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Understanding the role of a rapid charging infrastructure on urban and interurban mobility patters.

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Summary

Rapid Charge Network (RCN) is a 7 Million Euros project co-financed by the European Commission with the collaboration of Nissan, BMW, Renault, VW, ESB, ZCF and Newcastle University. The aim of this work is to share some of the insights from RCN on the use of rapid charging posts in the UK and illustrate how they could be extending the driving range of electric vehicles (EVs) and enabling the use of EVs by high-mileage drivers. The findings from this work would be used to inform the deployment of rapid charge networks in Europe and beyond.

Keywords: BEV (battery electric vehicle), demonstration, infrastructure, charging, range.

1 Introduction

In order to achieve the ambitious targets for reducing the use of transport-related emissions, sustainable mobility plans include a substantial shift towards the use of ultra-low carbon emission vehicles such as electric vehicles (EVs) [1], [2].

An ambitious shift towards EVs requires an appropriate charging infrastructure to support the mass uptake of electric cars. A key component of the charging infrastructure would be a network of publically available rapid chargers as part of an overall recharging infrastructure. A rapid charging station can recharge an EV from an empty battery to about 80% of full state of charge (SoC) in 20 to 30 minutes and would enable efficient long distance driving using EVs.

RCN is one of a number of European Commission's Trans-European Transport Network (TEN-T) projects on EV infrastructure. These projects are driven by the need to support decarbonisation and promote alternative fuels for road transport in the EU [3], [4]. RCN was officially launched in 2014 with the goal of deploying a network of 74 rapid chargers throughout the UK and Ireland. RCN is co-financed by the Commission's TEN-T funding with the collaboration of Nissan, BMW, Renault, VW, ESB, ZCF and Newcastle University[5]. The objective of RCN is to enable EVs to drive further, beyond the range of the EV battery.

The aim of this paper is to share the findings from the installation and usage of the rapid charge network. Additional data from a selected number of EVs close to network have been also collected and analysed. A more detailed analysis is presented in the Study activity final report available online [6]. The lessons learnt and insights from RCN are used to inform and shape the deployment of further rapid charging infrastructure in the UK, Europe and beyond.

2 Recharging Network Description

RCN deployed 74 rapid charging stations along the full length of Priority Project (PP) Road Axes 12 and 26 through the UK and into Ireland (Fig.1). This is a substantial real-world trial covering 1,100 km along major UK and Irish roads, which also links major seaports and International Airports. These road axes connect many UK regions with other EU member states including Ireland and mainland Europe [5].

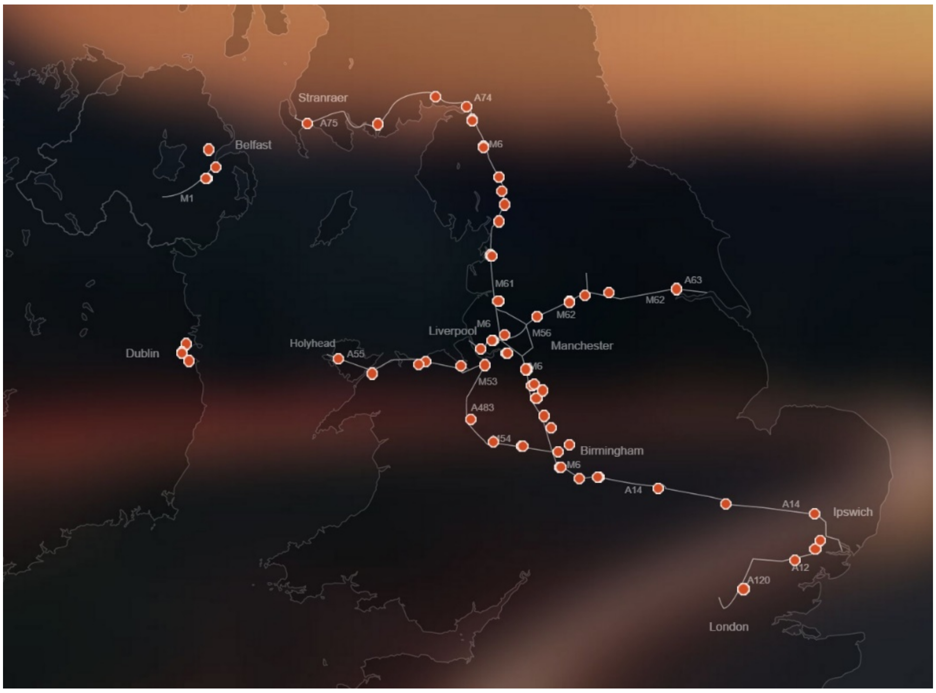

Figure 1. Map of RCN network charging points

76% of the RCN chargers are installed at motorway service stations (Welcome Break, Moto, Roadchef, Extra, Westmorland) with the remaining points installed at fuel filling stations, airports, seaports, Park and Ride, hotels and large retail stores. More specifically, the route links the East of England to Stranraer on the west coast of Scotland and Hull to Holyhead on the west coast of North Wales. The west coast locations then provide a link into Northern Ireland and Ireland through Belfast and Dublin respectively. 68 RCN chargers are located in Great Britain; 3 in Northern Ireland and the remaining 3 around Dublin in Ireland. RCN chargers in Great Britain are operated by Ecotricity and are fully integrated into its Electric Highway [7] whereas ESB ecars [8] operates the remaining sites in Northern Ireland and Ireland.

RCN brings four major automotive manufacturers together who collaborated on developing a charge point equipped with 3 charging outlets to ensure that all standardised EVs car use the recharging network regardless of the charging protocol used by the different EV Makes. The RCN charging stations have been manufactured by DBT-CEV [9] and are equipped with new and innovative multi-standard rapid charging technology, combining the CHAdeMO and Combined Charging System 44kW DC (Direct Current) chargers and 43 kW AC (Alternating Current) charger into one easily accessible charging station.

It is worth to mention that suitable sites for rapid chargers are determined by a number of aspects such as power availability, location, access, ownership, parking capacity and visibility; each of these aspects can be controlled by a different stakeholder which would create additional complications when trying to identify sites to deploy the charging stations.

3 Study Activity Description and Data Collection

The study activity of the RCN project is responsible for all aspects of understanding the usage and impact of the RCN charging infrastructure installed. Key areas of the study include the EV drivers' usage, attitudes and needs towards a rapid charge network. Detailed charging and driving behaviour of a number of EV users and their perception and views on EV usage, any barriers they perceive and general driving habits have been analysed.

Key to the study was the specification and collection of quantitative and qualitative data which was analysed to understand the charging and driving behaviour of EV users and their usage of the RCN network. In addition to collecting data from the rapid chargers, the RCN study activity asked for EV drivers to take part, either by completing questionnaires, by granting access to their car's electronic data or by volunteering to have a data logger installed in their car. The user engagement took place mainly via the RCN website were interested EV drivers filled in an initial questionnaire asking people how they would like to engage with the project, their contact details and the make and model of their EVs.

3.1 Online Questionnaires

The project recognises the importance of the EV drivers' input into the decision making for further infrastructure roll-out. As a consequence, RCN developed three online questionnaires that captured the perception, behaviour, experiences and requirements of the EV drivers towards EVs and the rapid charge network. Over 500 responses were collected, 299 individuals in total participated in the surveys with 59 participants completed all three questionnaires. The questionnaires included questions on ownership type of the EVs; the factors that influenced the purchase of the EV; overall level of satisfaction of the EV compared with the previous car; information on the previous vehicle that was replaced by an EV; driving and charging behaviour; usage of the rapid charge points; willingness to pay to use the rapid charging infrastructure and perception of carbon savings and energy. The majority of the drivers that participated in the study are between 41 and 50 years old; 89% of the participants are Male and 11% are Female and 64% of the participants earn above 35,000 GBP/year. 64% own their EV, while just over 20% are leasing it; other responses included the EV as a company owned EV. 84% of the participants stated that the EV us their primary vehicle. Finally, the participants believed that the most important factors that could impact the mass uptake of EVs were driving range, availability of rapid charge points and the price of the vehicle (Fig. 2).

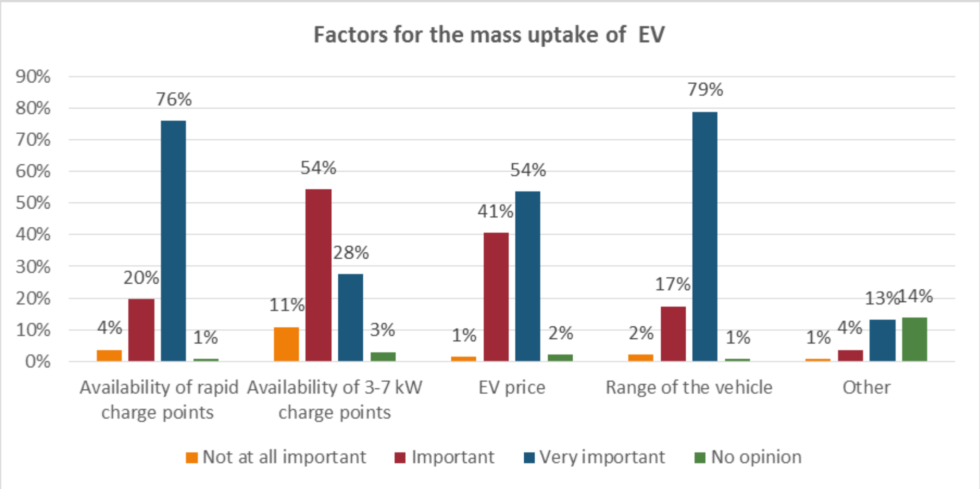

Figure 2.Factors impacting the mass uptake of EVs

More details on the questionnaires can be found in the RCN study final report[6]. The qualitative data collected from the questionnaires were compared with and complemented the quantitative data collected from the data loggers, OEM electronic systems and the rapid charging infrastructure. This helped identify differences between perceived and actual behaviour.

3.2 Data loggers

To monitor and measure the use EV drivers make of the RCN infrastructure and to understand what use they make of other charging infrastructure (home, work, public, etc.) it was desirable to recruit a cohort of EV drivers who were willing to have a data logger fitted to their vehicles. The data loggers enabled the research team to draw a detailed picture of the driving and charging behaviour which goes beyond the information that could be provided from the charging posts and the qualitative data. The data loggers provide up to second by second data allowing the project to monitor vehicles and their usage (e.g. GPS, state of charge, speed, battery current, battery voltage, and ambient temperature). The data logger trial was key to the research activity of RCN. All data collected through this medium was anonymized before publication. The trial and its success builds on Newcastle University's experience in running, since 2010, real world EV trials that included both qualitative and quantitative data collection.

Over 120 EV drivers volunteered to have a data logger installed in their car and the project selected 40 drivers based on their proximity to the RCN planned network and their EV ownership status (i.e. selected drivers owned the vehicle). Data loggers were installed in Nissan LEAFs (30), Nissan e-NV200s (5) and Renault ZOEs (5). 35 loggers were installed with private individuals while 5 loggers were installed as part of British Gas EV fleet (e-NV200s). Over 30,000 driving events and 10,000 charging events were captured over 10 month between February 2015 and December 2015. RCN trial user agreements were developed and signed between Newcastle University and the selected users to cover data logger installation and removal and data collection and protection. The RCN team travelled the RCN route, meeting the drivers and installing the data loggers in seven installation hubs. The team travelled to few participants who couldn't join the hubs. As an incentive for participating, each driver received vouchers for 200 GBP and access to a web portal showing summaries on their charging and driving events. More information on the data loggers is found in the RCN study final report[6].

3.3 Original Equipment Manufacturer (OEM) data

RCN vehicle manufacturer partners provided EV driving and charging data from their electronic data collection centres. The project had access to an anonymized dataset which consisted of charging and driving events aggregated by month for 985 Nissan LEAF drivers in the UK between January 2013 and July 2014. This dataset gave overall trends on distance travelled and number of rapid charging events for that period. Additional OEM datasets included data aggregated by driving and charging events (e.g. total distance per event; state of charge at the beginning and end of an event) for 29 RCN drivers (19 BMW and 10 Renault). The OEM datasets were less detailed than the data collected from the loggers; however, they gave insights on overall trends and increased the number of drivers analysed beyond the 40 drivers participating on the data logger trial.

3.4 Charging Infrastructure Data

Charging transactions data on the RCN network were provided by the Network Operators, Ecotricity's Electric Highway in the UK and ESB's ecars in Ireland. The charging data include a unique ID for each charge point, charging event and user, the start/stop times of each transaction, energy transferred and the connector type used.

4 Study Findings

4.1 Rapid Charge Network Usage

The RCN chargers were installed in 2014 and 2015. This section provides usage statistics for all sites in operation up to the end of November 2015. In total, the RCN chargers have delivered around 300 MWh of energy between July 2014 and November 2015 spread over more than 33,000 transactions. The bulk of that energy has been delivered by the units in Great Britain (more than 97%) where the majority of the chargers on RCN are installed. This equated to over 1.65 Million electric km.

On a month by month basis, the usage of the network has experienced a steady growth as new sites have become live, Fig. 3(left panel). Likewise, when the effect of new charger installations is removed, the energy drawn on a per charger basis has also been growing, Fig.3 (right panel), meaning that the usage of installed chargers is increasing every month.

With regards to the performance of individual chargers, Fig. 4 gives an indication of the variation experienced across chargers in terms of the energy delivered. The horizontal line represents the global monthly demand aggregated across all chargers (625 kWh/month). There is no relationship between the better performing sites (blue bars) and the date when chargers were first installed. This type of analysis allows us to identify the sites where more energy is transferred and, hence, prioritise the installation of additional rapid chargers in these popular locations. The average energy transferred per charging event is 8.9 kWh.

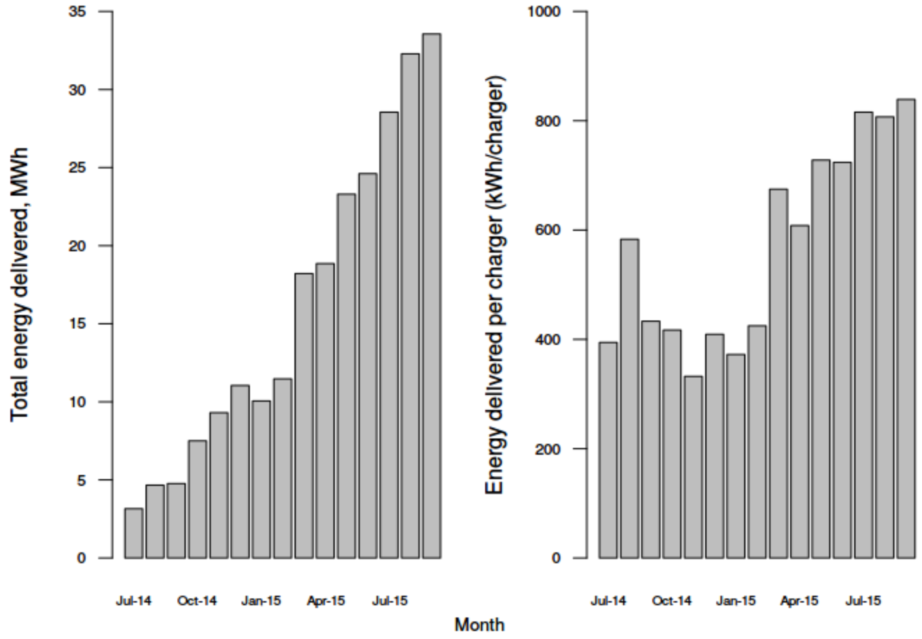

Figure 3.Energy delivered by RCN sites on aggregate on a monthly basis (left panel) and per charging unit (right panel)

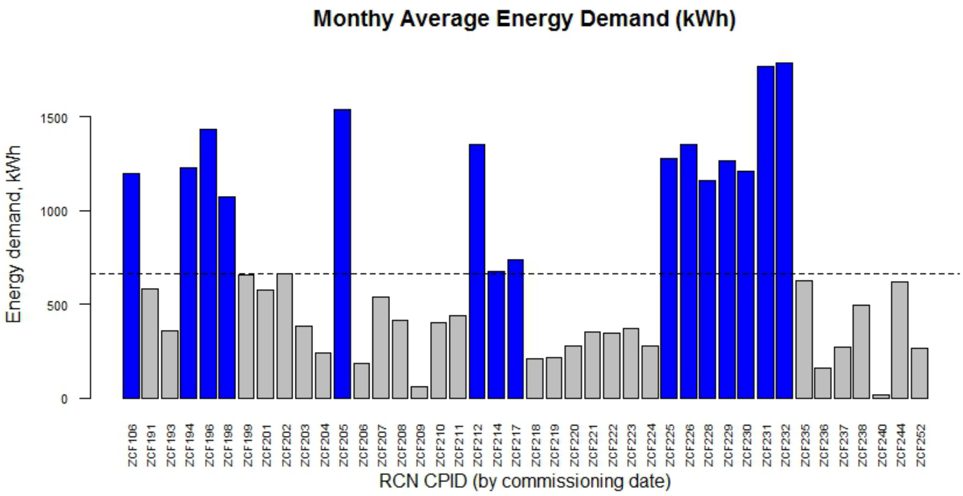

Figure 4.Variation in monthly energy demand across RCN sites.

4.2 Time of Use and Charging Duration

As it would be expected, the majority of rapid charging events take place during the day with the highest usage recorded to be between 12:00 and 18:00 (Fig. 5).

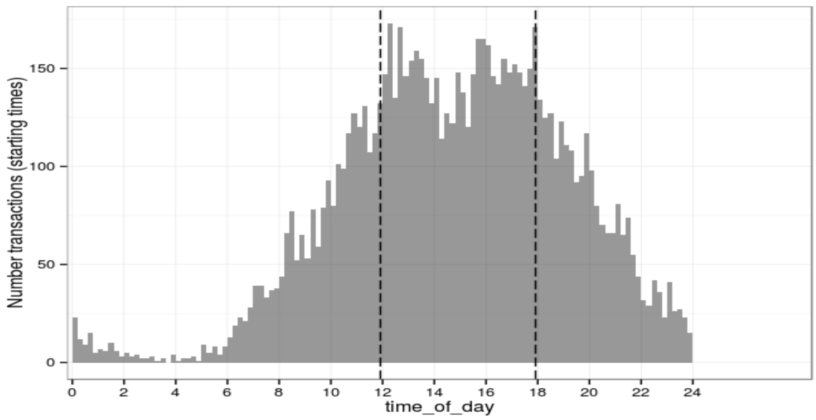

Figure 5. Rapid Charging events transaction start times.

In terms of transaction duration, the median recorded for RCN is 24 minutes and the average is just over 26 minutes as shown in Fig. 6. Transaction times in 32% of RCN recorded transactions are above 30 minutes. Charging duration above 30 minutes (when the battery is full or close to full charge and therefore takes additional charge at a much slower rate) will severely impact upon charger availability and are, therefore, undesirable. In addition, less than 5% of the online questionnaires respondents expressed their willingness to wait longer than 30 minutes if the rapid charger was occupied by another vehicle. Many respondents emphasized the need to enforce time restrictions per charge event in order to minimize the misuse of this type of charging infrastructure. For example some drivers suggested to "automatically stop a charging event after 30 minutes to allow the other outlets to be used", and "some people are using the RC to go to 100% and taking an hour. There is a need to prevent this and allow charge up to 80% only so that other people are not kept waiting."

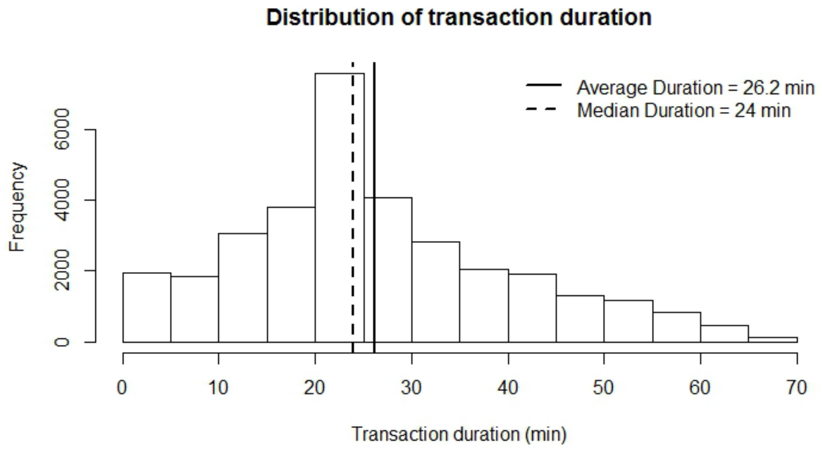

Figure 6.Distribution of Transactions duration.

4.3 Connector type usage breakdown

Recharging technology is driven by the EV manufacturers. Until 2012 the majority of EVs available in the UK required the 50 kW DC CHAdeMO rapid charging protocol. But in 2013 the CCS rapid charging protocol was introduced to the UK and Ireland with BMW and VW entry to the EV market. On an aggregate basis and for the period considered, the CHAdeMO outlet has been the most used delivering just over 72.1% of the energy (Fig. 7) which reflects that the UK's highest market share of electric vehicles use the CHAdeMO protocol. The CCS outlets follow with 14.5% but not far from the 43 kW AC, which has delivered 13.4% of the energy overall. Fig. 8 shows the energy transferred per outlet type over time. It can be noticed that the use CCS outlet is increasing and reflects the increasing number of CCS cars on the road (i.e. BMW, VW).

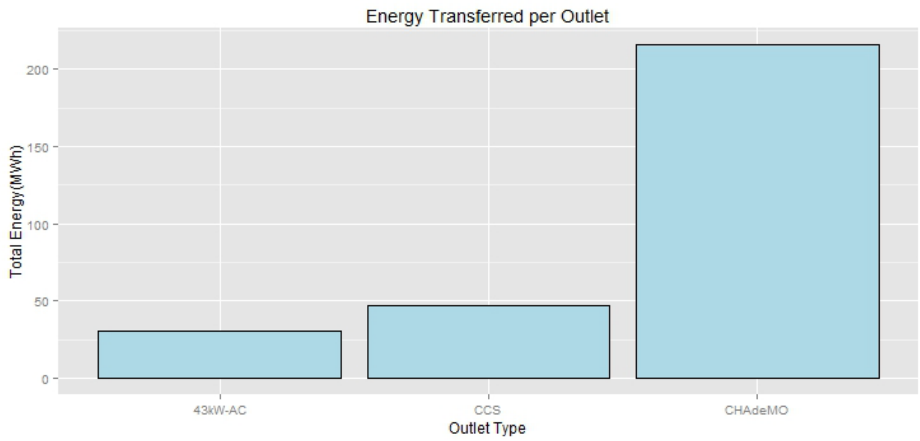

Figure 7.Energy delivered by RCN outlet type.

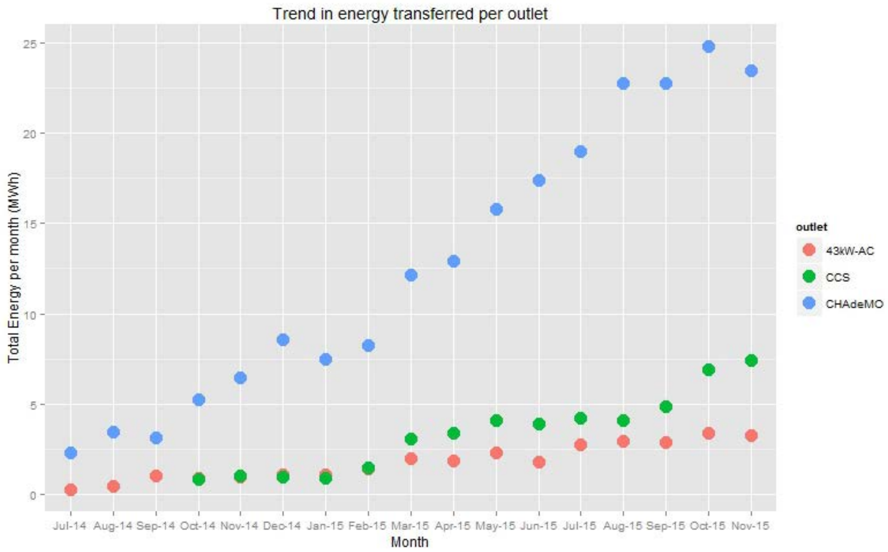

Figure 8.Energy transferred per outlet type over time.

4.4 Detailed charging and driving behaviour

4.4.1 Charging behaviour

An extensive EV recharging infrastructure is needed for a mass uptake of EVs. A network of rapid chargers is a key element in the whole EV infrastructure. The data logger trials allowed the RCN team to capture the overall charging behaviour of EV drivers and helped understand the usage share and the role that the rapid chargers play. Over 10,000 charging events were collected during the 10 month trial period and Fig. 9 illustrates the overall charging behaviour of the users on the trial. It can be seen that the users rely on home charging with 71% of the charging energy transferred at home; however, when charging in public locations their preference is for rapid chargers. 16% of their total energy is transferred at rapid chargers and 4% is transferred at other public charging locations (Fig. 9).

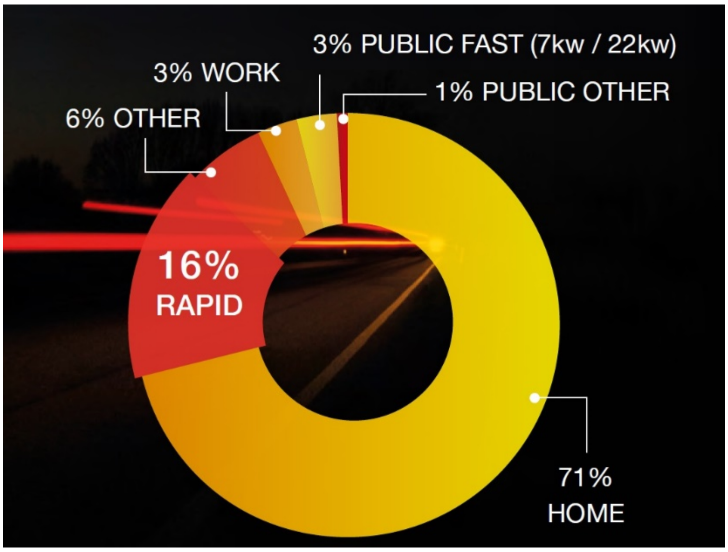

Figure 9.Energy breakdown by location of charging events.

4.4.2 Driving Behaviour

In addition to looking at the detailed charging behaviour, the data loggers allowed us to analyse people's driving behaviour. The distribution of daily travelling (i.e. Total distance travelled in one day) from the EV data loggers is positively skewed, with a median of 51 Km (Fig.10). The average daily driven distance of 61 km is within the range of an electric vehicle.

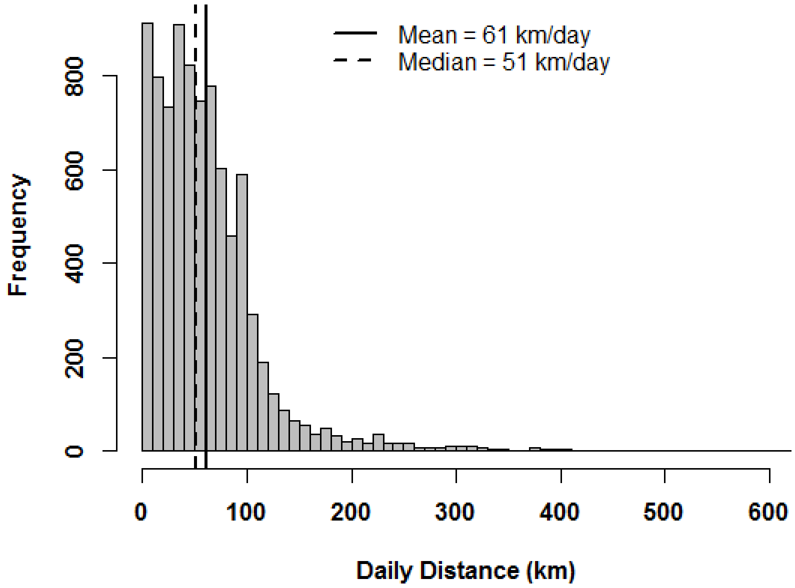

Figure 10.Distribution of daily driving distance on the data logger trial.

The distribution also shows a substantial number of events where the total driving distance in a day is over 150 Km (approximately 100 miles). These aggregated daily distances are above the driving range of the EVs on the trial and would require recharging during that day. We can also notice a handful of events where the total daily distance is above 300 Km. Additional analysis indicated that 5% of the daily events collected were above the range of EVs on trial and above the range of most of the EVs on the market currently (around 150 km). In addition, over 85% of the people who drove above 150km in day used a rapid charger, indicating that the rapid chargers helped extend the driving range of EVs.

Data provided by the vehicle manufacturers was used to study the relationship that may exist between rapid charging infrastructure and vehicle use. The most significant finding in this respect is shown in Fig. 11, which displays the relationship between the number of rapid charging events and the cumulative distance driven by a cohort of 985 Nissan Leaf drivers between 2013 and July 2014 (every dot represents a driver). The solid line is an estimate of the mean distance driven as a function of the amount of rapid chargers whereas the two surrounding dashed lines are 95% confidence bands for that mean. As it can be appreciated, the relationship is very strong and associates high total distance driven with high use of the rapid charging infrastructure.

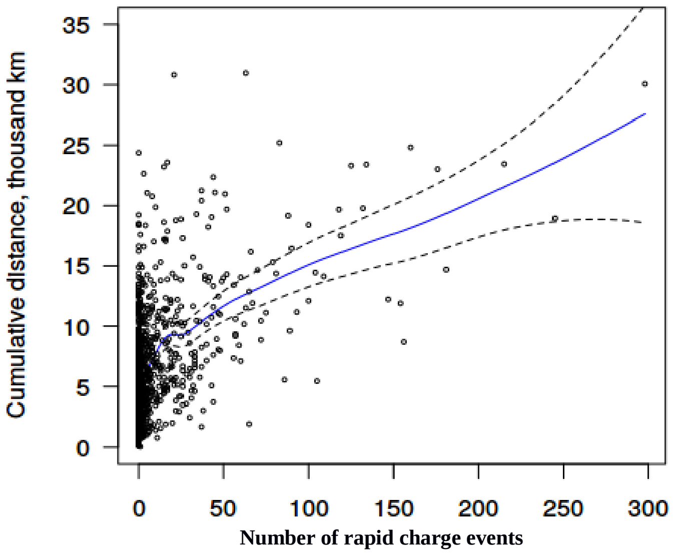

Figure 11.Total distance versus total number of rapid charging events (Nissan drivers: 2013-July 2014).

4.4.2.1 Examples of EV high usage

Considerations was also made as to understand how the availability of the RCN may facilitate future uptake of EV's by high-mileage users (e.g. Taxi fleets) and further support the uptake of EVs. As an example, we illustrate some cases where people pushed the range of their EV and drove way above daily and monthly averages. Fig.12 and Table 1 describe a 606 Km (379 miles) journey during one day. This journey started just before 8 AM in the North of England and ended in Surrey in the South just before midnight on the same day. The driver made 8 charging events including 7 rapid charging events.

Figure 12. 606km journey in one day

Table 1. Details of the 606 Km (379 miles) journey including the charging events.

##	event	site	site.pcode	type	time.begin	time.total	soc.begin	soc.end	soc.en	dist.mile
## 1	driving	<NA>	<NA>	<NA>	2015-02-28 07:47:31	43.9	95.8	44.3	-12.360	36
## 2	charging	16483	M17 8AA	fast	2015-02-28 08:31:22	194.2	44.3	88.8	10.680	NA
## 3	driving	<NA>	<NA>	<NA>	2015-02-28 11:45:35	136.8	88.8	17.7	-17.040	56
## 4	charging	44487	BB11 1RY	rapid	2015-02-28 14:24:00	39.0	17.7	70.7	12.720	NA
## 5	driving	<NA>	<NA>	<NA>	2015-02-28 15:03:02	63.0	70.7	27.3	-10.392	36
## 6	charging	ZCF201	PR7 5LR	rapid	2015-02-28 16:16:17	17.6	27.3	66.4	9.384	NA
## 7	driving	<NA>	<NA>	<NA>	2015-02-28 16:33:53	28.1	66.4	28.5	-9.096	28
## 8	charging	ZCF210	WA16 0TL	rapid	2015-02-28 17:02:00	27.2	28.5	77.9	11.856	NA
## 9	driving	<NA>	<NA>	<NA>	2015-02-28 17:29:12	59.8	77.9	16.5	-14.736	51
## 10	charging	ZCF207	WV11 2AT	rapid	2015-02-28 18:29:01	32.1	16.5	77.7	14.688	NA
## 11	driving	<NA>	<NA>	<NA>	2015-02-28 19:01:09	63.8	77.7	23.0	-13.128	50
## 12	charging	20602	CV35 0AA	rapid	2015-02-28 20:04:58	20.1	23.0	68.7	10.968	NA
## 13	driving	<NA>	<NA>	<NA>	2015-02-28 20:25:08	51.8	68.7	16.8	-12.456	42
## 14	charging	5745	OX33 1JN	rapid	2015-02-28 21:16:57	27.8	16.8	73.9	13.704	NA
## 15	driving	<NA>	<NA>	<NA>	2015-02-28 21:44:45	73.7	73.9	26.6	-11.352	51
## 16	charging	24475	KT11 3DB	rapid	2015-02-28 23:40:39	9.0	28.3	52.4	5.784	NA
## 17	driving	<NA>	<NA>	<NA>	2015-02-28 23:49:40	38.9	52.4	23.8	-6.864	29

Moreover, the network of rapid chargers allowed people to use their EVs for long journeys over several days. Some participants on RCN stated they have taken the EV on a week away from home (1280 Km in total) and others have reported driving to Amsterdam via Ferry and to Paris.

Finally, Fig. 13 and Fig.14 show the monthly driving distance versus the number of rapid charge events for a Renault ZOE and a BMW i3 drivers respectively. The average distance travelled by car per person per year in the UK was just over 8,000km in 2014 [10] and it can be clearly seen that these drivers would be exceeding this yearly average. Relationships of this type have also been seen in other drivers with similar characteristics. Remarkably, the two drivers we highlighted managed travelling up to 4,000km in a month in their EVs. It is also clear that there is a strong positive correlation between the number of times the driver has rapid-charged and the monthly distance covered indicating that the rapid chargers could enable users to extensively use their EVs when required.

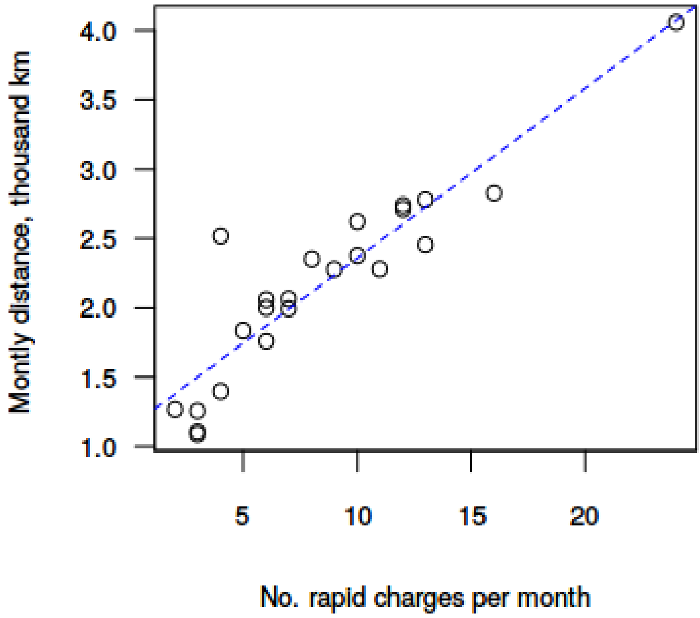

Figure 13. Monthly distance travelled versus the number of rapid chargers. (Renault driver: April 2013- July 2015).

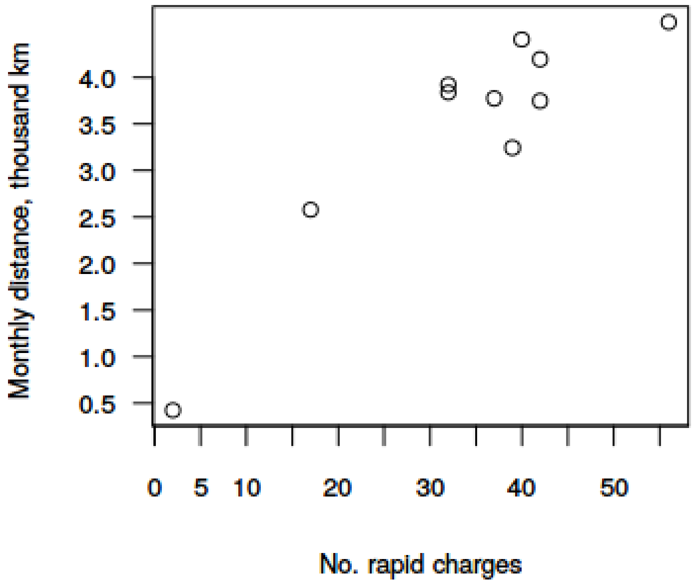

Figure 14.Monthly distance versus the number of rapid chargers. (BMW driver: February2015-October 2015)

5 Lessons Learnt

The EU recognises the need to adapt its road infrastructure to encourage EV uptake and meet the current and forecasted e-mobility requirements. RCN is one of a number of European Commission's TEN-T co-financed projects on EV infrastructure that promote low carbon emission transport. RCN has installed 74 rapid chargers over 1,100 km along major UK and Irish roads. The RCN Study activity key areas include understanding the EV drivers' usage, attitudes and needs towards a rapid charge network and detailed charging and driving behaviour of a number of EVs. In order to meet the study objectives, data was collected from the charging infrastructure, online questionnaires, data loggers installed in a selected number of vehicles and electronic data provided by the OEM for a selected number of vehicles. Over 500 survey entries were analysed, these were collected from 3 online questionnaires. Over 30,000 high resolution driving events and 10,000 charging events were collected and analysed from the loggers installed in the vehicles. In addition, over 33,000 events were collected and analysed from the rapid charge network equating to 300 MWh of energy delivered and over 1.65 Million km driven.

As new sites have become live on the Rapid Charge Network, the usage of the network has experienced a steady growth with energy drawn on a per charger basis also showing growth. The CHAdeMO outlet has been the most used delivering just over 72% of the energy which is expected as the Nissan LEAF (BEV) and the Mitsubishi (PHEV) are the dominant EV in the UK market currently and utilize the CHAdeMO protocol/connector. The CCS outlet use is increasing over time which reflects the increasing number of CCS cars on the road. There was a variation across chargers in terms of energy delivered with certain sites proved to be more popular, and the global monthly demand aggregated across all chargers was 625 kWh/month.

It is clear that there is a popular window of usage reflected in the highest usage being recorded between 12:00 and 18:00. This is significant when trying to develop a business case as revenue generation is reduced and cannot be assumed to be 24rs. Availability may be 24hrs but utilization is much lower and is time of the day constrained. The average energy delivered per transaction is 8.9 kWh and the average duration of a rapid charge event was 26.2 minutes. The figure of 8.9 kWh is showing that people are not using the full capability of the charger, as current battery capacity is around 24kWh.

Over 32% of the transactions were above 30 minutes, with many respondents emphasising the need to enforce time restrictions per charge event in order to minimise slow charging on a rapid charge infrastructure. The 30 minute point is very important as the power delivery curve of each vehicle allows rapid take of power up to 80%, then the charger reverts to slow charging. Therefore, with regard to the business case and utilization of the network it is preferred that people use the chargers to deliver the maximum power in the shortest time and not ‘hog’ them for a final % top up.

In general, the participants emphasised the need to decrease the uncertainties associated with the rapid charge infrastructure to allow long journeys to be completed confidently and without significant increase in journey times. Increasing the number of charging posts per site could mean that is more likely to have working and available chargers on arrival. We believe that a possible solution is to replicate the existing petrol station formula of multiple charge points per site which will provide a level of certainty.

The users relied on home charging with 71% of the charging energy delivered at home; however, when charging in public locations their preference is for rapid chargers. 16% of their total energy is transferred at rapid chargers and 4% is transferred at other public charging locations. The average daily driven distance is 61 km which is well within the range of an electric vehicle and similar to the national driving trends. Long daily driving events that are above the driving range of an EV were collected. 5% of the daily events collected were above 150km and over 85% of the people who drove above 150 km a day used a rapid charger. This indicates that the rapid chargers helped extend the driving range of EVs. A strong relationship was found between high total daily distance driven and a high use of the rapid charge infrastructure. Finally, the yearly average driving distance in the UK is just above 8,000km and several RCN drivers have been identified to drive well above this yearly average in their EVs. For example, some drivers managed to travel up to 4,000km in a month in their EVs. There was also a strong positive correlation between the number of times the drivers have rapid charged and the monthly driving distance covered indicating that the rapid chargers could enable users to use electric vehicles extensively when required. This is particularly important as it shows that a network of rapid chargers could facilitate the adoption of EVs by high-mileage users (e.g. taxi drivers).

The findings from this study would inform and support the expansion of existing rapid charging networks and the development of new networks across Europe. A more detailed analysis and results are presented in the RCN study final report and can be found online [6]. The report includes sections on charge point usage prediction, emission reductions associated with the charging network and a rapid charging infrastructure business model analysis.

5 Acknowledgments

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Authors

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