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Rapid Charge Network: breaking down the barriers to longer distance electric driving

Josey Wardle¹, Anya Bramich¹, Myriam Neaimeh², Dr Javier Serradilla²
Dr Claudia Pinna², Dr Graeme Hill², Dr Weihong Guo², Prof Phil Blythe²

¹*Josey Wardle, Zero Carbon Futures (UK) Ltd, Future Technology Centre, Barmston Court, Nissan Way, Sunderland, SR5 3NY, United Kingdom, josey.wardle@gateshead.ac.uk*

²*Transport Operations Research Group (TORG), School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, NE1 7RU*

Abstract

In 2013, four major Electric Vehicle (EV) manufacturers (Nissan, BMW, Renault and VW) came together for the first time to develop the EV marketplace, by studying the impact of the creation of a network of 74 multi-standard, interoperable rapid chargers, co-funded by the European Union's (EU) Trans European Network –Transport (TEN-T) funding programme. The [Rapid Charge Network](#) project's ambition is to ensure that EV drivers can drive further, all the way along the 1,100km of TEN-T defined priority road routes across the UK and into Ireland. Its aim is to break down one of the major remaining barriers to EV adoption by giving consumers the confidence that they can recharge where necessary, regardless of EV make or model. In order to study use of the network the project recruited around 200 drivers to take part in questionnaires, to provide electronic vehicle data and to agree to the installation of in-vehicle data loggers for a period of time. In parallel, the use of the rapid chargers has also been studied. In depth analysis of real-world driving and charging behaviour has therefore been conducted, alongside evaluating what EV drivers want from a recharging network. This paper explains the project's implementation process and summarises its main findings.

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

1 Introduction

Transport is a major source of greenhouse gas emissions, which cause global climate change. Therefore many European countries have introduced measures aimed at reducing transport emissions. The European Union's (EU) Clean Power for Transport policy[1] seeks to break Europe's dependence on oil for Transport, and therefore sets out a package of measures to facilitate the development of a single market for

alternative fuels for transport in Europe. The EU's Directive on the Deployment of Alternative Fuels Infrastructure[2] was adopted in September 2014 requiring Member States to adopt national policy frameworks for the market development of alternative fuels and their infrastructure.

The UK has been one of the most advanced countries in Europe for the demonstration of EV and the introduction of supporting recharging infrastructure. Incentives towards Ultra Low

Emission Vehicles (ULEV) purchase have been available since 2011. The UK government considers the availability of public charge points as necessary to encourage and enable the uptake of plug-in ULEV. Moreover, its Office for Low Emission Vehicles (OLEV) has been actively encouraging recharging infrastructure roll-out since 2010 by providing financial incentives to public bodies. However it is also keen to see private initiatives entering the marketplace as it begins to mature.

The Republic of Ireland has also provided similar incentives for EVs and since 2010 ESB's ecars[3] programme has created a national recharging infrastructure for Ireland, also supported by EU TEN-T funding.

Various recharging infrastructure projects across Europe are currently benefitting from EU funding, including the Rapid Charge Network[4] (RCN) described in this paper. All of these projects are supporting the EU towards its goal for the decarbonization of transport and contributing to the target of a 60% reduction of CO₂ emissions from transport by 2050.

This is a classic "Chicken and Egg" conundrum. Recharging infrastructure is required to enable drivers to consider buying EVs. Consumers require the comfort of knowing they can recharge if and when required, even if they subsequently don't often use the public facilities provided to meet those perceived needs. Recharging infrastructure falls outside of the EV manufacturers' traditional area of activity, creating an ongoing debate about who is responsible for recharging provision and ownership.

This paper explains how the Rapid Charge Network project has been delivered, and highlights the key findings to date. It covers practical lessons learnt concerning implementation and operation which other member states, regions and cities should find useful in planning their own recharging infrastructure roll-out. It also summarises the key findings from the academic study, investigating what changes in driving and charging behaviour may occur as the availability of rapid chargers becomes more widespread, and understanding the impact this may have on future EV adoption.

2 Project Methodology

2.1 Formation of the partnership

In 2013, four major EV manufacturers (Nissan, BMW, Renault and VW) came together through a shared understanding of the need for rapid recharging infrastructure. Together they decided to develop a project to roll-out the first multi-standard rapid chargers across the UK and into Ireland, and to study their adoption and use – The Rapid Charge Network (RCN) project. This was the first time these 4 traditionally competing OEMs had worked together in such a way, and the successful partnership has since supported a number of other rapid charging projects across Europe.

ESB were approached to complete the RCN partnership, in the knowledge of their experience rolling out a national recharging infrastructure in Ireland. This addition ensured that a cross-border project could be developed, joining two member states across the only land border between the UK and the rest of the EU, and also introducing a multi-modal transport aspect for travel between the two.

A successful award of EU funding through the EU's TEN-T programme followed in late 2013, enabling the partners to enter into a consortium agreement and begin their task.

2.2 Multi-standard rapid chargers

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 Combo rapid charging protocol was introduced to the UK and Ireland with BMW's entry to the market.

This new technology presented problems for the early recharging networks established in UK and Ireland, requiring new hardware and software and raising the issue of lost revenue opportunities as a result of different connector designs promoted by different EV manufacturers. Both EV manufacturers and charge point owners/operators wished to avoid the high cost risk of dedicated chargers appearing for each EV brand, and potential EV purchasers' lack of confidence if the charging infrastructure was fragmented and not interoperable. Early UK experience suggested that potential EV purchasers were unaware of incompatibility between vehicles and the existing

charging infrastructure. A simple rapid recharging solution was called for.

By bringing four major automotive manufacturers together in this novel partnership, the project ensured that all mainstream EVs could use the recharging network, regardless of make or model. This created a national network which was the first of its kind, providing charge points equipped with 3 charging outlets, incorporating the 44 kW DC Chademo and CCS, and 43 kW AC rapid charging protocols into one charging unit. The RCN partners specified the charger requirements and the nominated manufacturer DBT integrated them into a single unit. VW then carried out extensive testing on the unit.

These multi-standard rapid chargers can recharge all standardised EVs to 80% of full battery capacity in circa 30 minutes.

2.3 The route

RCN's strategic purpose is to accelerate the introduction of EV rapid charging infrastructure by studying adoption and use along over 1,100 km of TEN-T defined priority road routes across the UK and into Republic of Ireland. The Trans European Network - Transport (TEN-T) programme[5] exists to support the development of the single market by providing funding for transport infrastructure projects on a set of defined networks.

The defined priority roads through the UK cover some of the main motorways North to South and East to West. However they also encompass a number of rural areas which form the main road links to Ireland.

The RCN Project aims to install 74 multi-standard rapid chargers, each equipped with 3 charging outlets accommodating all 3 rapid charging protocols, and then to study their operation and use until the end of 2015. The chargers are located at motorway service stations and major retail facilities along main highways, and link through major air and seaports to multi-modal transport solutions. The project's objective is to enable EVs to drive further, beyond the existing battery range constraints, ultimately covering the full 1,100km distance by using rapid chargers at key staging points.

2.4 The Study

An important factor of this project was that an academic research study was co-funded as a major objective, so that any change in EV usage and drivers' corresponding attitudes to recharging could be captured and analysed as the rapid charging network was rolled out and used.

2.5 Dissemination

The RCN project is producing a practical guide for other Member States, regions and cities to use to create their own rapid charging networks. It will incorporate appropriate guidelines, recommendations for implementation and best practice, drawing upon the practical lessons learnt from the RCN experience in the UK and Ireland.

Throughout the project, feedback has been provided through the project's website www.rapidchargenetwork.com and at key industry events in the UK and Europe, keeping stakeholders up to date with progress. The website was also used to engage the study participants. Over 200 EV drivers across the UK and Ireland expressed their interest in participating.

3 Charger Implementation

3.1 Finding sites

Suitable sites for rapid chargers are driven by a number of considerations; power availability, location, access, ownership, parking capacity and visibility, each of which can be controlled by different stakeholders.

UK network operators were invited to propose sites for RCN rapid chargers along the designated routes. Ecotricity who already operate the Electric Highway[6] in the UK presented a large number of motorway service sites already under contract. These represented ideal locations for project implementation. ESB ecars provided the sites for installation in both Northern Ireland and Ireland. These Network Operators hold contracts with each site operator.

However, the rural areas of the UK route presented one of the biggest problems for the project; engaging sites where there was little existing infrastructure of any kind and little knowledge about EV. These areas were found to have comparatively low population and traffic densities and consequently lower EV ownership.

3.2 Station structure

The project planned to install overhead canopies at some charger sites. Early designs were scoped out but UK supplier interest was found to be very low for such small quantities. Therefore a feasibility study was conducted regarding the existing uses of canopies to assess their benefits in this application. The Network Operators viewed canopies as unnecessary infrastructure adding ongoing cost and liability to a nascent market. Therefore the rapid charger station structure was designed to include the charger, its feeder pillar, safety bollards, marked parking bays, and appropriate signage. A number of different parking bay configurations were used to suit the needs of individual site owners, maintaining 2 bays per charger wherever possible.

3.3 Installation, Operation and Maintenance

A framework of suppliers was engaged to provide UK civil and electrical works under set terms and conditions, including providing plinths, feeder pillars, switchgear and metering, signage and bay marking services. The charger manufacturer DBT nominated a commissioning and maintenance supplier British Gas to connect to power, check communications, perform limited functionality checks and provide 3 years planned maintenance. ESB engaged CARRA to provide the equivalent services in Ireland.

ARCADIS managed all UK on-site activities from preparatory surveys, building warrants and planning permission applications through to commissioning.

The rapid chargers installed by RCN are now operated free of charge to EV drivers until the end of 2015, under Ecotricity's Electric Highway network in the UK and ESB's ecars network in Ireland.

4 Study Methodology

The aim of the RCN study is to investigate and analyse the introduction, operation and consumer use of the proposed 74 rapid charge points. The key areas of the study include understanding the EV drivers' usage and attitudes towards the rapid charge network; the environmental impact of the network and the business case feasibility of such a network.

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 use of the RCN network. To enhance the understanding of EV drivers' behaviour and use of charging networks, the project obtained historic data (before the start of the project) from vehicles and charging infrastructure. These were used to capture any changes in behaviour of individuals as more rapid chargers have become available.

In addition to the EV use datasets collected by the project, publically available EV sales data and UK electricity carbon content data were collected and analysed to inform the environmental and business case studies.

The study's findings can be used to inform the expansion of existing rapid charging networks and the development of new ones across European road networks.

4.1 Network use, driving and charging behaviour

Quantitative usage data were collected from three sources; OEM vehicle data (including some historic data informing on EV use before the RCN chargers were installed), 40 data loggers installed on selected EVs, and data from the chargers on the RCN network. These extensive datasets give insights into the driving and charging behaviour of EV users, including the usage of the Rapid Charge Network.

4.1.1 OEM vehicle data

The project had access to an anonymised dataset which consisted of charging and driving events aggregated by month for 3000 EV drivers in the UK between January 2011 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 event (driving; charging) for 30 RCN drivers between August 2013 and October 2015.

4.1.2 EV Data Loggers

The significance of the data loggers in comparison to the OEM vehicle data is that they collect high resolution spatial and temporal data allowing in-depth analysis of driving and charging behaviour of real world EV users. The data loggers provide up to

second by second data allowing the project to track vehicles and their usage.

Over 120 EV drivers volunteered to have a data logger installed in their car. The project selected 40 drivers based on their proximity to the RCN network and their EV ownership status. The RCN team travelled the route, meeting the drivers and installing the data loggers in February 2015. The loggers then provided data from the moment of installation. As an incentive for participating, the drivers received vouchers for 200 GBP and access to a web portal showing their charging and driving events data.

4.1.3 Charging Infrastructure Data

Charging transactions data on the RCN network were provided by Network Operators Ecotricity's Electric Highway in the UK and ESB's ecars in Ireland. The data include a unique ID of the charging event, time and duration of each transaction, energy transferred and the connector type used. For the vehicles with installed data loggers it was possible to correlate their driving and charging data to the Network Operators data.

4.2 Qualitative study

Three surveys were conducted on line; to investigate the influence of the rapid charge network on the use of EVs, to inform on the business case and to investigate ways to encourage more use of rapid chargers as a means to increase EV uptake. The results from the questionnaires were compared to actual charging activities and EV trips recorded by the charging network and EV loggers to understand EV drivers' perception in relation to their real (measured) behaviour.

The first survey was carried out in early 2015. The questions aimed to understand the types of vehicles that had been replaced by EVs, common and difficult EV journeys characteristics. The survey also sought to understand the EV drivers' perception of their rapid charger use. 155 (out of 181) submitted questionnaires were regarded as valid and used in the analysis, with 86% of the respondents from the UK and 14% from Ireland.

The second survey was carried out in the summer of 2015. This questionnaire aimed to understand the respondents' overall transport costs, their desired locations for rapid chargers, the facilities they used whilst charging and their willingness to

pay. 176 (out of 218) completed questionnaires were regarded as valid and used in the analysis, 87% of the respondents were from the UK and 13% from Ireland.

The final questionnaire was released in November 2015. This sought to understand any changes in the use of rapid chargers and in the respondents' attitudes towards travelling further and more often in EVs. In particular, the survey sought to identify journeys that were seen as impossible to make by EVs one year ago which had since become possible using rapid chargers. This would lead to a sound understanding of the barriers and support required for the mass market uptake of EVs and inform future business cases.

4.3 Environmental impact

Electricity demand is subject to fluctuations on a yearly basis, seasonally, across the week and during the day. Generally, demand during the winter months is higher than in the summer. Demand is also influenced by particularly extreme weather conditions and other irregular events such as particular televised events. Periods of higher demand are associated with energy with higher carbon contents as the additional demand is normally met by energy originated from fossil fuels (carbon and gas).

The regulatory procedure used to calculate the carbon content of UK electricity is set out by the UK Government through The Electricity (Fuel Mix Disclosure) Regulations 2005[7] and associated fuel mix disclosure data tables. The procedure requires that the energy demand at a given point in time be matched with the carbon content of the electricity which needs to be generated to satisfy that demand; this latter set of data is available through National Grid for the UK and ESB for Ireland.

Demand arises as soon as an EV is plugged into the charger and finishes at the end of the charging operation. The amount of energy and the time of the day when that energy was drawn from the grid can then be used to estimate the total CO₂ emissions which can be attributed to the EV. This information comes from the charging transactions data provided by the Network Operators. The demand from the charging site is then apportioned proportionally to 30 minutes intervals to match the data from the National Grid.

4.4 Business feasibility

The question the project has addressed is whether a proposed capital investment in rapid-charging infrastructure and its associated operating costs can be recovered over time in addition to making a capital return which is sufficiently attractive for a prospective investor. The scope of this study is limited to the equipment, installation and running costs of multi-standard rapid chargers as installed in RCN. The only revenue considered is that coming from a sale of the recharging service to EV drivers. The conclusions are based on the actual costs incurred using a sample of 64 sites in the UK where rapid chargers were installed during the second half of 2014 and the first half of 2015.

Actual costs of setting up and operating the RCN chargers have been used as the basis of a financial business model. These include costs for equipment, civil and electrical installation works, new power supplies, commissioning, installation programme management, planning and permissions, electricity, rent, back office operation and routine maintenance services. The majority of these are fixed costs which do not vary with the transactions supplied. A number of assumptions have also been required to facilitate the model such as investment horizon, salvage value, energy costs, growth rates, discount and inflation rates. As a modelling assumption, charging events have been set to grow at 15% annually, in line with the growth seen in RCN. The model developed is flexible, enabling investigation of the sensitivity of any profitability measures to the pricing strategy adopted.

Furthermore, EV sales figures in western European markets have been analysed over time to understand historic growth and penetration. This data has been used to inform the assumptions made in the business feasibility study, and have been combined with local traffic count statistics along the length of the RCN route to investigate likely future requirements for chargers to meet likely future demand.

5 Study Results

This study builds upon extensive research conducted by Newcastle University's Transport Operations Research Group since 2010 investigating EV driving and charging behaviour [8-10]. These results are based upon the RCN technical reports produced.

5.1 Network use, driving and charging behaviour

5.1.1 Network Use

The following section gives an overview of the use of the RCN network. In total, RCN chargers have delivered 241 MWh of energy between July 2014 and September 2015. More than 97% of that energy relates to UK site, where the majority of the chargers are installed.

Figure 1 shows the total energy delivered every month per site. Irrespective of new sites added each month, the graph shows that the energy drawn from the network has been growing.

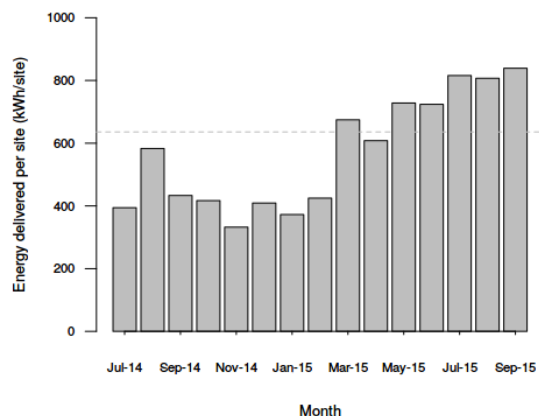


Figure 1. Monthly energy demand per site. Horizontal line is the aggregated average for all sites.

With respect to individual sites, Figure 2 gives an indication of the variation seen in terms of energy delivered by each of the sites in the network. The horizontal line represents the global monthly demand aggregated across all the sites (625 kWh/month). There are a considerable amount of sites performing better than average and this performance seems to be unrelated to 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.

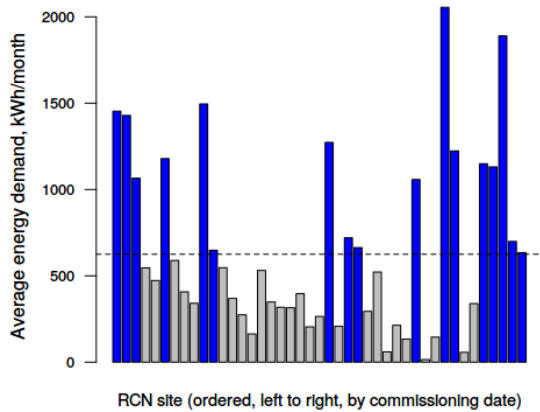


Figure 2. Variation in monthly energy demand across RCN sites.

The charging network dataset has also been used to investigate who is using the infrastructure. As shown with the Pareto chart in Figure 3, the distribution of the customers is rather asymmetric with around 80% of the transactions being undertaken by around 30% of the users.

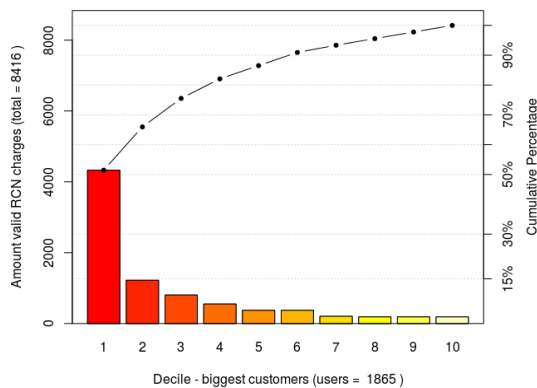


Figure 3. Most prolific users of the network

5.1.2 Driving and charging behaviour

OEM vehicle and EV logger data has been used to capture changes in driving behaviour. The distribution of daily aggregated trips from the EV data loggers is positively skewed, with a median of 51.8 km during the 6 month period considered. The distribution also shows a substantial number of long trips (over 100 miles or approximately 150 km) which require multiple recharging events over the day. A handful of those daily trips are over very long distances (above 300 km) as shown in Figure 4.

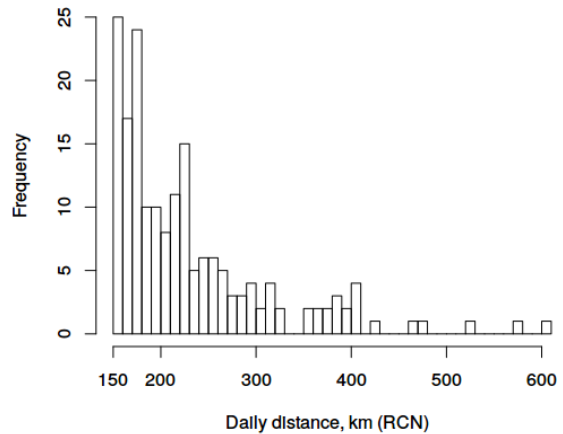


Figure 4. Distribution of daily aggregated trips (> 150 km) undertaken by RCN participants.

We have also made use of data provided by the vehicle manufacturers to study the relationship that may exist between rapid charging infrastructure and vehicle use. The most significant finding in this respect is shown in Figure 5, 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. The solid line is an estimate of the mean cumulative 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 vehicle usage with high use of the rapid charging infrastructure.

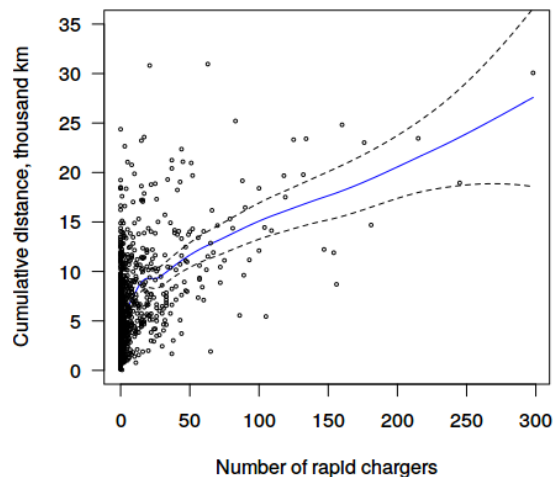


Figure 5. Total distance versus total number of rapid charging events (Nissan drivers: 2013-July 2014).

Further evidence in this regard is presented in Figure 6 for a Renault driver. Unlike the previous graph, the cumulative monthly distance is plotted on the y-axis.

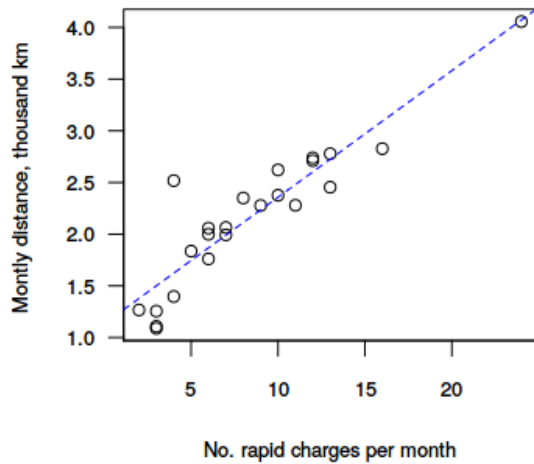


Figure 6. Distance travelled versus the number of rapid charges (Renault driver: April 2013-July 2015) Prediction from a linear model superimposed as a dashed line.

It is clear that there is a strong positive correlation between the number of times the driver has rapid-charged and the monthly distance covered. In particular, the driver has been recorded to travel for up to 4000 km in a single month. Relationships of this type have also been seen in other drivers of similar characteristics.

5.2 Qualitative study (CP)

5.2.1 EV Drivers' perceptions of EV use

Over 65% of the respondents had bought their EV, with the remainder using leased or company owned vehicles. The EV was claimed to be the primary car by 84% of the respondents. The three most important factors stated to influence the purchase were: long term cost savings (44%), contributing to environmental/climate protection (23%) and enjoying driving an electric vehicle (20%). For 128 drivers out to 155 the EV has replaced another vehicle in the household. In most cases (35.1%) the EV replaced a petrol car that was over 5 years old. so EVs are substituting vehicles which meet Euro 5 standards for exhaust emissions. The figure 7 shows the frequency of use of the EV for trips of various distances.

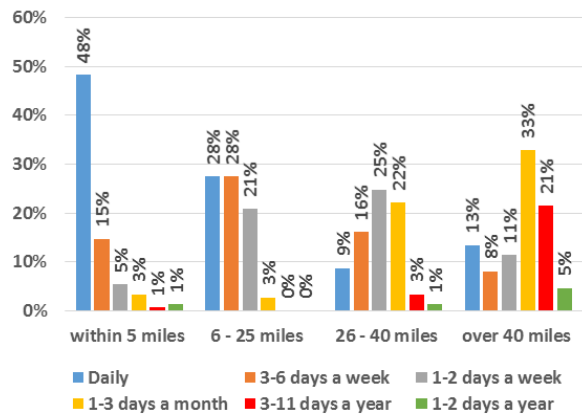


Figure 7. Use of the EV for trips of various distances

The average reported distance driven between charges in the sample is 83.7 km, with the range from 2 to 153 km. The average distance driven between charges stated by drivers who have a logger installed in their car is 78.9 km but their recorded average mileage between charges is actually lower (55.8 km). These findings are summarised in Table 1.

Distance between charges	Mean, km	SD, km	N
Sample (Questionnaire data)	83.7	27.0	155
Drivers with data logger (Questionnaire data)	78.9	23.2	27
Drivers with data logger (Logger data)	55.8	32.2	38

Table 1. Reported v. measured distance between charges

It was also reported that the limited range of the EV did impact on some respondents' travel. The longest trip reported by an EV driver was 1300 miles over a two week period where the EV was used for a vacation tour and the longest trip within a day was 379 miles. Both journeys used rapid chargers whenever possible.

To analyse the main differences between drivers who use the EV as the primary car and those who do not, the Mann-Whitney test has been applied (Mann, 1945). The result shows that financial incentives are considered very important for people who use the EV as primary car (p-value= 0.021). This finding can be useful to address new policies and strategies to encourage the uptake of EVs.

Kendall's τ_c test results suggest that the distance between home and workplace, the number of charging points within a 3 miles radius from home, from workplace and from the path between home and work do not influence the level of satisfaction with the EV and do not influence the use of the EV as primary car (p-value > 0.05). However, this factor is influenced by the availability of rapid chargers (p-value = 0.026). For this reason, it is important to install more rapid chargers where there are more potential users.

The second survey revealed that 76% of the respondents used the EV for commuting, 75% for shopping and 72% for leisure, frequently. The most used locations for rapid chargers were motorway services (93%), followed by petrol stations (40%), shopping malls (38%) and supermarkets (37%).

5.2.2. EV Drivers' perceptions of Rapid Chargers

Nearly 68% of the respondents agreed that they would not have bought the EV if there had been no rapid chargers available, with only 3% disagreeing. Over 65% of the respondents agreed that without rapid chargers they would not have completed some of their journeys. They considered the rapid chargers more convenient than other charging infrastructure and expected more rapid chargers at each and more locations. The main reasons stated for rapid charger use were 'needed to make a longer journey' (59%) and 'need to charge fast' (28%). Over 93% of the respondents stated that they had travelled further and 61% more often by EV, due to the availability of rapid chargers.

The EV drivers would like to see more rapid chargers installed at motorway service stations (95%), petrol stations (72%), supermarkets (58%), and shopping malls (55%). About 47% of the respondents would like to see more rapid chargers installed in their local area. The number one reason stated for frequent use of rapid chargers was that they were located on the way when travelling long trips (32%). Other reasons given were close to home (18%) and on their way between home and work (16%).

The most used facilities at rapid charger sites were toilet (55%), café (42%) and shops (31%), followed by shelter (14%) and cash machines (7%). Majority of the respondents spend money in nearby café and shops whilst using rapid chargers,

with 25% spending up to £5, 56% between £5 and £10, and 4% between £21 and £90. This information is useful in determining locations and possible business opportunities associated with the installation of future chargers. Only 5% of respondents did not spend any money whilst waiting for the car to be charged.

5.2.3 EV Drivers' willingness to pay

The survey revealed that 70% of the respondents knew how much it cost to recharge their EV from low to full at home, resulting in an average of £ 2.18 per charge.

The majority of respondents (65%) stated they were willing to pay to use rapid chargers. About 37% would be willing to pay only if they had no alternatives, whilst only 0.6% would switch back to a conventional vehicle. The main findings of this analysis are that the availability of rapid chargers affects the use of EV as the primary car, makes drivers travel more often and increases the likelihood of them choosing an EV as their next car.

Over 65% of the respondents stated they would prefer to pay per charge based on the energy used and only 15% would prefer to do so based on the time occupying the rapid charger.

The respondents were then asked in more detail about willingness to pay for the rapid charging service. When presented with a number of different examples 49% of respondents stated they were willing to pay £0.10 per minute, 20% would pay £0.15 per minute and 4% would pay £0.20 per minute. No respondents stated they were willing to pay £0.25 or more per minute.

Regarding fees in relation to actual energy supplied, over 64% of the respondents would pay £0.16 per kWh, 5% would pay £0.31 and only 1% would pay £0.40 per kWh. No respondents were willing to pay £0.55 per kWh.

Looking at a fixed fee to use a rapid charger, about 63% of the respondents said they would pay £2.00 per rapid charge, 32% would pay £3.00, 11% would pay £4.00, 4% would pay £5.00, and only 1% would pay £6.00 or £7.00. Finally 43% of the respondents said they would pay £100 per year for the service.

No significant correlations have been found between the participants' annual income and the willingness to pay at any of the rates proposed in the

questionnaire. However, if a fee was introduced along these lines 27% of respondents stated they would find an alternative way to charge for 50% of the time, 24% would continue to use the rapid chargers as they do now, whilst only 9% would stop using them.

5.3 RCN Usage: Predicted and Actual

If the deployment of a rapid charge network is to be shown to be a viable option for supporting EV uptake and use, then it must be shown that that it is both appropriately situated and that the individual charge points show adequate use. Figure 8 shows that the majority of charge points’ usage is currently below 400 kWh per month, with only a few delivering more than 1000kWh per month.

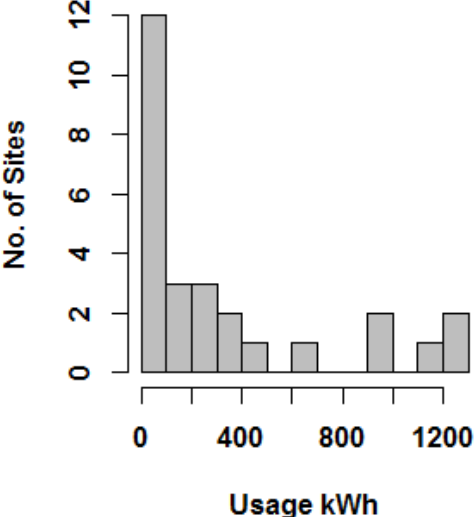


Figure 8: The distribution of power usage within the RCN sites

To understand the feasibility of possible future RCN sites or to look at the historic pattern of usage within current sites it is necessary to generate an idea of exactly what level of RCN usage could be expected.

Answering this question could be achieved in one of two ways, either a mathematical model (based on the number of EVs in the area etc.) could be created and the real world data compared to the theoretical result or the real world data could be used to create a statistical model for charge point usage and each individual point compared to the predicted result.

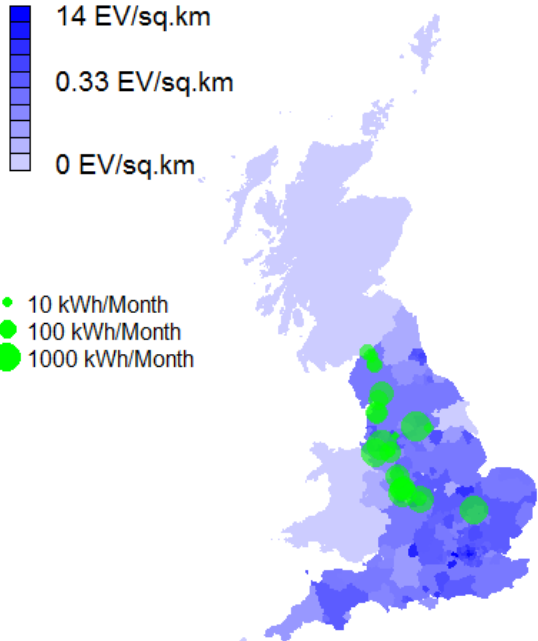


Figure 9: The relative density of EVs and the usage rates of the RCN points.

In figure 9 the current usage rates of the RCN sites are shown in comparison to the levels of EV ownership within the local area. In general it would be expected that this would be related to the level of EV ownership within the local area. However, it is likely that there are additional factors which could influence the usage of RCN sites. For example, the total level of traffic would likely be correlated with the demand for a refuelling system, and hence, the usage of an RCN site.

To predict the usage of sites not covered by historic data sets, a predictive model was created using the existing data. The model was then used to predict data across the entirety of the UK using the local variables used to train the model.

In figure 10 a log-linear regression model was used with the explanatory variables composed of a small subsection of local information. For the initial model only the local EV density, local flow density, total number of charging sites and number of cars in the local region was used. These explanatory variables were collated for every point across the UK and used to generate a predicted usage for an RCN site.

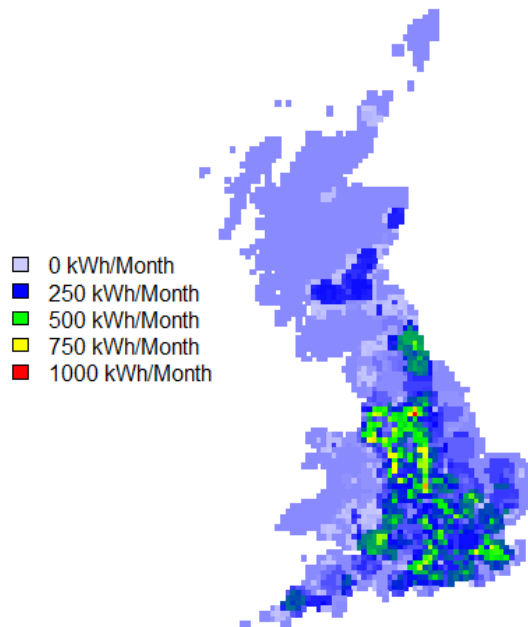


Figure 10: The predicted usage per month of an RCN site

The number of explanatory variables was limited to prevent overfitting the dependent variable, RCN site usage in this case.

5.4 Environmental impact

Between July 2014 and September 2015 inclusive RCN has delivered over 241 MWh of energy through its rapid chargers. The majority of that energy, over 97%, has been supplied by Ecotricity in the UK; the rest corresponds to the energy generated and distributed by ESB in Ireland.

Ecotricity's fuel mix is 100% from renewable sources[11] and, as such, it has no environmental impact in terms of CO₂ emissions or high level radioactive waste. Those 241 MWh equate to more than 1.32 million km driven by electric vehicles, using the actual efficiencies extracted from RCN data-loggers. The environmental impact of that distance, had it been covered in a new 2014 UK registered car (with average emissions of 124 gCO₂/km) would have amounted to more than 165 metric tonnes of CO₂.

An additional question that arises is what the CO₂ savings would have been had the electricity been drawn directly from the UK Grid as opposed to being 100% generated from renewable sources. To answer that, UK grid data has been matched to the demand from the RCN chargers in 30 minutes intervals since the beginning of the project. That

aggregated demand is shown in Figure 7 indicating that RCN chargers have consistent demand peaks between approximately midday and 17:00 hours. Those peaks tend to match the peaks in energy demand from the grid which, in turn, increases the environmental impact of the energy drawn. On average, every kWh drawn from RCN would have generated 460 gCO₂ in the period considered. In this second case, CO₂ savings would have been 54 metric tonnes, which are substantially smaller. This difference highlights how critical grid decarbonisation is in minimising the environmental impact from transport.

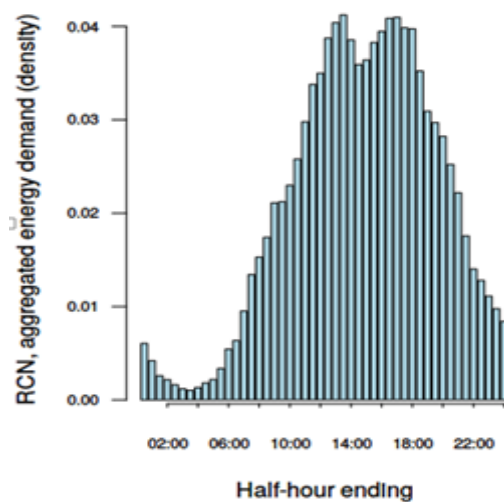


Figure 7. Intra-daily (aggregated) demand of energy in RCN chargers

As far as the drivers with loggers are concerned, each has contributed an average 65 kg of CO₂ savings per month by choosing an EV and charging using the UK grid (when compared with a new UK registered car in 2014). Had they chosen a green energy supplier, the savings per driver and month would have more than tripled.

5.5 Business feasibility

The business model built for RCN has allowed us to test different profitability measures under different pricing structures. Figure 8 is an example of the output under two different scenarios. As a summary (and for our modelling assumptions):

Scenario 1 - If an investor charged for the service provided in such a way that the price was 3 times the electricity purchase price, they would break

even after 13 years. The internal rate of return (IRR) for the 15 year investment would be 10.1%.

Scenario 2 - If the investor charged £6 every time somebody used the facility, they would break even in 11 years with a higher IRR of 13.5%.

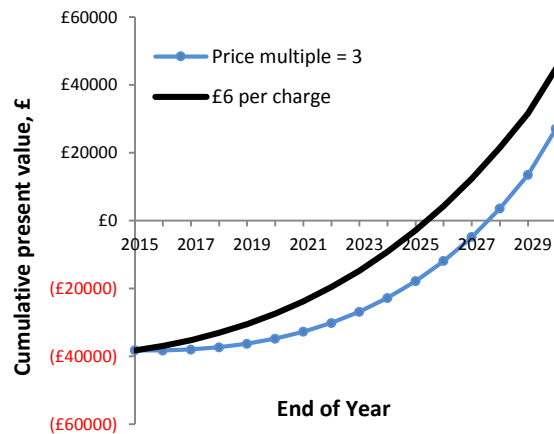


Figure 8. Business feasibility for two different pricing scenarios.

Additional wider economic impact benefits as well as scenarios for revenue generation from a retailer perspective can be added to our model. Any further revenue streams would only add value to the investment and, hence, improve the profitability of the investment.

6 Conclusions

Existing Network Operators proved essential in engaging RCN sites, however it proved difficult to engage suitable sites in rural areas of the route. New power connections were required in most rural locations adding cost and time to the installation programme. But additional power has also been required at some large motorway service stations where capacity had been reached.

There is a strong relationship between high EV usage (monthly distance travelled) and high use of the rapid charging infrastructure.

RCN chargers have delivered 241 MWh of energy in the 15 months studied, with a monthly average demand per charger of 625 kWh/month and this figure is continuing to grow. This equates to over 1.32 million km driven by electric vehicles, using actual efficiencies taken from RCN data-loggers. Renewable energy suppliers such as Ecotricity are important to maximise the environmental savings potential of EVs.

High use sites have also been identified where additional chargers may be installed to meet demand at peak times, and allow for future growth.

Qualitative research indicates that satisfaction with the EV is influenced by the availability of rapid chargers. 68% of RCN respondents indicated that they would not have bought the EV without rapid chargers available. The availability of rapid chargers affects the use of EV as the primary car, makes EV drivers likely to travel more often and increases the likelihood of them choosing an EV as their next car.

65% of drivers surveyed would be willing to pay for rapid charging services and most would prefer to pay per charge based on the energy used, rather than by time or fixed fee.

Using reasonably conservative demand growth assumptions, there is a basic business case for investment over a 10 to 15 year period. However feedback from EV drivers suggests they would be unwilling to pay the level of fees required. Further work is being conducted to assess the impact of the many variables to this model.

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Authors

Josey Wardle is Infrastructure Manager at Zero Carbon Futures, and is undertaking a PhD looking into the future for EV charging. Josey manages the UK's Rapid Charge Network project and NE England's Plugged in Places project, delivering and monitoring over 1,000 EV charge points over the last 5 years.

Anya Bramich is Marketing Manager at Zero Carbon Futures. Anya has promoted EV ownership and low carbon transport projects for the last 5 years, raising awareness and understanding of the benefits of low carbon driving.

Myriam Neaimeh is the lead data analyst on the RCN project. Myriam has been working on electric vehicles and charging infrastructure projects since 2011 and her work is focused on the interaction between transport and Energy.

Dr Javier Serradilla is currently a Research Associate in transport at Newcastle University. He has interests in industrial statistics and the environment. Since 2008 he has been working in multidisciplinary projects in the areas of process control, medicine and energy.

Dr Claudia Pinna is currently a Research Associate in transport at Newcastle University. Her main areas of research interest are older drivers' and EV users' driving behaviours and visual perception of road signs (VMS).

Dr Graeme Hill has a background in Physics and a PhD in Nanotechnology. Following analytical work with novel infrared spectroscopic methods he has moved towards a data analysis role specialising in statistics and analysis of data from large networks of sensors, usage and utility of Electric Vehicles and the novel predictive and analytical methods of large bodies of data.

Dr Weihong Guo is a lecturer in Intelligent Transport Systems at Newcastle University. Her area of research covers low carbon transport, electromobility, intelligent vehicles for ageing mobility, and driver behaviour. She is particularly interested in monitoring and assessing driver behaviour, testing and evaluating the effectiveness of technologies in improving road safety and understanding the barriers delaying the shift to electromobility.

Professor Phil Blythe is Professor of Intelligent Transport Systems at Newcastle University. Phil served as Director of the Transport Operations Research Group for 13 years until stepping down in June 2015 to take up a three year appointment as Chief Scientific Adviser for the UK Department for Transport (DfT). Phil is internationally recognised as an early pioneer of ITS research and has been involved in numerous EV and charging projects and trials for almost a decade.