/2022
3. A European standard containing technical specifications with a single solution for electric bus supply connectors and socket outlet. If feasible, this technical interoperable solution should be based on the standard developed for electric passenger cars and light duty vehicles	31/12/2019
4. A European standard containing technical specifications with a single solution for electric bus wireless recharging	31/12/2019

[20] https://osha.europa.eu/en/legislation/directives/council-directive-2006-95

[21] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:390:0024:0037:EN:PDF

[22] Smart charging is defined as the “charging of an EV controlled by bidirectional communication between two or more actors to optimize all customer requirements, as well as grid management and energy production including renewables with respect to system limitations, reliability, security and safety” [20]. The concept of smart charging can be achieved either through charging with demand response (open loop) or smart (re-/de) charging (close loop). Charging with demand response is controlled using price signal applied to energy and/or power (e.g. low hour tariff). This type of control is "open loop", i.e. the customer may take the signal into account, or decide not to do so (and pay in consequence). Smart (re-/de) charging is controlled by price and technical signals in relation to a combination of constraints such as overload risk, lack of balance between production and consumption, or coordination between loads to avoid peak demand exceeding the capacity of a network. Contractual clauses initially settled imply that a consumer will take them into account (generally through automation and management systems which include optimization algorithms).

[23] ftp://ftp.cen.eu/EN/EuropeanStandardization/HotTopics/ElectricVehicles/SmartChargingReport.pdf

[24] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN

5. A European standard containing technical specifications with a single solution for shore-side electricity for maritime vessels	31/12/2018
6. A European standard containing a technical specifications with a single solution for shore-side electricity supply for inland waterway vessels with higher power requirements in addition to standard EN15869-2:2010 or its later edition	31/12/2018
7. Establish technical specifications as a recommended interoperable solution for Alternate Current (AC) normal recharging points for L category motor vehicles	31/12/2016
8. Adopt an amendment to EN 62196-2 or otherwise supplement the said EN for the “Category type 2” socket outlet to include interoperable technical specifications with an optional solution for mechanical shutters	31/12/2015

2.4 References

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[19] http://www.vospers.com/electric/electric-at-home/

Annex 1 Work programme (as of November 2015)[25] – Standards published and under development

STANDARDS UNDER DEVELOPMENT	Reference	Title
CLC/SR 121B 'Low-voltage switchgear and control gear assemblies' (Assemblies for charging stations)	FprEN 61439-7 (PR=23923)	Low-voltage switchgear and controlgear assemblies -- Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations
CLC/TC 20 'Electric cables' - Charging cable	EN 50620 (PR=24105)	Cables for electric vehicles
CLC/TC 23E 'Circuit breakers and similar devices for household and similar applications' - IC-CPD for mode 2 charging cable	FprEN 62752 (PR=25097)	In-Cable Control and Protection Device for mode 2 charging of electric road vehicles (IC-CPD)
CLC/TC 64 'Electrical installations and protection against electric shock'	FprEN 61140 (PR=24640)	Protection against electric shock - Common aspects for installation and equipment
CLC/TC 69X 'Electrical systems for electric road vehicles' Electromagnetic compatibility of charging infrastructure	IEC 61851-21-1 (PR=59580)	Electric vehicle conductive charging systems - Part 21-1: Electric vehicle onboard charger EMC requirements for conductive connection to an a.c./d.c. supply
	prEN 61851-21-2 (PR=24401)	Electric vehicle conductive charging system - Part 21-2:EMC requirements for OFF board electric vehicle charging systems
	FprEN61980 -1 (PR=25038)	Electric vehicle wireless power transfer systems (WPT) - Part 1: General requirements (under M/533 on alternative fuels infrastructure)
	TS 62840 -1	Electric vehicle battery swap system Part 1: System description and general requirements (under M/533 on alternative fuels infrastructure)
	IEC 62840-2	Electric vehicle battery swap system - Part 2: Safety requirements (under M/533 on alternative fuels infrastructure)
	prEN ISO 17409 (WI 00301036)	Electrically propelled road vehicles -- Connection to an external electric power supply -- Safety requirements
	prEN ISO 15118-1 (WI 00301047)	Road vehicles -- Vehicle to grid communication interface -- Part 1: General information and use-case definition
	FprEN ISO 15118-2 (WI 00301035)	Road vehicles -- Vehicle to grid communication interface -- Part 2: Network and application protocol requirements
	FprEN ISO 15118-3 (WI 00301033)	Road vehicles -- Vehicle to grid Communication Interface -- Part 3: Physical and data link layer requirements

[25] ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/ElectricVehicles/M468_WorkPorgrammeUpdate2015.pdf

STANDARDS UNDER DEVELOPMENT	Reference	Title
	prEN ISO 15118-4 (WI 00301037)	Road vehicles -- Vehicle to grid communication interface -- Part 4: Network and application protocol conformance test
	prEN ISO 15118-5 (WI 00301038)	Road vehicles -- Vehicle to grid communication interface -- Part 5: Physical layer and data link layer conformance test
	prEN ISO 15118-6 (WI 00301040)	Road vehicles - Vehicle to grid communication interface - Part 6: General information and use-case definition for wireless communication
	prEN ISO 15118-7 (WI 00301041)	Road vehicles - Vehicle to grid communication interface - Part 7: Network and application protocol requirements for wireless communication
	prEN ISO 15118-8 (WI 00301042)	Road vehicles - Vehicle to grid communication interface - Part 8: Physical layer and data link layer requirements for wireless communication
	ISO/DIS 18246	Electrically propelled mopeds and motorcycles - Principles and requirements for conductive charging - Vehicle safety during charging from mains, grid and/or stationary external energy supply

PUBLISHED STANDARDS	Reference	Title
CLC/BTWG 112-1 'Improvement of EN 60309-1 and EN 60309-2'	EN 60309-1:1999 (PR=12444)	Plugs, socket-outlets and couplers for industrial purposes - Part 1: General requirements
	EN 60309-1:1999/A1:2007 (PR=16594)	Plugs, socket-outlets and couplers for industrial purposes - Part 1: General requirements
	EN 60309-1:1999/A2:2012 (PR= 23615)	Plugs, socket-outlets and couplers for industrial purposes - Part 1: General requirements
	EN 60309-2:1999 (PR=12871)	Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
	EN 60309-2:1999/A1:2007 (PR=16595)	Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
	EN 60309-2:1999 /A2:2012 (PR=23616)	Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
CLC/TC 64 'Electrical installations and protection against electric shock'	HD 60364-7-722:2015	Low voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supply of electric vehicle
	EN 61140:2002	Protection against electric shock - Common aspects for installation and equipment
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PUBLISHED STANDARDS	Reference	Title
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CLC/TC 69X 'Electrical systems for electric road vehicles'	EN 61851-1:2011	Electric vehicle conductive charging system - Part 1: General requirements
	EN 61851-23:2014 (PR=24554)	Electric vehicle conductive charging system -- Part 23: D.C. electric vehicle charging station
	EN 61851-24:2014 (PR=24517)	Electric vehicle conductive charging system -- Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging
CLC/TC 23BX 'Switches, boxes and enclosures for household and similar purposes, plugs and socket outlets for d.c. and for the charging of electrical vehicles including their connectors'	EN 62196-1:2014 (PR=24588)	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements
	EN 62196-2:2011 (PR=23259)	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories
	EN 62196-2:2012/A11:2013 (PR=23822)	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories
	EN 62196-2:2012/A12:2014 (PR=25110)	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles -- Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories
	EN 62196-3:2014 (PR=24566)	Plugs, socket-outlets, and vehicle couplers - conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for dedicated d.c. and combined a.c./d.c. pin and contact-tube vehicle couplers
CLC/TC 301 'Road vehicles'	EN ISO 15118-1:2015 (WI 00301034)	Road vehicles -- Vehicle to grid communication interface -- Part 1: General information and use-case definition