UK ELECTRIC VEHICLE CHARGING USE CASES FOR OPTIMISED INFRASTRUCTURE ROLL OUT

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Abstract

This paper presents an approach to determining the type and sizing of the electric vehicle (EV) charging infrastructure required to meet the charging demand of the UK vehicle parc once electrified. The findings indicate that while convenient home charging and destination charging can fulfil a portion of the UK's charging demand, public rapid charging emerges as the primary solution, satisfying approximately 65 to 75% of the total EV charging demand. Based on a 40% utilization rate, it is estimated that the deployment of 112,000 to 130,000 rapid chargers would effectively meet this demand. This ensures commercial viability and scalability of the UK EV infrastructure, but also promotes sustainability by significantly reducing the number of superfluous charging infrastructure assets, the associated grid impact, and the environmental impact on raw materials and supply chain. Whilst convenient home charging remains an important EV charging option, public EV charging infrastructure is key to deliver the national EV charging demand in a robust and sustainable way.

1. Introduction

As the UK approaches the 2030 sales stop of fossil fuel vehicles, it is vital that charging infrastructure is quickly scaled. As such, the UK government has set a target of having 300,000 public charge points by 2030 [1]. Whilst speed of roll out is important, it is crucial that infrastructure is implemented in the most sustainable and cost-effective way, to avoid underutilised and stranded assets, whilst maintaining ease of use for drivers. This paper presents the research for a roll out strategy that optimises the number of public charge points required for the transition to electric vehicles in the UK. It is often assumed that home charging will cover a lot of the UK's vehicle charging demand, however this could lead to millions of underutilised assets and tied up grid capacity, whilst leaving the public network underserviced for those who cannot charge at home. This paper sets out to challenge the home charging assumption, by mapping how much demand can be viably covered at home and presenting back the demand that public charging infrastructure will have to meet. This paper will present arguments for the minimal number of charge points required to meet the UK charging demand once fully electrified. This paper does not state that any charging scenarios should be completely excluded, however, this paper has selected three charging scenarios, that through research has shown can optimally roll out charge points as necessary to meet the UK's charging demands whilst retaining ease of use, safety, and security for UK drivers.

1.1 Charging Use Cases - Overview

Throughout this research, three different charging powers have been considered due to their real-world viability and use cases:

- 3.6kW AC in the home charge context,
- 25kW DC for public retail/destination charging, and
- 150kW DC public rapid hub charging.

A short overview of each is provided in this section. Other charging options and use cases were discounted on account of being sub-optimal for meeting the UK EV charging demand. Additionally, consideration was given to reducing market segmentation for public charging infrastructure to further improve the network service to customers and its commercial viability.

1.1.1 Home Charging: In the residential context, charging powers of 3.6kW or less are most optimal when considering length of dwell time, average miles driven, home fuse capacity, and cost to install. Any speeds faster than 3.6kW may result in too much capacity being cornered off from an already constrained electricity supply, that needs to support other consumer goods as well as heating. Home charging will provide a useful EV charging use case but may have significant limitations as to the overall EV charging demand it can satisfy in the UK.

1.1.2 Destination / Retail Charging: Destination charging can be considered as utilising medium length dwell time locations, such as 1 hour stays at retail locations. This use case is ideal for battery 'top-up' whereby a driver will add on significant driving range whilst going about their daily business, without the expectation to obtain a full charge. For this, 25kW DC charging is proposed as ideal. This is on account of all cars being released in the market today will be able to take the full power of 25kW DC charge points, plus reduces the need for car manufacturers to install high power AC chargers within their vehicles. Additionally, at 25kW, with an hour long stay drivers can anticipate getting approximately 80-100 miles of vehicle range. Based upon the average milage of a UK private use driver, this would require EV charging only once or twice a week.

1.1.3 Rapid Hub Charging: Rapid hub charging is the equivalent of what drivers are used to today with fossil fuel vehicles; driving to a centralised station and charging the vehicle to replenish significant range while waiting a short time. It is crucial that dwell time is kept to a minimum in this scenario. To do this, charging power must be high to significantly increase the SoC of the vehicle in a short time, whilst being commercially viable. As part of this study, it was found that for the majority of the batteries deployed within the vehicle parc, 150kW DC represents a favourable infrastructure choice. This is due to factors such as grid capacity and upgrade requirements, reduction in dwell times, installation costs, and sizing of vehicle batteries and their charging profiles.

1.1.4 Discounted Charging Powers: This research was completed on the basis that the following charging powers are not as optimal in commercial or technical value for meeting the UK's charging needs:

- 7.4 / 11 / 22 kW AC
- 50 / >150 kW DC

This does not mean that these charging powers have no relevance, but rather will play a minor role in the UK's future charging eco-system due to practicalities and commercial value. For the AC charging powers of 7.4 and 11 kW, both often found in public charging, the power output to dwell time ratio can be low from a utilisation perspective. This is due to average daily driver milage, meaning that the amount of energy put through and utilisation is low versus the cost of installing and operating the infrastructure asset, not to forget the resulting capacity hogging and the undesirable increase in street furniture. Similarly, the grid capacity that will be tied up for the millions of charge points required at this power to meet UK demand, does not optimally make use of the UK's existing grid network. 22kW AC is a charging speed with very few cars on the market today featuring this capability.

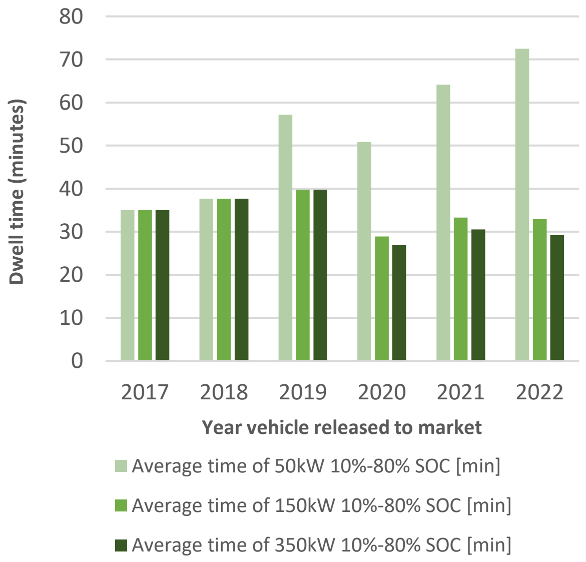

Figure 1 - Comparison of average dwell times of vehicles rapid charging 2017-2022

50kW DC was an excellent start to rapid, but it is now being outpaced by higher powered DC chargers, suited to increasing battery size reducing driver dwell time. Chargers with power > 150kW are not overly advantageous vs 150kW due to very few EVs being able to charge at that speed. Figure 1 shows a comparison of DC charging technology comparing dwell time at 50, 150, and 350kW showing that 150kW brings the most value for charging speed against dwell time and ultimately value for money.

2. Methodology

2.1. UK travel Demand

The UK's annual travel demand forms the basis of this research. When trying to understand how the UK's charging network should look, it is essential that it is defined by how many miles (ultimately kWh) need to be fulfilled against the number of vehicles there are in the UK. The first step in this analysis is to understand the breakdown of vehicle miles in the UK, splitting it into the categories displayed in Table 1.

Table 1 - UK Annual Travel Demand in Miles, 2021 [2]

Vehicle Group	Annual Milage (2021)	Market Share
Car and Taxi	221,400,000,000	74.40%
LCV	54,400,000,000	18.28%
HGV	17,500,000,000	5.88%
Bus & Coach	1,800,000,000	0.60%
Motorcycle	2,500,000,000	0.84%
Total Travel Demand	**297,600,000,000**	100.00%

Following this, an understanding of the breakdown of the vehicle parc in the UK was necessary to create an average milage picture per vehicle type. This is presented in Table 2.

Table 2 - Distribution of Vehicle Type - UK 2022 [3]

Vehicles Type	Number of Vehicles	Market Share
Cars	33,154,687	81.32%
LCV	4,633,551	11.36%
HGV	539,660	1.32%
Bus & Coach	145,152	0.36%
Motorcycle	1,458,477	3.58%
Other	840,860	2.06%
Total Vehicles	**40,772,387**	**100.00%**

2.2. Miles per kWh

Throughout the research, a calculated average of 3.3 miles per kWh was used and applied across all calculations. It should be noted that this figure is heavily dependent on driving style and can vary in real-world scenarios.

2.3. Travel Demand per Use Case

With the EV demand quantified as per Table 1 & Table 2, it is structured into use cases as defined in Section 1.1. Through industry experience, it was found very few Light Commercial Vehicles (LCVs) will be able to charge at home, similarly for Heavy Goods Vehicles (HGVs) and Buses; discounting them from the home charge demand model. Likewise, they are discounted from the destination charging use case in this research due to the charging speed and the lack of available data. Instead, it is assumed that LCVs, HGVs and buses will utilise the public rapid network and/or their own private infrastructure due to their larger battery sizes and need for specialist equipment in some cases. As such their charging demand has been included in the calculation for total charging demand within the rapid use case. With almost three quarters of the UK's travel demand found in cars and taxis, this formed a substantial basis of vehicles able to utilise home & destination charging for this study.

2.3.1 Home Charging: Stringent qualification of possible vehicles that could use this use case was necessary to calculate the volume of charging demand that could reasonably be fulfilled at home. The figures used are displayed in Table 3; note that 2021 car vehicle type figures were used to remain in line with the 2021 travel demand statistics. Additionally, the number of taxis were removed from the assessment as it was unclear which percentage of taxis fell into cars and which to LCVs.

Table 3 - Data points used for calculations, 2021

Data Point	Numeric	Unit	Ref
Number of cars UK	32,889,462	Cars	[3]
Privately owned	90%	percent	[4]
Access to off-street Parking	70%	percent	[5]
Home Ownership	65%	percent	[6]
Can install at home	55%	percent	[7]
Chargers per home	1	chargers	N/A
Average cars / household	1.4	cars	N/A
Charging power	3.6	kW	N/A
Daily average milage per vehicle	18.11	miles	N/A

Consideration has been given to the notion that as early adoption of EVs turns to standard practice, less drivers than currently seen today will charge at home. There is also a concern about the volume of charge points necessary if the UK simply installed charge points per vehicle. Thus, this paper set out to qualify the number of vehicles that can home charge, which involved limiting against the following criteria:

- Privately owned vehicles: Removing non-privately owned vehicles ensures a more reliable percent of vehicles that return home every night. This includes removing short term hire vehicles.
- Access to off-street parking: It has been widely noted that only 70% of UK homes have access to off-street parking.
- Can install at home: Based upon the UK housing stock, only 55% of homes can install charge stations due to factors such as fuse (amp) limitations, grid connections and other constraints.
- **Additional criteria:** Home ownership - With only 65% of the UK households owning their home, it may be unreasonable to expect those who rent a property to pay to install a charge point, meaning they are more likely to rely on public infrastructure. This is a further reduction that this paper has applied to give a range of demand that home charging may cover.

It was acknowledged that households may have multiple vehicles, enabling greater utilisation of a single charge point. Allowing for one charge point per household, this was multiplied by the average number of vehicles per household, increasing possible utilisation of the home charging unit.
The key output of how many vehicles could utilise this charging scenario case, and the demand thereof, was calculated using equations (1a), (1b) and (2).

$$PU = NC \times PO \times OS \times IH \quad (1a)$$

$$PU = NC \times PO \times OS \times IH \times \mathrm{HO} \quad (1b)$$

$$\%UKH = \left(\frac{\left(\frac{PU}{AC}\right) \times AM \times CC \times 365 \times 100}{TM} \right) \quad (2)$$

Table 4 - Variables for home charge demand calculation

Variables	Abbreviation
Possible home charge users	PU
Number of cars UK	NC
% of privately owned cars	PO
% access to off street parking	OS
% can install at home	IH
ADDITIONAL % home ownership	HO
Average number of cars per household	AC
Average daily vehicle milage	AM
Cars per charging unit at home	CC
Total UK vehicle miles	TM
Percent of total UK demand at home	%UKH

2.*3.2 Destination / Retail Charging*: For this analysis, supermarkets were solely and specifically selected as the destination use case due to the reliability of data, the time drivers spent on location, and the frequency that the driving public visit. It was found that 95% of car owners used their vehicle to drive to the supermarket [8]. Like that of the home charge scenario, LCVs and HGVs were discounted, to focus on the 75% of demand coming from cars. To create a reasonably accurate forecast, it was noted that many of the 12,701 supermarkets in the UK [9] will be city and metro-based convenience supermarkets, of which the public may not drive to, nor may they have a car park. Thus, this research only considered supermarkets with existing petrol stations as it can be reliably assumed that car parking is available and that the public will drive there. For the calculation, the potential demand of weekly visits from the driving public was determined, creating an optimal number of charge points per location, the resultant demand fulfilled, and the necessary grid demand per location. It should be pointed out that this is a very conservative view of potential demand that this use case could cover, due to the lack of data available about the number of supermarkets with car parks. There are far more supermarkets in the UK with large car parks, thus suggesting significant scalability of this use case to support future demand of EV charging. It is also noted that LCVs may utilise the destination charging use case, but the relevant data sets were not available to make an accurate calculation from a visits made perspective. The data points used for the calculations of both scenarios are in Table 5.

Table 5 - Destination charging data points

Data Point	**Numeric**	**Unit**	**Ref**
Household car access	32,889,462	cars	[3]
Car use for supermarket travel	95%	percent	[8]
Supermarkets with petrol station	1609	locations	[10]
Supermarkets in UK	12,701	locations	[9]
Average length of visit	0.62	hours	[11]
Number of visits per week	1.85	Visits	[12]
Assumed charge point utilisation	40%	Percent	N/A
Charging power	25	kW	N/A
Time spent at supermarket per year	59.46	hours	

The pessimistic calculation of charging demand - and resultant chargers per supermarket - that could be supplied via destination charging was calculated are shown in (3) and (4).

$$AD = HC \times ST \times AV \times \frac{SP}{SU} \times DkW \quad (3)$$

$$CS = \frac{AD}{DkW \times SP \times AU \times 365 \times 24} \quad (4)$$

Table 6 - Variables used to calculate destination charging

Variables	**Abbreviation**
Annual demand at destination	AD
Household car access	HC
% Car use for supermarket travel	ST
Average time spent at supermarket per person annually	AV
Number of supermarkets	SU
Supermarkets with petrol stations	SP
Number of chargers per site	CS
Assumed utilisation	AU
Destination charging power	DkW

2.3.3 *Rapid Hub Charging*: This use case determined the remaining number of charge points required to cover the full demand of the UK, minus the demand that the home and destination use cases could fulfil. All modes of road going transport seen in Table 1 are within this use case. The point of calculating the remaining demand with rapid charge points is this provides optimal economics when considering operation, install, minimising street furniture, and grid upgrade vs. the potential commercial incomings. This is due to the greater volume of kWh that can be sold through the charge points, plus the reduced number of assets required to be installed and maintained to standard. Ultimately, driving higher utilisation of fewer assets is more commercially optimal. The remaining data points used for the calculations in this use case are found in Table 7.

Table 7 - Rapid hub data points

Data Point	**Numeric**	**Unit**
Charging power	150kW	cars
Assumed charge station utilisation	40%	percent

The calculation used to find the optimal number of rapid charge points to meet the UK's full charging demand once fully electric is shown in (5) & (6).

$$DD = \frac{\frac{TM - HC - DC}{MP}}{365} \quad (5)$$

$$OR = \frac{DD}{RkW} \times AU \quad (6)$$

Table 8 - Variables to calculate optimal rapid chargers

Variables	**Abbreviation**
Total daily charge demand	DD
Total UK vehicle miles	TM
Demand covered by home charging	HC
Demand covered by destination charging	DC
Miles per kWh	MP
Optimal UK rapid chargers	OR
Rapid charging power	RkW
Assumed utilisation	AU

3. Results

It was found that with a 40% utilisation of the 150 kW rapid charging stations and the demand satisfied by home and destination charging, the UK requires in the order of 112,000 rapid charge points. Each scenario is broken down in the following sections.

3.1. Home Charging

In line with the hypothesis of this paper, it was found that home charging may satisfy a relatively small portion of the national EV charging demand. It has been deduced that between 8 million and 12 million vehicles will likely be able to charge at home. This would result in the roll out of 6 to 9 million home charge points, covering between 18% to 28% of the UK's total charging demand – 45 to 69 GWh daily. Whilst home charging is a great option for ease of use and will likely remain an option of interest to the consumer, it is essential to point out that even the lower estimate of 6 million home charging units is a lot of devices to cover not a lot of demand, particularly when their daily utilisation is as low as 9%. Should this demand be shifted away from the home charging use case, it *could* be covered by a further 60,000 public rapid charge points running at 40% utilisation, significantly reducing the number of necessary charge points and the maintenance and safety thereof.

Table 9 - Results for Home Charging

Results	Numeric	Unit
Resultant vehicles	8,230,588 to 12,662,443	cars
Charging units required	5.9 to 9 million	chargers
Miles charged per night	25.36	miles
kWh per night per household	7.68	kWh
Annual miles charged at home	54 to 84 million	miles
Annual miles charged in kWh	16.5 to 25.4 billion	kWh
Percent of private car demand covered	27.8 – 42.8 %	percent
Calculated daily charger utilisation	9%	percent
% of total UK demand covered by use case	**18-28%**	**percent**

Table 9 shows that between 28 and 42% of private car charging demand can be covered at home which represents 18 to 28% of the national total charging demand.

3.2. Destination Charging

By analysing the data points against the possible journeys made to supermarkets in the UK, it was found that in the scenario of 1609 suitable supermarkets, destination charging could cover 7% of the UKs EV charging demand – 16GWh daily. This would require an average of forty-two (42) 25kW DC charge points per supermarket, resulting in an additional 1.04MW capacity at each location. Additionally, by having charging infrastructure in a safe and controlled environment such as a supermarket, their operation can be monitored whilst drivers can benefit from increased protection of CCTV and staff on site. It should be noted that the number charge points per site may significantly reduce if more supermarket destination charging sites can be identified. Similarly, with more available sites, but with the same number of charging units per site, a greater charging demand potential could be realised. The calculated results for destination charging can be seen in Table 10.

Table 10 - Results for Destination Charging

Results	Numeric	Unit
Annual demand covered in destination charging	5,884 million	kWh
Annual miles charged at destination	19,416 million	miles
25 kW charge points required per location	42	chargers
Required kW capacity in scenario a.	1,043	kW
Demand potential of destination charging	**7%**	**percent**

3.3. Rapid Hub Charging

Considering the demand satisfied by the previous two scenarios, it was found that the remaining public EV charging demand in the UK requires approximately 112,000 rapid 150kW charge points to cover the total demand once the UK is fully electrified. This figure was calculated using the home charging demand results as if 9 million residential chargers were installed. If the smaller volume of charging demand from home charging was used, then almost 130,000 rapid chargers would be required. Scaling this back to create a comparison for 2030, there would be approximately 8 to 11 million EVs on UK roads [13], meaning the UK would only need 46,000 rapid charge points running at a utilisation of 40% to cover the total demand in 2030 of cars and LCVs on the public network, significantly less than the 300,000 presented by Government.
Lastly, should the UK decide to install enough public charge points without relying on the home charging or destination use cases as defined in this paper, it would require 171,000 chargers. All figures for the rapid hub use case can be found in Table 11.

Table 11 - Results for Rapid Hub Charging

Results	Numeric	Unit
Annual demand minus home & retail	194,474	million miles
TWh energy required	59	TWh/year
Daily charge demand	161,456,424	kWh/day
Charger output per day	3600	kWh/day
CPs required @ 100% utilisation	44,849	units
CPs required @ 40% utilisation	**112,123**	**units**

Figure 2 illustrates that between the three use cases as defined in this paper, rapid hub charging will cover a minimum of 65% of the UK's charging demand, almost 200 billion vehicle miles.

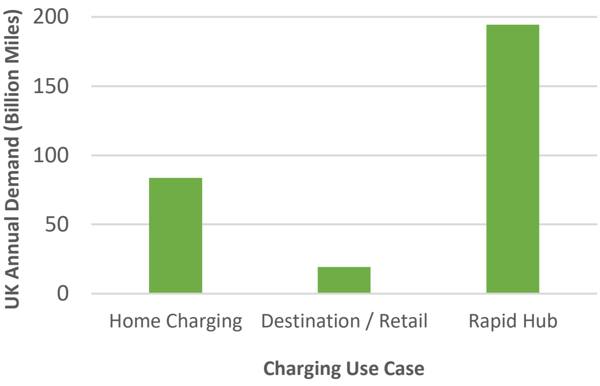

Figure 2 - Breakdown of charge demand per use case

It is key to point out that utilisation is a key driving factor for the number of charge points required. Figure 3 illustrates this, showing that as utilisation is driven towards 80%, significantly less charge points are required to meet the demand of the UK.

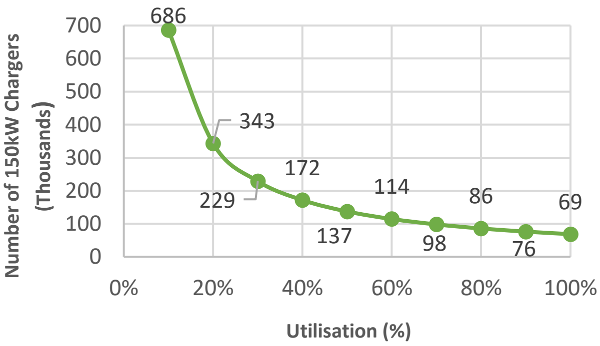

Figure 3 - Charge points required for total UK charging demand against utilisation

It is noted that human behaviour currently dictates that it is unlikely a charge point will reach an extremely high level of utilisation, such as 80%. However as autonomous vehicles and the reduction of car ownership comes into the eco-system, higher utilisation of charging infrastructure is likely. It should also be noted that the grid constraints for installing these charge points are a noted cost when clustering several units in the same location.

4. Risks, Limitations and Further Work

This analysis has been completed whilst being aware that significant investment may be needed for grid connections to enable this many rapid charging points. Calculating the optimal number of 150 kW charge points per hub by levelling cost of infrastructure upgrade against potential commercial value of a site would be a valuable follow-on piece of work to this study.

One limitation of this research is that battery charging profiles on rapid charge points dictate that if a vehicle is using a 150kW charge point, it is not necessarily taking 150kW peak power for 100% of the charging session. Figure 4 shows an example charging profile of a lithium-ion battery [14], showing out that charging current drops over time with voltage remaining roughly the same, meaning charging power drops as battery charge increases.

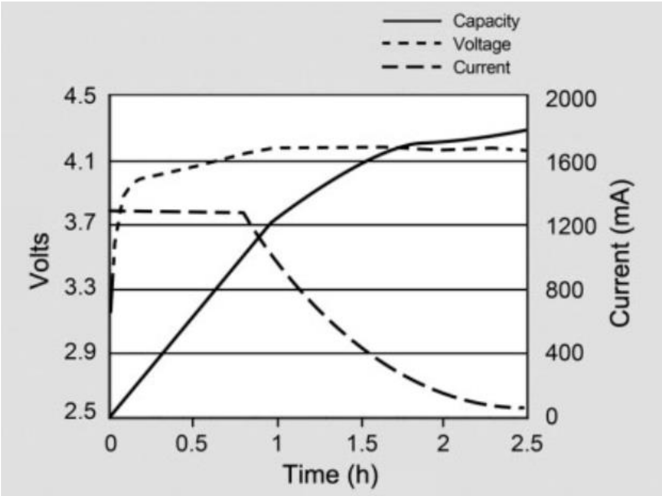

Figure 4 - Charging profile of lithium-ion battery

Lastly, the optimal number of rapid charge points per hub would also be a useful further piece of work, based upon demand profiles per location / region. This could focus on the cost benefit of grid infrastructure, likely utilisation of infrastructure and the number of sockets to meet the charging demand of vehicles travelling through the area.

5. Conclusion

This paper set out to determine the optimised charging infrastructure by type and sizing that the UK could roll out to meet the national EV charging demand once fully electric. The results included the potential demand segmentation between residential off-street, public destination and public rapid hub as a scalable and sustainable infrastructure mix. It was found that whilst home charging and destination charging could fulfil a smaller but not insignificant portion of the charging demand of the UK, rapid charging is best placed to deliver the majority of UK charging demand, satisfying 65 to 75% of total electricity consumption. With this, 112,000 to 130,000 rapid chargers would be required to meet this demand, assuming a 40% utilisation rate. It is felt this number provides an optimal strategy for the UK to meet their charging needs both from a commercial viability and sustainability perspective, due to the reduced number of chargers required by using rapid charging technology with increasing utilisation. It was also found that the Government figure of 300,000 public charge points by 2030 could be reduced to 46,000 if technology and market segmentation was focused on rapid charge points.

It is recommended that market segmentation should be minimised in the context of economy of scale to enable greater utilisation of optimal charging scenarios. The sector should constantly be aware that technology continues to be developed, and today's charging infrastructure may be replaced by alternative solutions. It is felt that high power charging solutions are likely to dominate the overall EV charging market in line with market disrupters such as battery swap stations.

The UK should consider if the additional 9 million home charge points are worthwhile from a sustainability point of view, when another 50,000 public rapid chargers could substitute home charging completely. This also raises the consideration of efficiency of running a large-scale network and the reduction of standby power through lower device numbers. However, in the wider connected home and V2H context, EV home charging remains of interest.

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