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# Methodology to determine the number of rapid chargers needed for electric vehicles in the UK

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### Highlights

- It is not the capability of a charger to deliver power but the capability of the car to receive power, which determines the amount of power transferred and the time it takes.
- The driver of the car decides which infrastructure to use and when.
- The consumer (car owner) is clearly demonstrating habits which may or may not be indicative of the future

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### Abstract

We have a paradigm shift in personal transport from an established fuel source of circa 100 years to an alternative, which in terms of current driving range is inferior and is not mature enough to have users with defined behaviours. There is also a constant cry that there is not enough infrastructure for Electric Vehicles (EV) to make them viable. Here we address the basic question of how many rapid chargers are required to support a given volume of Electric Vehicles (EV) both at city and national level, to ensure an acceptance by the public but will also support a national energy policy. The calculation requires operational parameters, EV take-up and usage patterns together with driver behaviour. The usage patterns are based on current technology, current usage, previous research and assumptions of what driver behaviour will be. We present a methodology to provide an average power delivery based on estimates of the maximum delivery for a single 50kW DC rapid charger when charging a Nissan 30kWh Leaf (the UK's most popular full EV). The EV driver is in many cases an early adopter but is subject to a rapidly changing ecosystem.

Key words; Behaviour change, charging infrastructure, rapid charger, power delivered, Nissan Leaf.

## 1. Introduction

Within many countries of the world there is a steady transition from the Internal Combustion Engine (ICE) to what are known as Ultra Low Emission Vehicles (ULEV) (DfT 2016). The UK's Office for Low Emission Vehicles (OLEV) defines ULEV as; cars or vans that emit less than 75 grams of $CO_2$ from the tailpipe per km driven, based on the current European type approval test. What is currently clear is that EV are inferior to the existing norm mainly due to range Neaimeh et al 2017). Whilst the average daily range is only (RAC) is acceptable there is a natural reluctance to travel beyond the point of no return, without a certainty of a charge. In Norway it was found that in 2014, 61% of BEV owners took their cars on vacation trips and by 2016 this had reduced to 37%. This the authors described and normalisation of BEV as a vehicle type (Figenbaum, Kolbenstvedt, 2016). Namdeo et al., 2014 and Roelich et al., 2015 suggest that*: The limited range of electric vehicles is still seen by many as the key barrier to the mass uptake of EVs. This could be addressed in one of two ways: either the actual range of the cars needs to be improved or through an abundance of public charging infrastructure which would give drivers the confidence that they could complete their journeys and top up their charge as and when it was needed.* The authors comment on the use of the word 'abundance' as it is not defined and the subject of this paper. This has resulted in the classic early adopter who is happy to put up with a life change and inconvenience, but this is questionable with the bulk of the population. In terms of social science theories, the aspects of consumerism applies to the vehicle but the charging infrastructure is not yet defined enough to offer choice. We have individuals who in an urban environment will make a value choice if they have an option and motorway users who face a zero sum situation. As with conventional fuel the driver can search for a better deal but only sum as we have regional and motorway monopolies. In the urban environment this is happening as private operators are charging a fee but some local authorities are maintaining free at point of use. It is recognised that there is consumer information with regard to the vehicles and how to charge via dealers and government information as a result of campaigns between OEM's and government (Neaimeh etal 1017). What is not evident is a national strategy to install a national network of chargers and reliance for reporting on network progress is via an independent web site, ZAP MAP. This however reports progress and is not setting strategy which it could support.

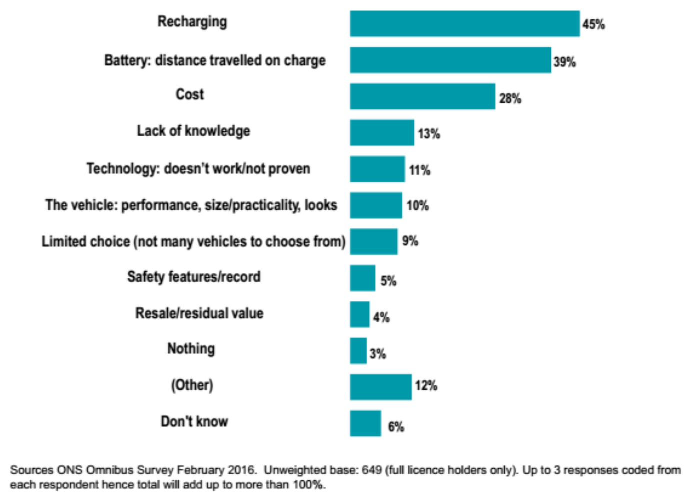


Figure1: Factors deterring people from buying an electric car or van, driving licence holders: 2016 results

The EV has been considered as another electrical device with parallels being drawn with other products such as mobile phone introduction. In looking for comparisons in terms of product introduction no examples of a product being introduced to the public, with what could be seen as a potential flaw was found. It was a big gamble of the car makers to launch a product with a clear weakness, and a hope that infrastructure would materialise to mitigate the weakness and enough people would take the leap of faith. Whilst both a phone and an EV require a plug in charge the consequences of a phone running out of charge is a lot less than a car. To allow for the adoption of ULEVs, a network of charging points has to be developed to augment the home option charge. As with all businesses, there has to be a business case to support investment with or without government subsidies, and this requires evidence of the quantities involved.

The public are aware that there will be a transition away from ICE cars but there is not a clear cohesion between governments and OEM's, as to what where and when. We excluded China, as they have a different decision and implementation model. Consumers (car buyers) are fed many stories by media, OEM's and government and are left to make their own decision. Initiatives such as the Milton Keynes EV Experience Centre (MKEC) give impartial advice as posted on social media such as the UK Go Ultra Low website. XXXX. Other variables are that; the OEMs to gain competitive advantage do not provide technical details of what will be released, and the charging infrastructure is getting more powerful. We are also seeing the traditional fuel companies enter the market and installing charge points (Shell and Total) as are the national and independent power companies (ESB, Alliander, ESB). What is known is that DC rapid chargers are requested by the population (XXX), however; these will be price sensitive and location critical to allow extended mobility. A question which has not been addressed fully is how many does any town, city or country need. So for this paper the overall goal is to determine, what infrastructure is required for a given population of EV by town, city or country based on a direct substitution of power requirement from fossil fuel to electric supply with an assumption of rapid charge reliance. There is also a need to identify the theoretical worst case scenario for all and specifically high power charging for grid impact. Norway is considered the exemplar for EV adoption so data from Norway research has also been applied in this work.

The methodology applied can be adopted for any country. The customer (car owner) has electively 3 choices; (1) charge at home, (2) charge at work or (3) charge at a public charge point. The split between these 3 options is not yet known but what is known, at a local level, is the split of homes with off street parking and homes with more than one car. In outer London 35% of households have no access to off-street parking, and in inner London this rises to 63% (TfL, 2012).

The societal challenge is that the OEM's understand how their product is doing in the market by sales achieved or pre-orders placed. For the prevailing paradigm (ICE) the infrastructure is not optional in that the owner must go to a filling station. The options of home or work charging are for most of the population not an option. An EV the customer can choose where they want to charge and the options include car parks, leisure centres and supermarkets. It is thought (RAC) that the EV filling station equivalent of a petrol station with rapid chargers will develop however the authors would argue that EV technology in terms of the vehicle and infrastructure are in their infancy and are being developed in parallel with sales. Potentially with the initial 24kWh battery and a real world range of 90 miles longer distance driving was left to traditional vehicle types. To try and provide the correct level of infrastructure in terms of rapids this methodology has been developed. Initial driver behaviour was with 24kWh batteries and now 30kWh batteries are in use and by early 2018 40kWh will be the norm for EV, the next step will be 60 and 80kWh (xxx). How these vehicles will charge in terms of power acceptance vs time is not known and based on past performance will not be known until the OEM releases the vehicle?

There are many variables relating to the total power which will be required for a given EV population, to drive the distances in a day that current ICE do. Currently there are two types of high power national networks: The Tesla network which is effectively private and networks such as the Ecotricity Electric Highway and the Polar network, which is open to all vehicles including Tesla cars (AC only). The maximum power delivery from a charger is 43kW (DC) and reflects the current maximum power accepted by mainstream EV (50kW). Not including the Tesla network there are over 1100 rapid chargers installed in the UK. The location and usage of chargers has been the subject of extensive research, for example Dong et al (2014) considered issues around the placement of charging stations. The European Commission co-financed a trial of the Rapid Charge Network (RCN) in 2015 (INEA, 2015) including research into drivers' responses. A specific large scale trial studied the behaviour of drivers as well as their usage patterns of rapid chargers (Neaimeh et al 2015). This led on to a report about the role of rapid chargers in the adoption of EVs (Neaimeh et al 2017). Latinopoulos et al (2017) explored the response of drivers to pricing policies in terms of dynamic charging. Research has focused on the importance of rapid chargers and how people use them, but does not consider the number of chargers that are needed. The work of Harrison and Theil (2017) introduced the concept of a charge point infrastructure based on revenue against installation costs and desired return on investment (ROI). This is a correct business approach but may not address social need.

The international Energy Agency (IEA) has just published its Global EV Outlook 2017: Two million and counting, in which they conclude that: despite a wide variability of low electric car market and stock shares, the EV/EVSE ratios have been assumed to converge towards 15 electric cars per publicly accessible slow charger and 130 electric cars per fast charger. These results were calculated on the basis of the electric car deployment projections outlined earlier and assumptions on the EV/EVSE ratios (by charger level). The assumptions were derived from the overview of the historical development of the EV/EVSE ratios, where the EV/EVSE ratios for each country are plotted against both the electric car market share and the electric car stock share. In this paper we are looking at the number of rapid chargers required based on power delivery and customer behaviours. The result of this work gives a figure of 125 rapid chargers for a given population of EV which relies on rapid chargers for mobility requirements, which is less than 5% variation from the figures produced by 2 different approaches. In determining the number of chargers needed, we are looking at those cars which cannot be charged at home or at work or are in long distance transit.

A key feature of EV is that unlike the current Internal Combustion Engine the take of fuel is not linear, but determined by the characteristic programmed into each vehicle. This article describes a methodology that provides an infrastructure figure. It is based on a consideration of logical components and analysis of current technology both on, and off car, considering how much power can realistically be delivered from a given rapid charger. A major consideration is that the delivery of power is not constant over time. The current delivery method for an ICE car is the petrol pump which can deliver a uniform amount of fuel over a given period of time which, when allowing for customer changeover allows calculation of the maximum amount that could be delivered if so required. It is instructive to calculate the maximum amount of power that could be delivered for EVs using the current infrastructure. The current EV population size of 90,000 is not enough to create a level of demand for constant usage in terms of back-to-back charging, however it will be reached sometime in the future. The realistic power delivery component in the calculation for infrastructure figures requires an assessment of what is likely to be acceptable charging behaviour in the space of 1 hour, over a 24 hour period with a nominal 10 minute vehicle change over time.

The next sections describe the derivation of a formula to calculate an infrastructure figure. The realistic power delivery is a vital component and we present a methodology for estimating the power take in a typical EV and interpreting it in terms of likely user behaviour. The statistical reliability of the resulting recommended number of chargers is evaluated based on the variability of the components making up the calculation (Morrison, 2009). The average power delivery figure is used to assess operational effectiveness and hence appraise the current and future infrastructure requirements.

## 2. Methods

### 2.1 Deriving an approximate formula for the number of chargers required

There are many complicating factors when trying to determine the infrastructure number of chargers needed currently in the UK. Analysing the problem objectively, it can be seen that the important issues include the number of EV vehicles, their typical daily activity and power needs and the time taken to satisfy the power needs. Standard input data from miscellaneous sources are used to attempt to address these issues (Table 1). Reasonable values for some of these components are derived from open data sources, others are assumed or set. Although the values tabulated are only best guesses they are still useful in developing a methodology and giving a feasible figure to work with.

Using data supplied from the RAC foundation it is known that there are 30m cars in the UK. The current % of EV is 0.003%, therefore in the UK we have 90,000 EV (0.3% of 30m). This paper assumes all EV accept rapid charging. The RAC Foundation gives the figure of 26 miles average journey per car per day. Using this mileage, the number of miles driven in EV per day is 90,000 x 26 miles = 2.34m miles per day.

It is also known from observation and publication that an EV can deliver 5 miles per kWh (this is driver dependant and is the current best case). Therefore the energy required to cover 2.34m miles is 468,000 kWh.

As with current vehicle use, drivers do not ‘fill’ every day, however; long distance drivers will fill and empty, whilst some users of rapid chargers will use them because they have no alternative, and will only drive the average daily mileage. The ratio of long distance to urban use will determine the utilisation of rapid chargers and the required population.

The number of chargers needed depends on the power delivery per charger and the number of hours it is used per day.

In Table 1, the key components **average power delivery** from a 50kW charger and **charge time** need to be found. As there are no published data for **average power delivery**, a reasonable approach is to carry out a practical experiment in reverse engineering as described in the next section. A recommendation for **charge time** is made based on the results of the experiment.

### 2.2 Average power delivery – practical experiment

It is the car that determines the flow of power when an EV is on a DC rapid charger. The flow of power is not linear and changes quite a lot by vehicle even from the same manufacturer. The Nissan Leaf 24kWh and 30kWh have been used as an example because they are the most common EVs at the present time. The experiment uses the current available technology but comment will be made, making reference to higher capacity batteries and more powerful charging equipment. Power curves were measured on a DBT rapid charger at intervals of one minute.

The experiment was carried out at various outside temperatures (from 4 to 15 degrees) to gather insight into the effect of ambient temperature. The collection of data was repeated on the newly released 30kWh battery.

The following data were collected every minute:

- Time interval
- Volts
- Amps
- State of charge

Data collection was carried out 5 times with a 24kWh battery and 2 times with a 30kWh battery. The intent was to replicate the fact that as confidence in the vehicle range grows then drivers should be arriving with a SoC of around 10 to 15%. As previous studies (Neaimeh et al 2017) have shown some drivers can come in at SoC as high as 40%. So these scenarios were also replicated.

**2.3 Statistical reliability of number of chargers**

As well as recommending a figure for the number of chargers, there needs to be some idea of the uncertainty in the estimate. Using the variance synthesis method described in Morrison (2009), the variance of the estimate is approximated by a weighted combination of the variances of the individual components. The weights are the squared partial differentials of the estimate with respect to the variable. The partial differentials are evaluated at the mean value of the variable.

Variance (H=no. chargers) ~ sum of {(partial differential of H with respect to each variable)$^2$ x variance of variable}

The variances of the components, however, are not known and these have to be best-guessed.

**2.4 Operational performance**

The derived equation is based on an established industry measure of Overall Operational Effectiveness (OEE) which is made up of availability x speed against design x quality of product. In our application, to measure the performance of a charger, the Operational Performance (OP) will be determined as:

Utilisation x power (delivery vs design) x availability.

**3. Results and discussion**

**3.1 Formula**

The formula for number of chargers recommended is a multiple of the different factors.

The number of chargers is H = AxBxCxD/(ExFxG)

Where

A = % of cars that are EV

B = number of cars

C = average daily mileage

D = % of mileage needing rapid charging

E = miles per kWh

F = average power delivery in kWh (depends on charge time) and we have assumed 30 mins

G = number of hours charger is in use

The dimensions of H are miles per day/((miles/kW) x kW x hours in a day) so dimensionless. Suitable values are obtained from a number of sources and are shown in Table 1.

Table 1 Input data

| Variable | Variable | Data | Provenance | Source |
|---|---|---|---|---|
| B | UK volume of cars and light vans | 30m | Derived | RAC Foundation www.racfoundation.org |
| C | Daily average distance driven per car | 26 miles | Derived | RAC Foundation www.racfoundation.org |
| B x C x 365 | Total UK miles driven per year | 311bn | Derived | RAC Foundation |
| A | % cars that are EV | 0.3% | Derived | Office of Low Emission Vehicles |
| E | Miles available per kWh | 5 miles | Derived | Actual performance of a 30kWh Leaf (Best achieved). |
| **F** | **Average power delivery from 50kW charger** | **27kW** | **Calculated** | **Experimental as described in this article** |
| D | Percentage charge at home/work | 90% | Assumed | Accepted prediction |
| | **Charge time** | **30 mins** | **Set** | **Using 80% rule in 30 mins** |
| A x B | Current UK EV volume | 90K | Derived | Office of Low Emission Vehicles |

Once the state of charge vs time relationship is understood, the power levels vs state of charge can be found and the average power delivery can be calculated for a selected charge time. The components can then be combined in a calculation to give a figure for the number of chargers needed.

## 3.2 Calculating average power delivery

### 3.2.1 SoC vs time

It was found that the 30kWh vehicle has the same charging time to 80% state of charge (SoC) as the 24 kWh vehicle. This is achieved by the 30kWh battery accepting more power at circa 380 volts. The results are shown in Figure 1.

The graph also shows that an extra 15% of charge takes a further 25minutes. The vehicle would not go beyond 95% SoC which has been monitored post trial.

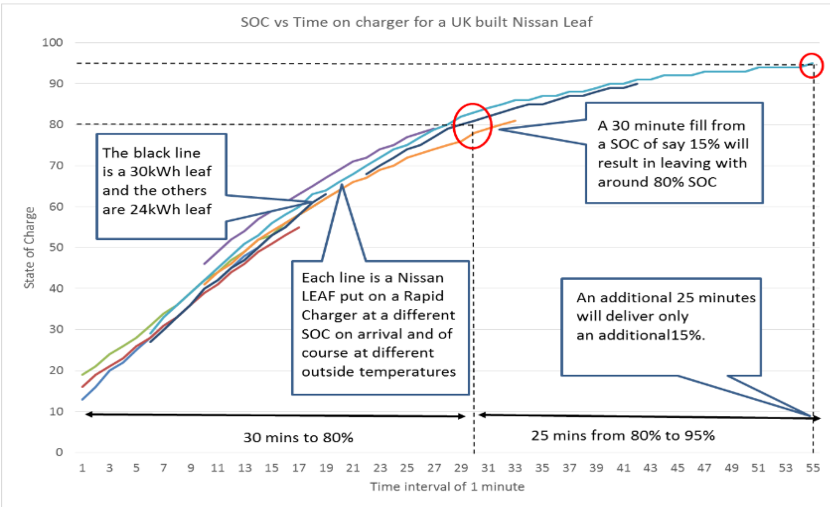


Figure 1: State of Charge (SOC) vs Time for a UK manufactured Nissan Leaf

The different lines were at different ambient temperatures and is can be seen that ambient temperature had little impact on the charging curve. The start temperatures when data was collected varied from 6 to 15 degrees Celsius. Using Meteorological Office data (1982 – 2010) the average minimum temperature for the UK is 5.9 degrees and the maximum temperature is 13.5 degrees Celsius. This potential variable was discounted.

### 3.2.2 Implications for power delivery

The kW were then calculated (volts x amps). The amps being the variable (Figure 2) with power (in W) on the vertical axis and SoC as a % on the horizontal axis. The different plots reflect ambient temperature. The difference between 24kWh and 30kWh vehicles is very clear in that the 30kWh Leaf is taking a higher level of current for a longer time. The key intersections on Figure 2 are:

- SoC of 65% in 20 minutes
- SoC of 85% in 30 minutes
- Maximum delivery of 95% SoC in 55 minutes

In Figure 2 it can be seen that the 30kWh Leaf maintains high power (accepted) taking around 380 volts and 106 amps (40kW) until a SoC of 65% then it tails off. The 24kWh Leaf has a very quick drop off of power. It is also clear that the power drop off gradient for both the 24 and 30kWh batteries follows a similar trajectory after the 65% SOC. The 65% point is important as Figure 2 shows, as this occurs after 20 mins. The 85% point has also been marked as this was the termination point of the trail after 30 minutes. The next stage (Figure 2) is to determine the average power delivered up to 65% SoC then 65% to 85% SoC. A recent report by the RAC Foundation (2017) assumed incorrectly that 30mins on a 50kW charger will deliver 25kW but accepts it will not be linear. This study (Figure 2) shows variation between and within models of the same car maker and quantifies the non-linearity.

### 3.2.3 Developing average power delivery

Using the data collected from the trials it is now possible to create, by using Figure 2, the following:

Charging characteristics for a 30kWh battery are:

- 41kW for 20 mins which is 13.66kWh
- 20 kW for 10 mins which is 4.0 kWh

So one 30kWh car charging for 30 mins will consume 17.66kWh. Data from the RAC paper (2017) suggests a delivery of 22kWh over 30 mins which is a 20% variation and will be greater if a 24kWh battery is charging. When looking at a car pool of say 1million cars this represents a lot of energy error.

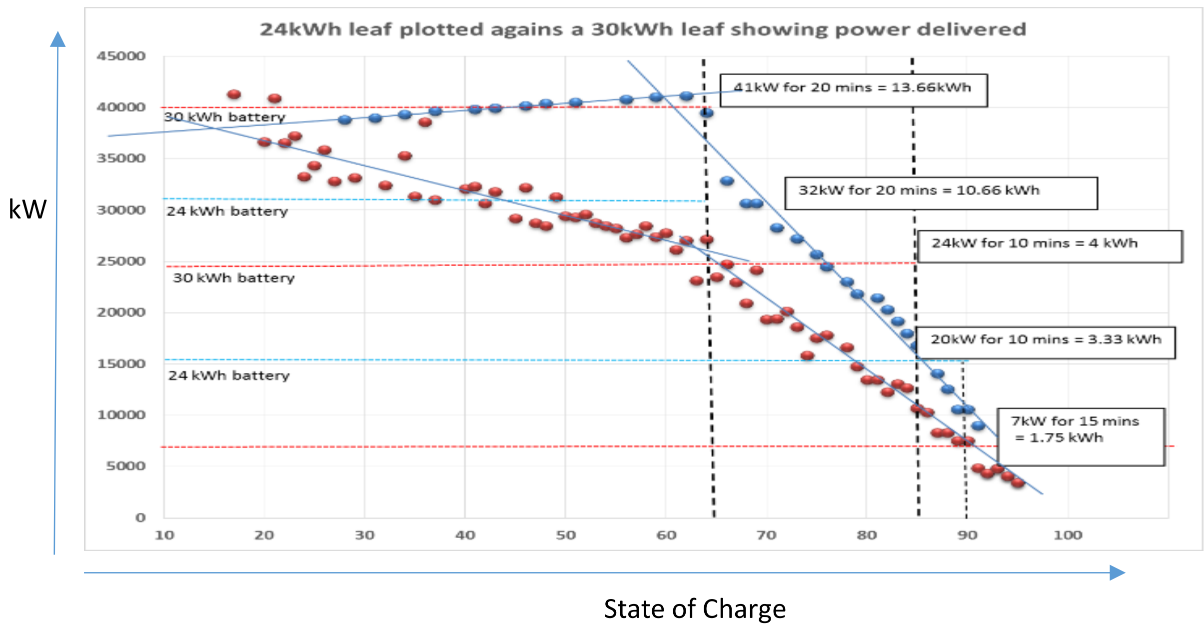


Figure 2: Power delivery as state of charge increases; using averages for 24Kwh (red dots) and 30kWh Leaf (blue dots).

### 3.2.4 Developing power delivery per hour or multiples of

Figure 1: illustrates nicely the origin of the 80% SoC in 30 mins norm in many manufacturers' statements. This curve has been used to provide reference data for the required calculation of power delivered over 1 hour. The 30min charge is gaining more significance as the main provider of motorway service EV charging has brought in a flat payment rate for 30 minutes. It is acknowledged that other payment methods are now being tested which are:

- Time restricted;
- Connection fee plus price per kWh;
- Price per kWh; and
- Connection fee plus price per kWh where the connection fee is waivered if domestic electricity is taken from the operator.

As it is not possible to disconnect, drive away, allow second vehicle to park and connect with no time loss, a nominal changeover of 10 mins has been allowed. This means there is a 50min delivery window each hour. This also does not assume continual use for 24hrs but the overall developed model will use a suitable factor, as will the 'Operational Performance' calculation. Various operators of infrastructure are trying different payment methods based on either time or a connection time plus a kWh price or a combination. Research to date has been carried out during a period when the charging infrastructure has been free at the point of use to the car driver. Payment was universally introduced by private operators in 2017 but not uniformly by local authorities. The impact of charging has not been researched and will prove difficult in the short term as rival operators search for the correct payment formula and local authorities have individual policies. For this article it is assumed that the user will use the chargers as required, and will not be influenced by price. To try and estimate the average power delivered on a charger the observed power delivery curve (Figure 2) shows a clear power deliver trend to 65% SoC over 20 minutes then a further smaller change to 85%, 10 mins later. A 30-minute charge has therefore been taken as 20 minutes plus 10 minutes. A nominal 10-minute changeover has also been considered and the charger is fully utilised during the day which the authors acknowledge is not a current real situation.

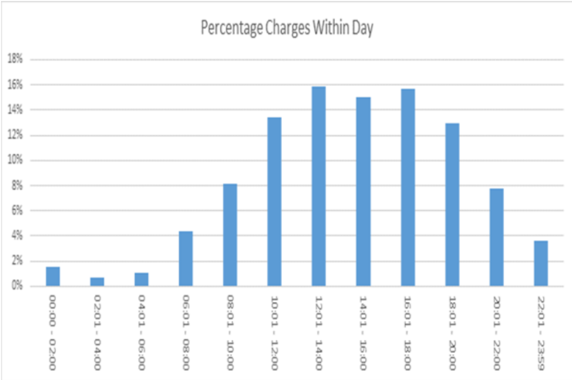


Figure 3: Percentage of daily charging behaviour against time.

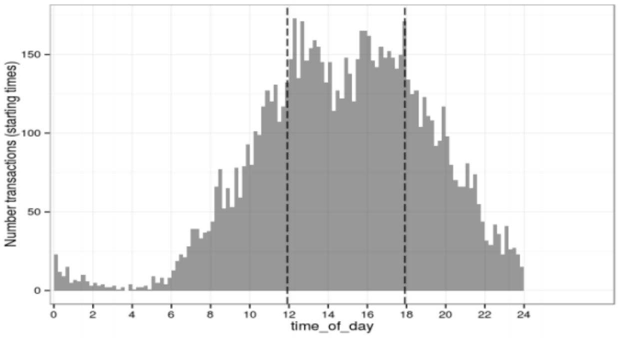


Figure 4: Number of transactions against time from the RCN study

Note:

- Figure 3 shows on an aggregated basis which are the most popular times of the day for charging by percentage
- Figure 4 shows the cumulative figure for a whole trial by time of day
- Figure 5 shows a complete national charging estate in terms of utilisation by hour and by day

The above figures (Figures 3 and 4) contradict assumptions held and the recent report by the RAC foundation (2017) that: demand for fast charging will take place outside of off-peak times, with peaks for rapid charging occurring in the morning and evening rush hours (RAC 2017). The supplied figures show that the main utilisation (60% of total) takes place between 10am and 6pm and support the 2015 Rapid Charge Network Study (RCN) study in 2015 (INEA, 2015). Access to the actual estate utilisation Fig (5) gives more detail than Fig (3) and shows clear daily behaviours in terms of utilisation, in line with the RCN study Fig (4). Looking at what would be considered peak times i.e. 6am until 8am it can be seen that this constitutes just over 4% of the utilisation, 8am until 10am is 8% of the utilisation and for the evening 6pm until 8pm there is 13% of the utilisation. In reality the morning rush hour is over by 9am so the morning peak period has much lower utilisation of the network at under 12% than might have been expected. The evening peak period is more condensed and will end by 8pm and shows a similar utilisation as the morning at 13%. So what can we take from this? It would suggest that rapid chargers are being used for what they are being designed for which is extending the range of journeys and not for commuting. Obtaining the localities of the more utilised chargers could confirm this theory but currently this is too commercially sensitive. Absence of the data set has resulted in a population average estimated at 4% with a peak of 12%.

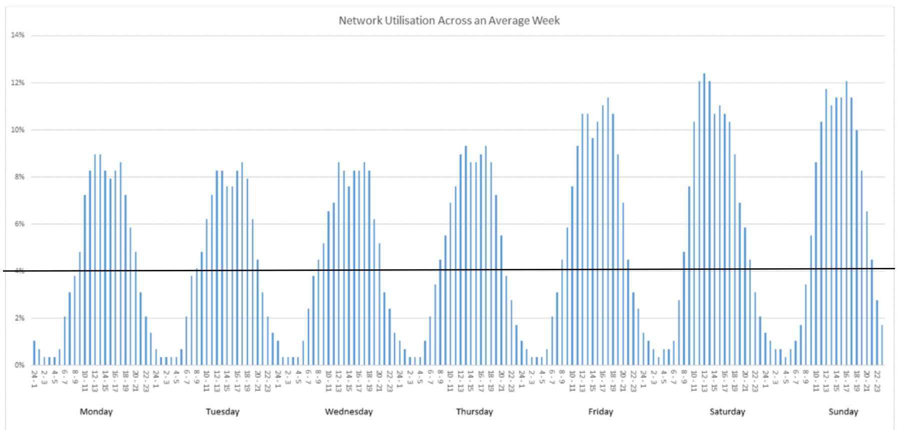


Figure 5: Percentage of daily charging behaviour against time

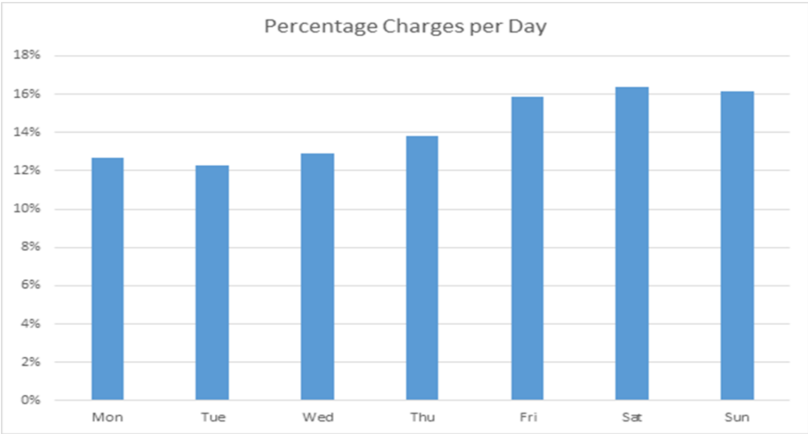


Figure 5: Charging activity shown as a percentage by day.

Looking at the spread of charging by day (Figure 6) from the same operator there is little actual variance by day during the week with a greater usage on Friday, Saturday and Sunday which suggest recreational travel away at a distance, which requires a recharge. It must be stressed that this data does not differentiate by:

- car maker
- battery size
- AC or DC charging

Going forward the impact of 40kWh batteries and high power charging will have to be evaluated. Fortunately for this study it can be assumed that the majority of the charging will be Nissan as Nissan cars are 100% BEV and rely on the network for long-distance driving.

To determine a theoretical maximum delivery, we will assume back to back charging then introduce an 'utilisation factor'. The real life situation is not machine but human dependant in that the customer will determine the time on a charger.

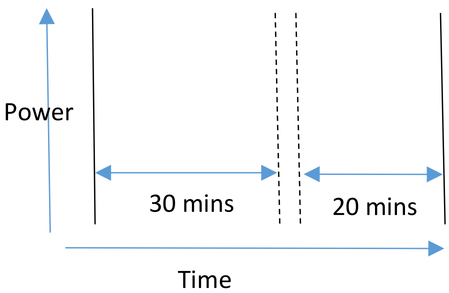


Figure 6: Representative charging window of 60 minutes

Substituting power delivery

- One 30kWh charge followed by a second 30kWh charge = 31.32 kWh (41kW for 20 mins which is 13.66 kWh plus 20 kW for 10 mins which is 4.0 kWh plus 41kW for 20 mins which is 13.66 kWh)

This gives a figure of 31.32 kWh for 2 cars charging back to back with a 10 min change over. Note: There will be a 'knock on effect' of the second car encroaching into the second hour (see Figure 7)

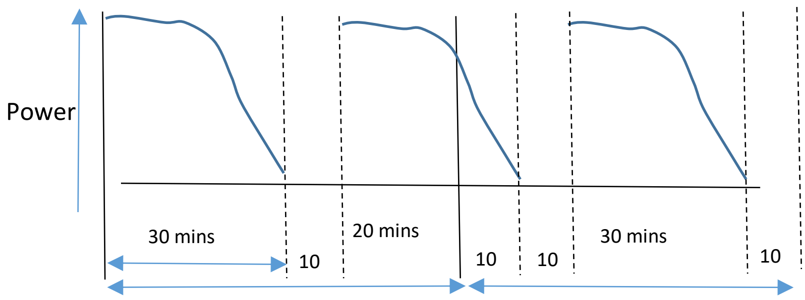


Figure 7: Practical use of charging point

If we have cars back to back charging, then using the 30kWh +30 kWh +30 kWh car scenario as shown in Figure 7, we get power delivery

= [17.66 + 0 + 13.66] + [4 + 0 +17.66 + 0] = 52.98kWh over 2 hrs or 26.5kWh per hour.

Giving owners the option of a 45 min charge on a 50kW charger will require more chargers to service the park requirements. The extra 15mins charging will deliver an average of 7kWh. The consequences of this are that chargers will be occupied but delivering small amounts of power. This creates a conflict between a driver's desire to 'fill the car up' and the national/business need to dispatch as much power as possible quickly. This fact was highlighted by Neaimeh et al. (2017). Their research showed that, in terms of charger duration, 32% of the events in the UK and 21% of the events in the US were above 30mins. The charging rate slows down when the battery is close to full resulting in long charge events that impact on the chargers' availability.

Assuming back to back charging and that the larger battery will become the norm as well as accepting that larger capacity batteries will appear soon, the figure of 26.5 kWh has been selected.

**3.2.5 Calculation of number of chargers needed**

The number of chargers can now be calculated as H = AxBxCxD/(ExFxG)

Where

A = 0.3% of cars that are EV

B = 30m number of cars

C = 26 average daily mileage

D = 10% of mileage needing rapid charging

E = 5 miles per kWh

F = 26.5kWh average power delivery

G = 24 hours charger is in use

The final figure is H = 72 derived as follows:

A=0.3% current proportion of population of cars (B=30m) are EV giving 90,000 EVs

Average daily mileage is C=26 miles

Miles per kWh is E=5

So 90,000 x 26/5 = 468,000 kWh needed per day

Assuming that [1,2] 90% of charging will be at home or work, 10% of the national mileage per day requires rapids, so

D=10% of the national EV mileage per day requires rapids so 46,800 kWh

A 50Kw rapid can deliver currently F=27kW per hour for G=24 hours which is 648kWh of energy

We need 46,800kWh /648kWh = H=72 chargers.

Using data from Zap Map (Oct 2017) there are 1162 rapid charge devices in the UK. As we have calculated we need 72 chargers at 100% utilisation it would suggest the network is operating at 6% utilisation which seems to tie in with figure supplied by the national network operator. The assumption made is that all sales are 100% EV to project into the future but currently registrations show 48% BEV giving a 2.88% utilisation which is reflected in figure 5 form the network operator. It is recognised that some chargers will be heavily used and some which have been installed to enable theoretical travel will be much underused. The network operator offered the suggestion that during the initial phase of EV adoption a much larger percentage will be those that can charge at home and get 100% charge …so it further distorts the infrastructure requirement by reducing the dependency.

If we use the end point of the current rapid charger population of 1162 rapids at full utilisation and 10% use by the EV population, they would support a UK population of 1.4m EV.

Using the current figure of 9,000 vehicles (10% of 90,000) that are using rapid chargers today this gives a ratio of 125 cars to each rapid charger, if operating at their theoretical performance and not 'operational performance' (see 3.2.7). This reflects the IEA figure of 130.

**3.2.6 Statistical reliability of number of chargers**

The statistical reliability of the recommended number of chargers (72) can be evaluated based on the variability of the components making up the calculation using variance synthesis (Morrison, 2009).

The statistical reliability of the number of chargers is:

Variance (no. chargers) ~ sum of {(partial differential of H with respect to each variable)$^2$ x variance of variable}

Carrying out partial differentiation of the equation for H, the variance of number of chargers is

= (BxCxD/(ExFxG))$^2$ Var(A) + (AxCxD/(ExFxG)) $^2$ Var(B) + (AxBxD)/(ExFxG))$^2$ Var(C) + (AxBxC)/(ExFxG))$^2$ Var(D)

+ (-1) (AxBxCxD)(ExFxG)$^{-2}$ )x(FxG) Var(E)+ (-1) (AxBxCxD)(ExFxG)$^{-2}$ )x(ExG)Var(F) + (-1) (AxBxCxD)(ExFxG)$^{-2}$ )x(ExF)Var(G)

The partial differentials are evaluated at the mean value of the variable. Variance is the square of standard deviation.

[1] The institute of Transport Economics at the Norwegian Centre for Transport Research have published EV user research which suggests 94 to 95% home or workplace charging. The authors have used a similar but more conservative figure of 90%.

[2]The proportion of EV owners with ability to charge at home stands at 80% and 25% have charger access at place of work (Zap-Map (2015)

Table 2 Variance synthesis

| Variable | A | B cars | C miles | D %charging | E kWh | F kW | G hours |
|---|---|---|---|---|---|---|---|
| Mean | 0.003 | 30,000,000 | 26 | 0.1 | 5 | 27 | 24 |
| Standard deviation | 0.0001 | 300,000 | 1 | 0.01 | 0.2 | 1 | 0.1 |
| Coefficient | 24,074 | 0.00 | 3 | 722 | -14 | 3 | -3 |
| Contribution | 6 | 0 | 8 | 52 | 8 | 7 | 0 |

The standard deviations are best guessed from a knowledge of how the values (A to G) were obtained. Using the means and standard deviations in the table, the variance of number of chargers is 81, made up from the sum of the contributions shown in the bottom row of Table 2. It can be seen from Table 2 that the variance is mainly dominated by D because its contribution to the variance is large. The variance can be interpreted as the reliability of the figure for the number of chargers. Table 2 shows that the uncertainty in the %charging has a large effect on the reliability of the figure for the number of chargers but the uncertainty in the number of cars does not have much effect.

An approximate 95% tolerance interval for the number of chargers can be calculated as twice the standard deviation either side of 72. Standard deviation is the square root of the variance, so standard deviation = 9. A 95% tolerance interval is approximately 72+/-18, which is 54 to 90 chargers. It is important to consider the uncertainty in the estimate of number of chargers as this serves to reinforce the fact that it is dependent upon current best guesses at this stage.

**3.2.7 Operational performance (ref 2.4)**

The performance of a charger, the Operational Performance will be determined as:

Utilisation x power (delivery vs design) x availability or hours used/24.

We assume that power vs design is the power delivery figure of 26.5kW divided by the maximum power delivery from a charger which is 43kW rated.

So for a charger delivering for a total of 1.5 hrs per day (6% utilisation) and an availability of 97% we get:

100 x 26.5/43 x 0.97 x .06 = 3.55%

- The utilisation is set by need, price and location.
- Power delivery is set by battery design
- Availability is due to design and maintenance

The calculation to deliver Operational Performance would suggest a current level of 6% for the network. This means that an estate of 1200 chargers operating at 6% would deliver the same as 72 at 100% utilisation.

If we build in the current spread and utilisation this roughly equates to 1162 which is the current UK estate. Note: The authors have used an average figure as some chargers will be heavily used and some will be lightly used.

**4 Discussion**

The above calculations assume an even spread of drivers and vehicles. As we are looking to the future the 24kWh battery has been discounted as OEM's will be producing larger capacity batteries. The modelling must take into consideration the arrival of 40 and 60kWh batteries as well as 150kW chargers. As we do not know the charging characteristics of larger capacity batteries, assumptions will have to be made. An overriding factor is that; it is not the capability of a charger to deliver power but the capability of the car to receive power, which determines the amount of power transferred and the time it takes.

The mass introduction of Plug in Electric Vehicles will require a viable charging infrastructure, both to actually charge the vehicles, and to address range anxiety. What has not been produced for towns, cities and countries is a model to calculate what charging infrastructure is actually required, based on known variables and declared assumptions. Ongoing there will be changes to technology regarding vehicles and charging equipment. The charging habits of owners have not yet been established based on variables, such as power delivery payment models. This article puts forward a figure for the current situation at the time of writing within the UK, working on theoretical delivery. Additional insight, which may help in future forecasts, may be derived from studying other infrastructure networks, such as the number, location and spatial distribution of masts for mobile phones.

**5 Conclusions**

This paper conclusions must be caveated with the comments that transition to EV is being attempted on a scale which has never happened before and the variables are true variables in that, business models (payment) and both vehicle and charger technology is evolving rapidly. The consumer (EV driver) is faced with upgrades and trials of payment which are testing the market to determine what charging level is acceptable and what level will return on charge point operator investment. The uncontrolled installation of charge posts and specifically rapid chargers also clouds the situation along with local authority's making different decisions on payment which can directly conflict with private operators. Correct usage and numbers of charge posts is critical to energy policy but there is no current linkage.

The figures derived show that the current charging estate can cope with the current utilisation with accepted hot spots. A follow on paper should map population centres with traffic flow, and introduce actual driver's habits, as opposed to predicting them especially now payment for power has been introduced. The utilisation figure of less than 5% if correct would suggest that there is enough infrastructure, but in a business context not all in the correct place. For a social need the spread is important, however it impacts on the business case for investment. Future traffic projections should be employed to plan infrastructure need. A secondary question is the cost of infrastructure roll out in terms of installing equipment, power supply and impact on the grid either local or combined. Assumptions have been made as to grid impact but not the cost of installing a national charging infrastructure. It is also possible that managed use of vehicle charging could benefit the grid. The national grid has to maintain an overall power capacity which has an operating base load. Excess power generated at night from sources such as wind power could be utilised for EV charging. As driver confidence grows and batteries increase in capacity the driver will arrive with a lower State of Charge (SoC) then take more power for a longer journey. What has been ascertained from a network operator is that the combination of: payment, confidence and change in battery size has resulted in an average power delivery increasing by 26%.

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**Glossary**

BEV battery electric vehicle
EV electric vehicle
EVSE electric vehicle supply equipment
ICE internal combustion engine
OEM original equipment manufacturer
OLEV the UK's Office for Low Emission Vehicles
SoC state of charge
ULEV Ultra Low Emission Vehicles

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