Rapid Charge Network
Activity 6 Study Report

Study undertaken by: Newcastle University

Prof Phil Blythe, Principal Investigator, Myriam Neaimeh, Project Manager,
Dr. Javier Serradilla, Dr. Claudia Pinna, Dr. Graeme Hill, Dr. Amy Guo

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## GLOSSARY OF TERMS

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACEA</td>
<td>Association des Constructeurs Européens d'Automobiles</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>BMRS</td>
<td>Balancing Mechanism Reporting System</td>
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<tr>
<td>CCC</td>
<td>Committee on Climate Change (UK)</td>
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<td>CCS</td>
<td>Combined Charging System</td>
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<tr>
<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>DfT</td>
<td>Department for Transport (UK)</td>
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<td>DECC</td>
<td>Department of Energy &amp; Climate Change (UK)</td>
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<tr>
<td>DNO</td>
<td>Distribution Network Operator</td>
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<tr>
<td>EEA</td>
<td>European Environment Agency</td>
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<tr>
<td>EOY</td>
<td>End of Year</td>
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<tr>
<td>Eurostat</td>
<td>Statistical Office of the European Union</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle (both BEV and PHEV)</td>
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<tr>
<td>FCI</td>
<td>Fixed Capital Investment</td>
</tr>
<tr>
<td>GB</td>
<td>Great Britain (England, Scotland and Wales)</td>
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<tr>
<td>GHG</td>
<td>Green House Gas</td>
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<tr>
<td>INEA</td>
<td>Innovation and Networks Executive Agency</td>
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<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
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<tr>
<td>MARR</td>
<td>Minimum Attractive Rate of Return (discount factor)</td>
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<tr>
<td>NG</td>
<td>National Grid</td>
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<tr>
<td>NI</td>
<td>Northern Ireland</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
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<tr>
<td>ROI</td>
<td>Republic of Ireland (referred to as Ireland)</td>
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<tr>
<td>RCN</td>
<td>Rapid Charge Network</td>
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<tr>
<td>SMMT</td>
<td>Society of Motor Manufacturers and Traders (UK)</td>
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<tr>
<td>TEN-T</td>
<td>Trans European Network- Transport</td>
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<tr>
<td>ULEV</td>
<td>Ultra Low Emission Vehicle</td>
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<tr>
<td>UK</td>
<td>United Kingdom (Great Britain and Northern Ireland)</td>
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Rapid Charge Network

**KEY POINTS**

- Between July 2014 and November 2015, RCN chargers have delivered, in total, around 300 MWh of energy. More than 97% of that energy has been delivered in Great Britain.
- The usage of the network has experienced a steady growth as new sites have become live and energy drawn on a per charger basis has also been growing.
- The global monthly demand aggregated across all chargers is 625 kWh/month.
- The average energy delivered per transaction is 8.9 kWh and the average duration of a transaction is 26.2 minutes.
- Over 32% of the transactions were above 30 minutes and many respondents emphasised the need to enforce time restrictions per charging event.
- Over 15% of the transactions on the charging network have failed. Many respondents emphasised the need for a reliable charging network.
- In addition, the participants expressed the importance of decreasing charger down time, 24/7 availability, ensuring reliable connection to validate the cards; eliminating ICE vehicles blocking the posts; providing real time information on charge point availability and increasing the number of charging posts per site.
- 68% of the RCN respondents indicated that they would not have bought the EV without rapid chargers available and over 90% of the respondents indicated that the availability of a rapid charging infrastructure increases the likelihood of purchasing an EV as their next car.
- Highest levels of predicted rapid charging infrastructure usage are in areas with a higher car/EV density combined with a higher interurban flow.
- **EV users rely on home charging** with 71.1% of the charging energy delivered at home.
- **When charging in public, the preference is for rapid chargers.** 15.9% of the total energy is transferred at rapid chargers and 3.5% is transferred at other public charging location. 9.5% of the total energy was delivered at other locations including the work place.
- The average daily distance driven is 61km which is well within the range of an EV and similar to the national driving trends of conventional vehicles.
- 5% of the daily events collected where above 150km which is above the range of the EVs on trial and above the range of most of the EVs on the market currently.
- Over 85% of the people who drove above 150 km a day used a rapid charger indicating that the rapid chargers helped extend the driving range of EVs.
Some drivers on the trial managed to travel up to 4,000km in a month in their EVs (the UK yearly average driving distance in 10,000km). We found 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 the use of EVs extensively when required.

We calculated an EV average emission figure of 81gCO₂/km. When comparing with UK car emission figures, an EV is saving 75.6 gCO₂ per km driven when it replaces a car from the UK car parc and 43.6gCO₂/km when it replaces a new vehicle. EV emissions will be further reduced with a move towards low carbon electricity generation.

Ecotricity is a Green Energy company and the EV emissions associated with the charging events on the RCN network are close to 0 gCO₂/km. The RCN network delivered around 300 MWh of energy that equates to 1.65 million electric km driven. As a result, the RCN network has saved 205 tonnes of CO₂ when compared against the emissions which could have been produced by a new registered car and 257.8 tonnes of CO₂ saved when compared against the UK car parc.

BEVs have currently a higher environmental impact at the production stage; however, we found that an ICE vehicle has circa a 25% higher environmental impact than a BEV over its lifetime (using 225k km lifetime mileage).

On average, the RCN multi-standard rapid charger cost account for 55% of the Fixed Capital Investment (FCI). The second largest expenditure related to site preparation works which accounts for circa 31% of the FCI. New DNO power connections have added, on average, 15% to the initial investment costs but only one in every four sites in RCN have required them.

Under the lowest, most conservative growth scenario (10% market share in 2030), investors could either sell the recharging service at a minimum variable price of 3.5 times their kWh purchase price or at 5.5GBP per charge. They would recover their investment in 10 years. Setting their price levels at either 5 times their energy purchase price or at 7.8GBP per charge will achieve a return of 15% and pay back the investment costs in circa 8 years. Under the CCC’s central scenario for ULEV uptake of 60% in 2030, a price multiple of 2.9 times the purchase price or a 4.5 GBP per charge will achieve a 15% return. The only revenue stream on consideration in this study is that from selling a recharging service. There are other opportunities for income generation which will add value to the investment.
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1 INTRODUCTION

Road transport contributes about 20% of the EU’s total emissions of carbon dioxide (CO₂), the main greenhouse gas (GHG). The EU GHG emissions have fallen by over 3% in 2012; however, they are still 20.5% higher than the 1990 levels. Transport is the only major sector in the EU where GHG are still rising[1].

To mitigate CO₂ and other GHG emissions and to define a pathway towards the reduced use of fossil fuels in transport, the UK Government (along with many other Governments across the UK and Worldwide) have supported the adoption and roll-out of electric vehicles to meet their emissions targets[2]. Moreover, the recent governments’ statements at the Conference of the Parties (COP) in Paris on reducing GHGs imply that EVs could play a major role in delivering these reduction pledges. This ambitious shift in transport energy vectors towards ultra-low carbon alternatives such as electric vehicles (EVs) requires coordination and support both in terms of encouraging individuals and businesses to adopt EV’s through education and financial incentives and the corresponding support for an appropriate charging infrastructure to support a mass uptake of EVs[3]. A key component of this infrastructure would be a network of publically available rapid chargers as part of the ‘mix’ of an overall recharging infrastructure. An interoperable rapid charge network would enable efficient long distance driving using EVs and could overcome one of the key perceived barriers to future EV adoption, namely the operating range of the vehicle.

The European Union (EU) recognises the need to adapt its road infrastructure to encourage EV uptake and meet the current and forecasted e-mobility requirements. Rapid Charge Network (RCN) is one of a number of European Commission’s TEN-T co-financed projects on EV infrastructure. These projects are driven by the need to support decarbonisation and promote alternative fuels for road transport in the EU[4], [5].

RCN is rolling-out 74 rapid charging stations along the full length of Priority Project (PP) Road Axes 13 and 26 through the UK and into Ireland[6]. This is a substantial real-world trial covering over 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. The RCN charging stations are equipped with new and innovative multi-standard rapid charging technology, combining the CHAdeMO and Combined Charging System 44 kW DC (Direct Current) chargers and 43 kW AC (Alternating Current) charger into one easily accessible charging station.

Activity 6 of the RCN project (The Study) is responsible for all aspects of understanding the usage and impact of the RCN charging infrastructure installed. The key areas of the study include the EV drivers’ usage, attitudes and needs towards a rapid charge network; predictive
analysis of future network use; 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; the environmental impact and the business case feasibility of a rapid charge 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 usage of the RCN network. In addition to collecting data from the rapid charges, Activity 6 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 response was remarkable and over 200 EV drivers expressed their interest in participating in the RCN project.

Over 500 survey entries were analysed, these were collected from 3 online questionnaires with 299 unique individuals participating in total. 40 electric vehicles of users who live close to the RCN network were fitted with data loggers. These loggers collect high resolution spatial and temporal data on driving and charging behaviour. 35 loggers were installed with private individuals and 5 were installed as part of British Gas EV fleet. Data was collected between February and December 2015 and over 51,000 driving events and 11,500 charging events were captured. These equated to over 521,000 Km driven and 97 MWh of energy transferred. Over 47,000 RCN network transactions were processed from 51 charging stations between July 2014 and November 2015.

The findings from this study would inform the expansion of existing rapid charging networks and the development of new networks across Europe.

2 EV USERS’ ENGAGEMENT STRATEGY AND DATA COLLECTION
To understand what impact the implementation of an EV rapid charging network may have, it is important to study the driving and charging behaviour of actual EV drivers. The significance of the RCN study is that it has engaged with real world users of EVs who are located close to the RCN network in order to understand their driving and charging behaviour and their needs and attitudes towards the network. Following some initial publicity from the project and a request for EV drivers to consider getting involved in the project, over 200 EV drivers expressed their interest in participating in the RCN project and took part by either completing online questionnaires, granting access to their EV electronic data (provided in an anonymous way from the OEM’s) or by volunteering to have a data logger installed in their EV.
The user engagement took place mainly via the RCN website where interested EV drivers filled in an initial online questionnaire. The questionnaire asked people how would they like to engage with the project (i.e. questionnaires, electronic data, loggers); contact details; Make and Model of their EVs; etc. 231 people expressed interest initially (in the UK and Ireland). The project team then contacted everyone and asked them to participate in the questionnaires and to provide electronic data while 40 participants were selected for data logger installations. The selection of participants to install data loggers is described in section 2.2.1.

2.1 ONLINE QUESTIONNAIRES FOR QUALITATIVE DATA COLLECTION
RCN 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 (Figure 1) that captured the perception, behaviour, experiences and requirements of EV drivers towards electric vehicles 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. In order to answer the study objectives for RCN, 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.

<table>
<thead>
<tr>
<th>ONLINE QUESTIONNAIRES</th>
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<td>TITLE</td>
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<tr>
<td>Final Questionnaire Rapid Charge Network Project</td>
<td>11/26/2015</td>
</tr>
<tr>
<td>Created 10/30/2015</td>
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<tr>
<td>Business Case Questionnaire Rapid Charge Network Project</td>
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<tr>
<td>Created 7/3/2015</td>
<td></td>
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<tr>
<td>Questionnaire for Rapid Charge Network (RCN) Project</td>
<td>10/25/2015</td>
</tr>
<tr>
<td>Created 6/2/2015</td>
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Figure 1. Online questionnaires and the number of responses.

The first questionnaire was developed with the objective to investigate and capture drivers’ attitudes towards electric vehicles and charging infrastructure, individual drivers’ habits and behaviour and information about the vehicle replaced by the electric vehicle. 86% of the respondents were from the UK and 14% from Ireland.

The second questionnaire was designed to inform the development of a business case for a rapid charging infrastructure. The questionnaire captured the drivers’ willingness to pay for using the charging infrastructure and their acceptance of different tariff structures (per minutes,
per kWh, per charge, per year, for monthly package). The questionnaire also investigated the preferred locations for charging posts and activities undertaken while charging. Out of the 184 respondents, 87% were from the UK and 13% from Ireland.

The final questionnaire sought to identify any changes in behaviour attributed to the Rapid Charge Network, the overall charging and driving behaviour and attitudes towards carbon savings and energy use following the introduction of rapid chargers along the designated RCN routes. This questionnaire also repeated some of the questions from the first questionnaire to ascertain whether any attitudes or usage of EV’s and the RCN infrastructure had changed.

An overview of the key themes of the questions asked in each of the surveys is provided below:

2.1.1 RCN First online questionnaire
The first questionnaire included 35 questions covering the following items:

1. **Personal information** (Age, gender, number of household occupants);
2. **Information on the electric vehicle** (ownership type; primary vehicle; other types of vehicles considered before choosing the EV; most important factors influencing the purchase of the EV; fuel savings associated to the EV; overall level of satisfaction of the EV compared with the previous car);
3. **Information on the previous vehicle that was replaced by an EV** (Make, model, engine size, fuel type, year, average annual mileage);
4. **Usage of the electric vehicle** (frequency of use of the EV for trips of various distances; average distance travelled between charges; maximum distance travelled with the EV; percentage of trips affected by the driving range of the EV; reasons for unsuitability of EV to make these trips; alternative mode of transport used to carry out these trips; level of satisfaction about the driving range of the EV);
5. **Charging Behaviour** (frequency of charging at different locations (i.e. home, work, public including rapid); role and impact of rapid charge points on EV travel and EV purchase; motivation for the use of rapid charge points; feedback on the usage of rapid charge points including time spent to recharge, activities undertaken whilst charging and unavailability of charge points.)

2.1.2 Business case questionnaire
The Business Case questionnaire contained 35 questions concerning the following items:

1. **Personal information** (Age, gender, number of household occupants, annual household income);
2. **Transport related expenditure** (money spent on different modes of transport for personal and business purposes; approximate cost of EV home charging; perception about cost of EV home charging);
3. **Usage of the electric vehicle** (frequency of use of the EV for different purposes (e.g. commuting, business, etc.); influence of charging cost on driving style);
4. **Usage of rapid charging points** (role of additional/extensive rapid charging infrastructure on EV driving; preferred and desired charging locations (e.g. Motorway services, supermarkets, etc.); most used rapid charge point and reason for using it;
use of facilities at the rapid charge point and associated spending; influence of introducing a charging fee on the use of the rapid charging points;

5. **Willingness to pay for rapid charging infrastructure** (future willingness to pay for currently free rapid charging; willingness to pay and feedback on different tariff structures (per minutes, per kWh, per charge, per year, for monthly package); perception and willingness to pay to reserve a charging point).

2.1.3 Final questionnaire
The final questionnaire included 36 questions covering the following items:

1. **Personal information** (Age, gender, number of household occupants; Make, Model and year of EV);

2. **Information on the previous vehicle that was replaced by an EV** (average yearly mileage driven with previous vehicle);

3. **Usage of the electric vehicle** (overall feedback on owning an EV; factors for EV uptake; average yearly mileage driven with the EV; total EV daily driving distance; total daily driving distance in other household vehicle; % of regular trips requiring a rapid charging point (rcp); number of longer trips (above 50 miles) in a month requiring an rcp; longest journey undertaken that involved using an rcp; purpose of these longer journeys; EV journeys to outside the UK);

4. **Charging behaviour and usage of the rapid charging points** (Access, frequency and percentage energy transferred at different charging locations; state of charge of the battery at the beginning of a charging event at different locations; details of activities while EV is plugged into rcp; usage of rcps during the last 3 months; frequency of monthly usage of rcps; main motivation for using the rcps; influence of infrastructure availability on travelling further and more often with the EV during the last 12 months; feedback on unavailable and out of service rcps; feedback on potential rapid charge network related services (e.g. real-time information, reservation);

5. **Perception of carbon savings and energy** (Renewable energy systems installed in households; importance of charging using green energy; willingness to pay extra for clean energy).

2.1.4 Understanding the trial participants
This section presents some of the characteristics, demographics and profile of the trial participants.

Drivers included in the study belong to 11 age groups (Figure 2); the majority are between 41 and 50 years old. In addition, 89% of the participants are Male and 11% are Female.
As part of the profiling the participants were asked if they were the only driver using the EV and the responses showed that 57% share the vehicle with their partners.

Figure 3 provides an overview of the household income of the respondents; almost 10% preferred not to reply and over 64% of the participants earn above £35,000 a year. The Households Below Average Income (HBAI) report from the Department of Work and Pensions shows that the UK national average annual household income was £29,172 in 2013/14 [7].

64% of the participants own their EV, while just over 20% are leasing it; other responses included the EV as a company owned EV. The “Other” section included answers where the EV was part of a community car sharing scheme (Figure 4). Furthermore, 84% of the participants stated that the EV is their primary vehicle.
Figure 4. Vehicle ownership type

Over 87% of participants had replaced their previous conventional vehicle with an electric car and only 11% considered it as an additional vehicle in the household (Figure 5). In most cases (36%), the EV replaced a petrol car that was over 5 years old indicating that the EVs are substituting vehicles that do not meet the most recent standards for exhaust emissions. Figure 6 shows the EV makes and models in use by the study participants. The majority drive a Nissan LEAF which reflects the high proportion of this car sold in the UK EV market to date.

Figure 5. Characteristics of vehicles replaced by the EVs
The participants believed that the most important factors that could impact the mass uptake of EVs were driving range; availability of rapid charging points and the price of the vehicle (Figure 7).

Figure 6. Make and Model of EVs of the RCN participants (n=161).

Figure 7. Factors impacting the mass uptake of EVs
2.2 DATA LOGGER TRIAL DESIGN FOR QUANTITATIVE DATA COLLECTION

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 to provide the project with a richness of driving behaviour data.

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 significance of the data loggers is that they provide high resolution spatial and temporal data allowing in-depth analysis of driving and charging behaviour of EV users. The data loggers provide up to second by second data allowing the project to monitor vehicles and their usage. The data logger trial was key to the research activity of RCN. All data collected through this medium was anonymized before publication. The trial is described below 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.

2.2.1 Participants selection

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 planned network and their EV ownership status. Figure 8 maps the location of the EV users who purchased an EV and expressed their interest in installing a logger. It can already be noticed that some users are closer to the RCN network than others. In order to identify the study applicants who are closest to the network; the distances between the home address of every user and every charging point on the RCN network were calculated. The 40 participants with the shortest distance to the network were selected and contacted to start the logger installation process. Table 1 shows an example of the distance calculated between the home address of one user and 10 RCN charging points. It can be noticed that this user is close to the RCN network (34 km away to the closest charger) and as a consequence they will be selected for logger installation. RCN recruited 35 private individuals and 5 British Gas fleet drivers. Data loggers were installed in LEAFs (30), e-NV200s (5) and ZOEs (5). RCN Trial User agreements were developed and signed between the University and the selected users to cover data logger installation and removal and data collection and protection. RCN is in compliance with the Data Protection Directive of the EU.
Figure 8. Plot of postcodes of people who own an EV and expressed their interest in installing a data logger (Blue cross) and the RCN network (red dots).

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination- RCN charging points</th>
<th>Distance (km)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>User X Home</td>
<td>Birch services</td>
<td>34</td>
<td>25 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>Charnock Richard services</td>
<td>40</td>
<td>25 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>Rivington services</td>
<td>42</td>
<td>26 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>IKEA Manchester</td>
<td>47</td>
<td>34 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>Leeds Airport</td>
<td>54</td>
<td>1 hour 3 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>IKEA Leeds</td>
<td>84</td>
<td>57 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>IKEA Birmingham</td>
<td>180</td>
<td>1 hour 54 mins</td>
</tr>
<tr>
<td>User X Home</td>
<td>Brampton Hut</td>
<td>289</td>
<td>2 hours 59 mins</td>
</tr>
<tr>
<td>User X home</td>
<td>Port of Stranraer</td>
<td>349</td>
<td>3 hours 48 mins</td>
</tr>
<tr>
<td>User X home</td>
<td>Beacon Hill</td>
<td>391</td>
<td>4 hours 2 mins</td>
</tr>
</tbody>
</table>

Table 1. An example of the distance between the home address of a participant and the 10 closest chargers to that user on the RCN network.

2.2.2 Logger Installation
The RCN team travelled the RCN route, meeting the drivers and installing the data loggers in February 2015. Seven installation hubs were chosen (Table 2) as within EV driving distance for the majority of the participants and the RCN team travelled to a few participants who couldn’t join the hubs. The loggers then provided data from the moment of installation. 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.
Table 2. Installation hubs

<table>
<thead>
<tr>
<th>Hub</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>Hub 1</td>
<td>Leeds</td>
</tr>
<tr>
<td>Hub 2</td>
<td>Moto Birch Services</td>
</tr>
<tr>
<td>Hub 3</td>
<td>Ikea Warrington</td>
</tr>
<tr>
<td>Hub 4</td>
<td>Solihull</td>
</tr>
<tr>
<td>Hub 5</td>
<td>Houghton on the hill</td>
</tr>
<tr>
<td>Hub 6</td>
<td>Newport Pagnell</td>
</tr>
<tr>
<td>Hub 7</td>
<td>Sudbury</td>
</tr>
</tbody>
</table>

Figure 9 presents some pictures from the installation week and quotes from the drivers about what inspired them to get involved in the RCN data logger trial.

Figure 9. Selected pictures and participant’s quotes from the loggers’ installation week
2.2.3 Data Loggers in more details
Newcastle University acquired 40 data logging devices (logger, GPRS and GPS antenna) for installation in electric vehicles to provide high resolution CAN and GPS data. The data is used for research on the driving and charging behaviour of electric vehicles drivers. Newcastle University followed a competitive tendering process and three companies submitted tenders to supply RCN with EV data logging equipment. A tender scoring process determined CrossChasm as the successful company who provided the loggers for the project. The scoring criteria included price and the ability to meet the technical requirements of data collection.

The logging equipment is compact and simple to install in the vehicle in a non-disruptive way for the driver, with no requirement for hard wiring into the vehicle’s system. The equipment easily connects to the vehicle’s diagnostics port in a listen-only-mode and provides access to the naturally-communicated data messages broadcasted on the vehicle’s CAN bus. CAN (Controller Area Network) data are communicated when one controller is sending data packets (messages) to another controller in the vehicle’s network. These controllers control the various components and powertrain systems of the vehicle. The data available on this network can be recorded and include signals such as battery State of Charge (SoC) and other relevant data from the natural message traffic on the CAN bus. The encoded data that are recorded on the devices is uploaded to a server where they will be decoded.

Newcastle University required the data logger energy requirement to be minimal (42 mA while logging). In addition, the logger goes into sleep mode when the CAN bus is not active and the related energy requirement is 7 mA. Any firmware and software updates that could be required by the devices can be made remotely.

2.2.3.1 Data Acquisition and Decoding
Although CAN-bus data is, to some extent standardized, each OEM implements their codes in a particular way and closely guard this data. Even with OEM’s being the four major partners in the project, it was not possible to obtain the CAN-codes directly from the OEM’s. Thus the solution that was used was to reverse engineer the electric vehicle CAN codes by measuring the signals that relate to a particular function of the vehicle. CrossChasm, with the support of Newcastle University and Zero Carbon Futures (ZCF), undertook decoding work on several electric vehicle models during 10 days in January 2015. The vehicles were lent to the project by the OEM’s with the full knowledge that the CAN-bus data reverse engineering (often called ‘CAN-sniffing’) was to be performed. The decoding work involves observing non-decoded vehicle data on the vehicle’s CAN bus by using real-time data monitoring and graphing systems. The Institute for Automotive and Manufacturing Advanced Practice (AMAP) at the University of Sunderland kindly hosted the logger supplier in their facilities to carry out this work. ZCF and Newcastle University contacted EV dealerships in the region to ensure the
delivery of the different EV Models and Makes to AMAP for the duration of the reverse engineering work. In addition to the in-vehicle decoding work, an additional two weeks were needed for the system back-end parameter tuning (without the need to access the vehicle). The resulting configuration file for each vehicle Model developed before, during and after the decoding work was then incorporated into the logging devices to ensure that the encoded messages that are collected from the vehicles, would be successfully translated and usable.

2.2.3.2 Data Transfer and Storage
Once installed the data logger records all relevant activity of the vehicle when it is being driven, being charged or being parked up. When collecting data from the loggers, a data file is automatically uploaded to the back-end server for decoding once the vehicle’s CAN bus is no longer active. Each decoded file contains all the data from one specific logger for a specific period of time; these files are stored by logger ID on a secure Newcastle University server (Figure 10 and Figure 11). The individual files are then aggregated and analysed. If the vehicle is in an area with no cellular connection and is unable to connect to the back-end system; the data is stored locally on the micro SD card of the device to ensure that data are not lost and will be uploaded once the logger can establish connection.

Figure 10. Decoded data storage on server

Figure 11. Example of a decoded file for one specific logger for a specific period of time.
Software developed at Newcastle University aggregates the logger files and extracts information on driving and charging behaviour from the extensive datasets. Table 3 shows the key measures collected; some of which are used to determine compound new measures. For example, the GPS coordinates collected during a driving event are used to calculate the distance travelled during that driving event. Battery Current and Voltage are used to calculate the energy transferred.

<table>
<thead>
<tr>
<th>Measure Name</th>
<th>Frequency-Charging</th>
<th>Frequency-Driving</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time stamp</strong></td>
<td>minute</td>
<td>Second</td>
<td>DD:MM:YYYY hh:mm:ss</td>
</tr>
<tr>
<td><strong>GPS (Lat, Lon)</strong></td>
<td>minute</td>
<td>Second</td>
<td></td>
</tr>
<tr>
<td><strong>Ambient Temperature</strong></td>
<td>minute</td>
<td>Second</td>
<td>Degrees</td>
</tr>
<tr>
<td><strong>Ignition signal (On/Off)</strong></td>
<td>0</td>
<td>Second</td>
<td>0/1</td>
</tr>
<tr>
<td><strong>Charging Lead Indicator</strong></td>
<td>minute</td>
<td>0</td>
<td>0/1</td>
</tr>
<tr>
<td><strong>State of Charge</strong></td>
<td>minute</td>
<td>second</td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle Speed</strong></td>
<td>minute</td>
<td>second</td>
<td>Kph</td>
</tr>
<tr>
<td><strong>Battery Current</strong></td>
<td>minute</td>
<td>second</td>
<td>A</td>
</tr>
<tr>
<td><strong>Battery Voltage</strong></td>
<td>minute</td>
<td>second</td>
<td>V</td>
</tr>
</tbody>
</table>

Table 3. Key measures collected by the data loggers.

### 2.2.3.3 Web Portal

Additional access to a web portal developed by the logger supplier, provides charging and driving event summaries. Access to this web portal was made available to the participants on the data logger trial to enable them to monitor their own use if they wished. The web portal provides a dashboard of key performance metrics, daily utilization summarizes, graphs showing the impact that ambient temperature and eco-driving is having on EV range, trip and charge event logs, and a host of other features and visualizations of the data collected from EVs. Feedback from the trail participants suggested that, for those that used the portal, they valued the information provided to them highly. Figure 12 illustrates an example of the web portal access.
2.3 **ORIGINAL EQUIPMENT MANUFACTURER (OEM) DATA**

RCN vehicle manufacturer partners provided electric vehicle 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 event (driving; charging) for 29 RCN drivers (19 BMW and 10 Renault). The data collection period for these 29 users varied and spread between August 2013 and October 2015. Data user agreements were prepared and signed between the OEMs, the University and the drivers to ensure compliance with data protection.

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.
2.4 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. Table 4 illustrates an example of the data collected from the charging infrastructure.

<table>
<thead>
<tr>
<th>Charging Event ID</th>
<th>User ID</th>
<th>Charging Post ID</th>
<th>Start Date</th>
<th>Start Time</th>
<th>End Date</th>
<th>End Time</th>
<th>Energy Transferred (kWh)</th>
<th>Outlet Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>9108796</td>
<td>BB0C2C</td>
<td>DBTDQ_ZCF202</td>
<td>08/03/2015</td>
<td>10:32:19</td>
<td>08/03/2015</td>
<td>10:55:17</td>
<td>5.6</td>
<td>CHAdeMO 50 kW DC</td>
</tr>
<tr>
<td>4189814</td>
<td>203D26B</td>
<td>DBTDQ_ZCF198</td>
<td>08/03/2015</td>
<td>10:39:38</td>
<td>08/03/2015</td>
<td>11:10:31</td>
<td>15</td>
<td>50kW CCS DC</td>
</tr>
<tr>
<td>7696759</td>
<td>A0BF51B</td>
<td>DBTDQ_ZCF194</td>
<td>08/03/2015</td>
<td>10:59:05</td>
<td>08/03/2015</td>
<td>11:23:52</td>
<td>8.1</td>
<td>CHAdeMO 50 kW DC</td>
</tr>
<tr>
<td>1701388</td>
<td>0B65FFC</td>
<td>DBTDQ_ZCF214</td>
<td>08/03/2015</td>
<td>13:28:51</td>
<td>08/03/2015</td>
<td>13:58:29</td>
<td>14.8</td>
<td>50kW CCS DC</td>
</tr>
<tr>
<td>1967592</td>
<td>EB9AD2</td>
<td>DBTDQ_ZCF203</td>
<td>08/03/2015</td>
<td>13:29:14</td>
<td>08/03/2015</td>
<td>13:46:20</td>
<td>4.6</td>
<td>43kW AC</td>
</tr>
<tr>
<td>8807870</td>
<td>3B25D3</td>
<td>DBTDQ_ZCF194</td>
<td>08/03/2015</td>
<td>13:10:17</td>
<td>08/03/2015</td>
<td>14:28:22</td>
<td>14.9</td>
<td>43kW AC</td>
</tr>
<tr>
<td>1701388</td>
<td>0B65FFC</td>
<td>DBTDQ_ZCF214</td>
<td>08/03/2015</td>
<td>13:28:51</td>
<td>08/03/2015</td>
<td>13:58:29</td>
<td>14.8</td>
<td>50kW CCS DC</td>
</tr>
</tbody>
</table>

Table 4. Example of the charging infrastructure data
3 STUDY FINDINGS

The key areas of the study include analysis of the overall charging and driving behaviour of the EV users; understanding the EV drivers’ usage, attitudes and needs towards the rapid charge network; the environmental impact of the network and the business case feasibility of such a network. The findings from this study would inform a successful expansion of existing rapid charging networks and the development of new ones across European road networks.

Table 5 summarises the data used to meet the study objectives; the detailed data collection methodology was described in Section 2 (“EV users’ engagement strategy and data collection”).

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Focus</th>
<th>Period of data collection</th>
<th>Brief details of data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logger data</td>
<td>40 drivers</td>
<td>February 2015-December 2015.</td>
<td>High resolution spatial and temporal data on driving and charging behaviour (Table 3).</td>
</tr>
<tr>
<td>Vehicle Manufacturer electronic data</td>
<td>985 UK LEAF drivers</td>
<td>January 2013-July 2014</td>
<td>Measures on charging and driving event aggregated by month. E.g. monthly distance travelled; number of rapid charging events per month.</td>
</tr>
<tr>
<td>Vehicle Manufacturer electronic data</td>
<td>19 BMW i3 and 10 Renault ZOE drivers</td>
<td>August 2013-October 2015. (timeframe of data collection varied between users)</td>
<td>Measures on driving and charging events. E.g. total distance per event; State of Charge at the beginning and end of an event.</td>
</tr>
<tr>
<td>Charging infrastructure data (Ecotricity and ESB)</td>
<td>Over 35,000 events analysed</td>
<td>July 2014- November 2015.</td>
<td>Time and duration of transactions, energy transferred and the connector type used</td>
</tr>
<tr>
<td>Online Questionnaires</td>
<td>3 surveys (over 500 responses)</td>
<td>2015</td>
<td>Attitudinal data- see section 2.1 for details.</td>
</tr>
<tr>
<td>Electricity Carbon content data</td>
<td></td>
<td>2014-2015</td>
<td>National Grid</td>
</tr>
</tbody>
</table>

Table 5. Summary of data collection on RCN
3.1 MONITORING THE USE OF RAPID CHARGE NETWORK

RCN is rolling-out 74 rapid charging stations through UK and Ireland along the full length of Priority Project (PP) Road Axes 13 and 26 which links the UK to Ireland (Figure 13). This is a substantial real-world trial covering over 1,100 Km along major UK and Irish road network routes, which also links major seaports and International airports. 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 [8] whereas ESB ecars [9] operates the remaining sites in Northern Ireland and Ireland.

The multi-standard rapid chargers are equipped with three charging outlets supporting the charging protocols 44 kW DC CHAdeMO, 44 kW DC CCS and 43 kW AC. These chargers have been manufactured by DBT-CEV [10] and can provide an 80% charge in less than 30 minutes.

Figure 13. Map of RCN network charging points
3.1.1 **RCN 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.

On a month by month basis, the usage of the network has experienced a steady growth as new sites have become live, Figure 14 (left panel). Likewise, when the effect of new charger installations is removed, the energy drawn on a per charger basis has also been growing, Figure 14 (right panel), meaning that the usage of installed chargers is increasing every month.

With regards to the performance of individual chargers, Figure 15 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 14. Energy delivered by RCN sites on aggregate on a monthly basis (left panel) and per charging unit (right panel)](image-url)
Figure 15. Variation in monthly energy demand across RCN sites.

3.1.2 **Rapid Chargers location preference**

The quantitative and qualitative data was used to help us understand the preferred rapid charging location from the users’ perspectives. 95% of the drivers stated that their preferred location for a rapid charger were motorway service stations followed by petrol stations (Figure 16). The analysis of the RCN transactions data confirm that the most used sites on the RCN network are located at motorway service stations. Moreover, Figure 17 shows that the main motivation for using a rapid charger is to extend the range of the electric vehicle when undertaking a long journey (76%). These two qualitative findings are aligned; people perceive the rapid chargers as a mean to extend their journeys and would like them placed in locations associated with undertaking long journeys (e.g. Motorway service stations). Some of the survey participants expressed that that would like to charging stations placed at “transit points/trunk roads rather than destination points”. Moreover, they suggested to “place them at the end of a service station instead of prime locations to minimise them being ICEd”.

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1 Colloquial term meaning an Internal-Combustion Engine car has parked in a space reserved for electric vehicles.
Figure 16. Desired charging locations

Figure 17. Motivation for using the rapid chargers.
3.1.3 Additional Network data analysis

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 (Figure 18) 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. Figure 19 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).

![Pie chart showing energy distribution

Figure 18: Energy delivered by RCN outlet type.

![Line chart showing energy transferred per outlet type over time.

Figure 19: Energy transferred per outlet type over time.
Furthermore and 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. (Figure 20).

![Figure 20. Rapid Charging events transaction start times.](image)

In terms of transaction duration, the median recorded for RCN is 24 minutes and the average is just over 26 minutes as shown in Figure 21. 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 21. Distribution of Transactions duration.

3.1.4 Is charge anxiety replacing range anxiety? The paramount importance of network reliability.
A reliable charging infrastructure is key to ensure a successful uptake of electric vehicles. People making long journeys using their EVs need to be confident that rapid charging infrastructure is available and operational if they need to use it. The majority of the RCN participants reported experiencing poor reliability of rapid chargers and emphasized the need to decrease downtime due to faults. When asked “if you have arrived at a rapid charge point that has been out of service, what did you do?” only 13% responded that this was not applicable. The analysis of the network data also showed several unsuccessful transactions. Figure 22 shows the total number of successful and unsuccessful transactions, it also shows the number of events where no energy transfer was recorded even though the duration of the charge events was above 5 min. 9,798 failed charging events were collected initially, but further processing disregarded the events when the same user repeatedly tried to use the faulty charging posts in a 5-min interval. In more details, if user X arrived to faulty charging post Y and attempted to charge 3 times in 5 minutes, we considered those 3 failed attempts as one failed charging event. As a consequence, we disregarded 3401 repeated failed events.
It is vital to decrease the uncertainties regarding the charging stations and ensure that they are available in order to guarantee that EV drivers can confidently complete their long journeys without significantly increasing their journey times. In more details, the charging posts should be operational the vast majority of the time and if broken, the down time should be kept to a minimum. There should be time restriction enforcements on the charging duration to avoid instances where people slow charge on a rapid charge network. There should also be enforcements to avoid the charging posts being blocked by ICE vehicles. A 24/7 accessibility is important so as ensuring a reliable connection to validate the cards. In addition, real time information on charge point availability through the vehicles' navigation systems or phone Apps is highly desirable. Finally, increasing the number of charging posts per site (e.g. 2 or more charging stations) could mean that it is more likely to have working and available chargers on arrival.

3.1.5 Benchmarking RCN
This section benchmarks RCN against the usage seen in two other more established networks located in Ireland and Northern Ireland. NI's Department for Regional Development has kindly provided usage data from a network of 15 rapid chargers spread across the region. Likewise, ESB in Ireland has shared a similar dataset relating to 39 chargers from its national database. Those two networks are more established than RCN and the chargers' median age are 24.2
and 14.3 months respectively, for the units in NI and Ireland (which compares with 10.4 months for the 43 units in RCN analysed for this benchmarking exercise).

### 3.1.5.1 Key Performance Indicator

An average energy delivered per month across each network on aggregate is a simple, yet effective, metric that can be used to compare performance. In order to make the comparison balanced, we have only considered the charging transactions from July 2014 onwards, i.e. the first month where we have transactions for RCN. As a network, RCN is delivering, on average, 625 kWh/month which exceeds the performance of the other two networks (Table 6). On a charger by charger basis, there is a great deal of variability across the three networks as we report in Figure 23.

<table>
<thead>
<tr>
<th>Network</th>
<th>Chargers</th>
<th>Total Energy, kWh</th>
<th>Average, kWh/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>NI</td>
<td>15</td>
<td>8412</td>
<td>480.4</td>
</tr>
<tr>
<td>RCN</td>
<td>43</td>
<td>241354</td>
<td>624.9</td>
</tr>
<tr>
<td>Ireland (ROI)</td>
<td>42</td>
<td>63195</td>
<td>276.5</td>
</tr>
</tbody>
</table>

*Table 6. Network performance comparison*

![Figure 23](image)

*Figure 23. Monthly energy average delivered by the chargers benchmarking RCN; red dots denote network averages.*

### 3.1.6 The EV charging Infrastructure Dilemma

The first and last RCN online questionnaires featured two exact questions in order to capture any changes in attitudes towards the role and impact of rapid chargers on EV travel. The responses of 68 drivers who answered these questions in both surveys have been analysed. The analysis shows that people over estimated their reliance on the rapid chargers and how much they affect their driving behaviour. As an example, when the participants were initially
asked if rapid charge points help them travel more often, 85% responded yes. However, this number dropped to 56% in the final questionnaire completed 6 months later. Figure 24 and Figure 25 present the comparisons between the responses. These findings relate to the classic EV infrastructure dilemma where people need to see infrastructure for reassurance but then don't actually use it as much as they perceived they would. Nevertheless, it is important to note that over 90% of the respondents indicated that the availability of a rapid charging infrastructure increases the likelihood of purchasing an EV as their next car (Figure 26).

![Figure 24. Charging infrastructure impact on EV usage. Comparison between first and last questionnaire. (1/2)](image1)

![Figure 25. Charging infrastructure impact on EV usage. Comparison between first and last questionnaire. (2/2)](image2)
Figure 26. Impact of rapid charge points on EV purchase.

3.1.7 Charge Point Usage Prediction

If the RCN network is to be shown to be a viable option for EVs then it must be shown that that it is both appropriately situated and also that the individual charge points are showing adequate usage.

To understand this, it is necessary to generate an idea of exactly what level of RCN usage would be expected and, using this information, it is then possible to assess the feasibility of future RCN sites.

Answering this question could be achieved in one of two ways. In the first method, a purely theoretical simulation or 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. However, constructing a simulation runs the risk of introducing systematic errors which are difficult to resolve without a fundamental understating of the basic concepts underpinning charge point usage. The second technique, which was used in this work, uses real world data of rapid charging events to create a statistical model for charge point usage, which then allows each individual point to be compared to the predicted result.
In Figure 27 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 expected usage of a vehicle within these zones would likely be correlated with the demand for a refueling, 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 28 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.
The number of explanatory variables was limited to prevent overfitting the dependent variable, RCN site usage in this case.

We can see that the highest levels of predicted RCN usage are indeed in the areas we might expect, those areas with a higher car/EV density combined with a higher interurban flow. A prominent spike in predicted charging in the Northeast around Newcastle can be seen despite the lack of RCN charge points in this area. A tentative conclusion may be that extending the network up to Newcastle would be a logical next step.

One possible flaw in the model can be seen around the London area where there is a substantial reduction in the level of predicted usage over what would be expected. This is due to the lack of interurban flow data within the London area. Future models will include an "urban" traffic variable.
3.2 OVERALL CHARGING AND DRIVING BEHAVIOUR

3.2.1 Charging and driving behaviour overview
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. 11,500 charging events were collected during the 10 month trial period and Figure 29 illustrates the overall charging behaviour of the users on the trial. It can be seen that the users rely on home charging with over 70% of the charging energy transferred at home; however, when charging in public locations their preference is for rapid chargers. 15.9% of their total energy is transferred at rapid chargers and 3.5% is transferred at other public charging locations².

In addition to looking at the detailed charging behaviour, the data loggers allowed us to analyse people’s driving behaviour. Over 45,000 driving events were collected; the distribution of daily aggregated trips from the EV data loggers is positively skewed, with a median of 51 Km (Figure 30). The average daily driven distance of 61 km is within the range of an electric vehicle. The longest trip (no stopping) recorded was 151 km and the average speed of that journey was 43 kmh. Previous work have illustrated the impact of speed on range and drivers could extend the range of their car if they drive in an eco-friendly way[11].

² Fast: 7/22 kW
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.

**3.2.2 Rapid Chargers extend the driving range of Electric Vehicles.**

As mentioned above, a charging event (using any type of charger) would be required in order to undertake journeys where the total daily distance is above the driving range of an EV. In order to investigate if a rapid charger was used to enable these long daily distances (>150km); we aggregated the driving and charging events into daily events where for each event we calculated the total distance driven that day and the total number of rapid charge events. A daily event corresponds to a unique day and driver. Then we separated the daily events in two groups. The first group contains all the events with no rapid charging and the second group contains all events where people charged at least once at a rapid charger. The analysis is presented in Figure 31 and Figure 32. The first thing to note in Figure 31 is that no rapid charger events took place for the majority of the daily events (88%). While only 12% of the daily events had a rapid charge event, it can be noticed that only this second group had events above 200 km a day.
Similarly to the figure above, Figure 32 shows the density of the events represented as two distributions, one for the daily events with no rapid charging and one for the daily events with at least one rapid charge event. We can see more clearly the percentage of events >150 km. 5% of the events were above 150km and over 85% of the people who drove above 150 Km a day used at a rapid charger, indicating that the rapid chargers helped extend the driving range of EVs (range of EVs on trial and most of the EVs on the market currently is up to 150 km).

The relationship between the number of daily rapid charge events and the total daily distance is shown in Figure 33. 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% population intervals for that mean. As it can be appreciated, the relationship is very strong and associates high total daily distances with high use of the rapid charging infrastructure.
We’ve also aggregated the data by weekly events. We’ve separated the data in three groups, each represented by a boxplot (Figure 34). The median weekly driving distance increases with an increase in the number of rapid charge events indicating clearly that people are driving further when using rapid chargers.

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3 The vertical dimension of the boxes display the variation of the data. The bottom of the box is the 25th percentile of the data (transaction time value below which 25% of the observations may be found). The top of the box is the 75th percentile of the data. The horizontal bold line inside the box is the median (50th percentile of the data). The end of the whiskers (lines extending vertically from the boxes) can represent several alternative values; for this graph, we chose them to represent the minimum and maximum of all of the observations.
Finally, the relationship between driving distance and number of rapid charger events can be also strongly identified when aggregating over months. Figure 35 displays the relationship between the number of rapid charge events and the cumulative distance driven by 985 Nissan LEAF drivers between January 2013 and July 2014 (every dot represents a driver). This anonymized dataset was provided by Nissan. Similarly to the relationship seen in Figure 33, a high total distance driven is associated with high use of the rapid charging infrastructure.

![Figure 35. Total distance versus total number of rapid charge events (Nissan drivers: January 2013-July 2014)](image)

The analysis above illustrates the importance of rapid chargers to allow EV drivers to travel longer distances and extend their driving range. 72% of the online questionnaire participants responded that they would travel further with rapid chargers (Figure 24) and we used real world driving data to investigate and confirm this response.
3.2.3 Examples of EV high usage
We illustrate some examples of people who pushed the range of their EV and drove way above daily and monthly averages. Figure 36 and Table 7 describe a 379 miles (606 Km) 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.

![Nissan LEAF - 26 Feb 2015 - 379 miles](image)

Legend
- Blue markers: charging location
- Green marker: home location
- Green circles: RCN sites with data (up to end June 2015)
- Grey circles: RCN sites coming on stream
- Navy circles: Best performing RCN sites

Figure 36. 606 Km journey in one day.

<table>
<thead>
<tr>
<th>#</th>
<th>event</th>
<th>site</th>
<th>site_code</th>
<th>type</th>
<th>time_begin</th>
<th>time_total</th>
<th>soc_begin</th>
<th>soc_end</th>
<th>soc_en</th>
<th>dist_mile</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>driving</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 07:47:31</td>
<td>43.9</td>
<td>95.8</td>
<td>44.3</td>
<td>12.360</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>charging</td>
<td>16483</td>
<td>M17 8AA</td>
<td>fast</td>
<td>2015-02-28 08:31:22</td>
<td>194.2</td>
<td>44.3</td>
<td>88.8</td>
<td>10.680</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>driving</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 11:45:35</td>
<td>136.8</td>
<td>88.8</td>
<td>17.7</td>
<td>17.040</td>
<td>56</td>
</tr>
<tr>
<td>4</td>
<td>charging</td>
<td>44687</td>
<td>BB21 LRY</td>
<td>rapid</td>
<td>2015-02-28 14:24:00</td>
<td>39.0</td>
<td>17.7</td>
<td>70.7</td>
<td>12.720</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>driving</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 15:03:12</td>
<td>63.0</td>
<td>79.7</td>
<td>27.3</td>
<td>10.392</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>charging</td>
<td>ZCF201</td>
<td>PR7 SLR</td>
<td>rapid</td>
<td>2015-02-28 16:16:17</td>
<td>17.6</td>
<td>27.3</td>
<td>66.4</td>
<td>9.384</td>
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</tr>
<tr>
<td>7</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 16:33:53</td>
<td>28.1</td>
<td>66.4</td>
<td>28.5</td>
<td>9.086</td>
<td>28</td>
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<tr>
<td>8</td>
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<td>ZCF218</td>
<td>WA16 8TL</td>
<td>rapid</td>
<td>2015-02-28 17:02:00</td>
<td>27.2</td>
<td>28.5</td>
<td>77.9</td>
<td>11.856</td>
<td>NA</td>
</tr>
<tr>
<td>9</td>
<td>driving</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 17:39:12</td>
<td>50.8</td>
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<td>10</td>
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<td>WV11 THN</td>
<td>rapid</td>
<td>2015-02-28 18:29:01</td>
<td>32.1</td>
<td>16.6</td>
<td>77.7</td>
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<td>11</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 19:01:00</td>
<td>63.8</td>
<td>77.7</td>
<td>23.0</td>
<td>13.128</td>
<td>50</td>
</tr>
<tr>
<td>12</td>
<td>charging</td>
<td>20062</td>
<td>CV35 0AA</td>
<td>rapid</td>
<td>2015-02-28 20:04:58</td>
<td>20.1</td>
<td>23.0</td>
<td>68.7</td>
<td>10.906</td>
<td>NA</td>
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<td>13</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 20:25:08</td>
<td>51.8</td>
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<td>14</td>
<td>charging</td>
<td>5745</td>
<td>UX33 L1H</td>
<td>rapid</td>
<td>2015-02-28 21:16:57</td>
<td>27.8</td>
<td>16.8</td>
<td>73.9</td>
<td>13.784</td>
<td>NA</td>
</tr>
<tr>
<td>15</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 21:44:45</td>
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<td>73.0</td>
<td>26.6</td>
<td>11.352</td>
<td>51</td>
</tr>
<tr>
<td>16</td>
<td>charging</td>
<td>24475</td>
<td>KT11 3DG</td>
<td>rapid</td>
<td>2015-02-28 23:40:39</td>
<td>9.0</td>
<td>28.3</td>
<td>52.4</td>
<td>5.784</td>
<td>NA</td>
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<tr>
<td>17</td>
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<td>&lt;NA&gt;</td>
<td>&lt;NA&gt;</td>
<td>2015-02-28 23:49:40</td>
<td>39.8</td>
<td>52.4</td>
<td>23.8</td>
<td>6.864</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 7. Details of the 379 miles (606 Km) journey including the charging events.
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. The longest journey communicated though the questionnaires was 2080 Km over 2 weeks where the participants used their EV to go on holiday around Ireland, making 30 charging events in total to complete their journey, including 17 rapid charging events (Figure 37).

![Ireland Map](image)

*Figure 37. 2 weeks on holiday with an EV.*

Finally, Figure 38 and Figure 39 show the monthly driving distance versus the number of rapid charge events for a Renault ZOE and a BMW i3 drivers respectively. The yearly average driving distance in the UK is 10,000km [NTS] 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.
In the previous two sections we analysed the usage of the rapid charge network, and we collected EV users’ attitudes and needs towards the network and we analysed charging and driving behaviour using real world usage data. The findings include identifying motorway services as the preferred location of rapid chargers where the majority of the RCN chargers have now been installed. In addition, it was highlighted that the reliability of the chargers and imposing a strict charging duration are key in decreasing the uncertainty related to the availability of charging infrastructure and encouraging people to rely on it. Most importantly, we found that the rapid charging infrastructure is helping drivers to extend their journeys using...
their electric vehicles; qualitative and quantitative data demonstrated that the rapid charging infrastructure is allowing people to drive further if required.

In the following section (3.3), we will quantify the levels of emissions associated with EVs in order to demonstrate the contribution of the uptake of EVs on the reduction of GHG emissions. Section 3.4 will look at EV sales and investigate if the rapid charge networks has impacted the sales. Finally, section 3.5 will consider the feasibility of the business case for the operation of a rapid charging infrastructure.
3.3 ENVIRONMENTAL IMPACT OF EVs.

3.3.1 Introduction
Transport is the second largest contributor to GHG emissions behind the energy sector in the EU. Notably, it is the only sector which has seen a rise of GHG emissions compared to 1990 levels [1]. The EU has developed a range of policies in order to mitigate the GHG emissions from the transport sector. These policies include mandatory caps on CO₂ emissions for new cars and vans whereby car manufacturers have to ensure that their new car fleet does not emit more than an average of 130 g CO₂/km by 2015 and 95 g CO₂/km by 2020. For vans the mandatory target is 175 g CO₂/km by 2017 and 147 g CO₂/km by 2020. Additional policies include CO₂ labelling of cars defined in EU legislation to ensure that consumers are informed about the fuel efficiency and CO₂ emissions for new cars; reducing the CO₂ intensity in fuel; defining minimum levels of bio-fuels mixed into petrol; and the encouragement to move towards alternatively fueled vehicles such as electric vehicles[12][Citation].

Although Europe has generally met the 2015 target to ensure the fleet average of new cars in 2015 is 130 g CO₂/km, there is still a clear challenge to meet the 2020 new car fleet average of 95 g CO₂/km. Electric vehicles are one direct way to help OEM’s to meet their fleet target obligation. Under current UK legislation, BEVs are classed as zero tailpipe emission vehicles; emissions of a comparable new UK registered ICE vehicle are, on average, 124.6 gCO₂/km for 2014.

It is necessary to quantify the levels of emissions associated with EVs in order to accurately measure the contribution that EVs make towards meeting the CO₂ emission reduction targets.

We investigate the emissions associated with the electricity production and vehicle operation of EVs. There are no CO₂ emissions associated with vehicle operation, i.e. tailpipe emissions is zero; however, there is an environmental cost related to the generation, transmission and distribution of electricity needed to power the electric vehicles. Transport decarbonisation will not only require a substantial growth of the ultra-low emission vehicle market but will only succeed if it its accompanied by the de-carbonisation of the electricity used to power the vehicles. It is this latter source of carbon emissions that we review here in order to account for the CO₂ savings which have arisen so far as a result of the RCN project. This work builds on previous studies undertaken by Newcastle University[13], [14].

In addition, by combining the results from this analysis with literature published data, we provide a life cycle assessment between an ICE vehicle and a BEV.

3.3.2 Carbon Content of the electricity
Electricity demand in the UK 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 televised events with a high demand commonly known as “TV pick-ups”. Electricity demand including EV charging demand is met by different types of fuel sources (commonly known as fuel mix), all of which have a different carbon content.

The yearly and seasonal electricity demand variations can be clearly seen in Figure 40, which shows the daily energy variation for 2015 broken down by the fuel source. Moreover, demand also fluctuates over the course of the day influenced by different degrees of human activity as show in Figure 41 for a typical middle of the week winter day.

![Daily transmission system demand in the UK over 2015 by fuel source](image)

*Figure 40. Daily transmission system demand in the UK over 2015 by fuel source[15]*

![Power demand in the UK over a typical weekday by settlement period](image)

*Figure 41. Power demand in the UK over a typical weekday by settlement period (03 March 2015)[15].*
Data on the fuel mix used for generating Britain’s electricity for each half hour settlement period in the British electricity market is available from the official Balancing Mechanism Reporting system site [15]. The data is provided by Great Britain’s Transmission System Operator, National Grid (NG), who is responsible for balancing electricity supply and demand.

The procedure to calculate the carbon content of the electricity is set out by the UK Government through The Electricity (Fuel Mix Disclosure) Regulations 2005 [16]. Attached to those Regulations, is a "fuel mix disclosure data table", reproduced here in Table 8, which provides average CO₂ emissions rates by kWh of energy generated and broken down by fuel source.

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂ Content (gCO₂/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>910</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>380</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
</tr>
<tr>
<td>Renewables</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>600</td>
</tr>
</tbody>
</table>

*Table 8. Carbon dioxide emissions factor by power source (2015)[17]*

The carbon emissions for the electricity generated for every settlement period⁴ are calculated as an average of the emission rates weighted by the percentage of each energy source in that period. Figure 42 is the result of applying this procedure to the generation data in Figure 41.

![Figure 42. Intra-daily carbon content of the electricity generated in the UK on 03 March 2015 by settlement period.](image)

---

⁴Electricity in the UK is traded in a wholesale market with generators and suppliers entering into contracts with one another every half hour of the day; these time intervals are known as settlement periods.
As it is shown, the carbon content of the electricity is sensibly lower during the early hours of the day; it starts to increase around 05:00 in the morning, as a result of the start of the working day, and commences to drop substantially again around 22:00. Averaging again over a 24-hour period, weighted by the proportion of the daily energy used in every settlement period, produces daily averages similar to those shown in Figure 43 for 2014 and 2015. The carbon content over the winter months is substantially higher than over the summer months. Seasonal and weekly fluctuations are also clearly visible.

There are also carbon emissions which arise as a result of electricity losses produced through the transmission and distribution of the electricity. The regulations stipulate that these are to be taken into account by using an electricity loss factor of 12%.

![Figure 43. Daily (weighted) carbon content of the electricity generated in the UK during 2014 and 2015.](image)

### 3.3.3 Carbon content of electricity associated with the EV charging events
The RCN data loggers collected high resolution data on distance travelled and the associated energy demand of the EVs on trial. Specifically, over 45,000 charging events were collected over a period of 10 month; the total distance travelled was over 521,000 Km and the associated energy demand has amounted to around 95 MWh. The data has allowed us to derive an average EV energy consumption of 182.2 Wh/Km that will be used in the following calculations.

In parallel, section 3.3.2 presented the national methodology used to calculate the half-hourly averages of the carbon content of the electricity generated in the UK. These half-hourly
averages are different for each day of the year. In order to estimate the carbon content of the electricity used to recharge the EVs (g CO₂/kWh); the day and time of the charging events are required.

In order to accurately determine the carbon content of the electricity used to recharge the EVs (g CO₂/kWh); we have differentiated between the rapid charging events at the RCN network and the charging events that were collected during the data logger trial. The charging events at the logger trial includes home, public, work and rapid charging events.

The charging events data collected at the RCN network have only a start and end time of the charge event and the associated energy transferred. Using that information, the energy demand can be apportioned proportionally to 30 minutes intervals as needed to match the frequency (i.e. half hourly) of the data from NG.

The high data resolution from the loggers allows to determine the energy demand from the cars every 30-minutes with no further assumptions.

It was found that the charge time of the energy demand on the RCN chargers is substantially different from the energy demand collected by the data loggers. As it would be expected, the RCN chargers have consistent demand peaks between approximately 12:00 and 17:00, while the data loggers collected energy demand peaks at around 01:00 reflecting the impact of home charging. Further energy demand peaks in the logger data are seen around 17:30 which coincides with arrival at home after work. Figure 44 illustrates these differences.
Using the day and time of the rapid charging events only; the associated carbon content of the electricity delivered was calculated to be 460 g CO$_2$/kWh. This is equivalent to an average EV emission figure of 83.8 g CO$_2$/Km (460 g CO$_2$/kWh * 0.1822 kWh/Km).

Using the day and time of the charging events collected by the data loggers; the associated carbon content of the electricity delivered was calculated to be 445 g CO$_2$/kWh. This is equivalent to an average EV emission figure of 81 g CO$_2$/Km. It can be noted that the carbon content of electricity calculated using the data logger charging events data is lower than the number calculated using the RCN network data. This is not unexpected as most of the charging energy demand recorded by the loggers was delivered at night at home (Figure 44 and Figure 29). The electricity used at night has a significantly lower CO2 level due to the fact that carbon intensive power stations that generate the day time peak electricity demand are not operating at night.

3.3.4 Carbon emission savings of EV Km driven

The rapid Charge Network, run by Ecotricity (GB) and ESB (NI and Ireland), has delivered around 300 MWh of energy to electric vehicles between July 2014 and November 2015. Most of this energy was delivered in the GB were most chargers are installed. The energy
transferred is equivalent to 1.65 million electric km driven\(^5\) over that period. The carbon emissions savings associated with this energy delivered for recharging the EVs vary following two scenarios:

- Electricity has been generated fully from all-green sources. Ecotricity\(^6\) is a Green Energy company and the energy delivered from the recharging network is supplied from renewable energy sources[18]. As a result; the EV emissions are 0 gCO2/Km.
- Electricity has been sourced from the UK Grid\(^7\) which will be a more realistic future scenario as EV uptake increases in the future. The resulting EV emissions for rapid charging as calculated above is 83.8 gCO2/Km.

The average CO2 emissions for the UK car parc\(^8\) during 2014 was 156.6 gCO2 /Km and the average CO2 emissions for new car registrations was 124.6 gCO2 /Km [19]. As a result, 1.65 million electric km driven by conventional vehicles would emit on average 205 tons of CO2 for new registered cars and 258 tons of CO2 when considering an average vehicle taken from the existing UK car fleet. Summary is presented in Table 9.

<table>
<thead>
<tr>
<th>Electricity source</th>
<th>Vehicle type (for comparison)</th>
<th>EV emissions, gCO2/km</th>
<th>CO(_2) savings, tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable</td>
<td>Avg. UK car parc: 156.6 gCO2 /Km</td>
<td>0.0</td>
<td>257.8</td>
</tr>
<tr>
<td>Renewable</td>
<td>New UK car : 124.6 gCO2 /Km</td>
<td>0.0</td>
<td>205.2</td>
</tr>
<tr>
<td>Grid</td>
<td>Avg. UK car parc: 156.6 gCO2 /Km</td>
<td>83.8</td>
<td>119.9</td>
</tr>
<tr>
<td>Grid</td>
<td>New UK car : 124.6 gCO2 /Km</td>
<td>83.8</td>
<td>67.2</td>
</tr>
</tbody>
</table>

Table 9. Summary of CO\(_2\) savings on the RCN network up to the end of September 2015; associated with 1,320,000 Km driven.

In this section we quantified the carbon emissions savings from the RCN network associated with 1.65 million electric km driven between July 2015 and November 2015 for both renewable electricity sources and actual carbon content of the electricity in the UK. Using the day and time of the charging events and the associated carbon content of electricity in the UK ; we calculated an average EV emission figure of 83.8 gCO2/Km. However, this figure took into consideration only charging event happening at the rapid charge network. For an overall EV emission figure that would take into consideration charging events at home, work, etc… the logger data was used to take into consideration the day and time of all charging events. The average EV emission figure, as calculated above, was found to be 81 gCO2/km. As a result, it can be observed that for every car replaced from the UK car parc; an EV is saving 75.6 gCO2 per km driven (156.6 gCO2/km-81 gCO2/km). Figure 45 below shows that 95% of the

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\(^5\) Using an average EV energy consumption of 182.2 Wh/km as derived from the data loggers on the RCN trial. \(300*10^6\)Wh/182.2Wh/km=1.65million km.

\(^6\) Ecotricity generates and supply electricity from renewable energy sources.

\(^7\) 2.6% comes from ESB (Irish Grid) so the error in making this assumption is very small.

\(^8\) Car parc refers to the number of cars and other vehicles in a region or market.
RCN online questionnaire participants have replaced a conventional vehicle by an EV and they are already contributing to the reduction of carbon emissions from the transport sector for every Km they drive.

![Fuel of the vehicle replaced by the EV](image)

**Figure 45. Fuel of the vehicle replaced by the EV.**

Moreover, if an EV is chosen as the next car instead of a conventional combustion engine vehicle, every Km driven will save 43.6 gCO$_2$ (124.6 gCO$_2$/Km-81 gCO$_2$/Km). Figure 26, shown earlier in the report, emphasize the importance of a rapid charging infrastructure to encourage the uptake of EVs and contribute to the reduction of carbon emissions. In more details, over 90% of the participants replied “Definitely yes” and “Probably yes” when asked if the availability of Rapid Charge Points increase the likelihood of them choosing an EV as their next car.

The data logger trial collected over 45,000 driving events with an associated 521,000km driven. Using the average EV emission of 81 gCO2 per Km, the EVs on the logger trials have saved between 23 and 39 tonnes of CO$_2$. The savings depend on what vehicle type is chosen as a reference (new vehicle vs UK car park).

Finally, the EV emission number used is based on the electricity generation mix of 2015 which still predominately consists of carbon intensive fuel sources (i.e. coal and gas). In order to meet the UK legally binding obligation of reducing GHG emissions; carbon intensive sources in the generation mix will be replaced by nuclear and renewables. As a result, the carbon content of the electricity will drop and so will the associated EV emissions which could reach 0 gCO$_2$/Km if every energy provider in the UK follows Ecotricity’s green energy approach. 49% of the participants already have renewable energy systems installed at their homes and over 78% of the participants answered that it is “Important” or “very Important” that their charge comes from green energy. This captures the customers changing attitudes towards energy.
use and could suggest that these customers would choose a green energy option when these options become more widely available.

3.3.5 Lifecycle Assessment (LCA) emissions
We demonstrated that electric vehicles could save 43.6 gCO2 per Km driven when chosen as the next car instead of an ICE vehicle and 75.6 gCO2 per Km driven when replacing a car from the UK car parc. It could be argued that it is necessary to conduct a life cycle assessment emissions and consider the impacts generated from processes upstream in addition to the emissions related to the kms driven.

A (simplified) lifecycle assessment of an BEV versus and ICE car with the data we have derived from the EV logger trial shows that an ICE vehicle has circa a 25% higher environmental than a BEV over its lifetime (using a 225k km lifetime mileage). The relative environmental benefit of the BEV over the ICE vehicle reduces with the lifetime mileage as BEVs have a higher environmental impact at the production stage.

Processes upstream include all the stages related to vehicle manufacture and transport as well as all the phases related to the extraction, transport and further processing of the fuel. Downstream stages are mainly related to vehicle refuelling infrastructure, disposal and/or recycling. The comprehensive and aggregate assessment of the environmental impact in each of the aforementioned stages lead to a full lifecycle assessment which are widely used in company's reporting (eg, see[20]). The main stages are, however, those related to vehicle manufacture, fuel preparation (ie. electricity generation in the case of EVs) and vehicle use. By considering only these main processes and data extracted from the literature with regards to the emissions generated at the vehicle production stage [21] we have produced a LCA under two different scenarios. This assessment, although simplified, provides a good indication as to what point in time an EV is more environmentally friendly than a conventional ICE vehicle. The two scenarios we have considered are as follows:

1. An average driver, with an annual mileage of 10k km and a lifetime mileage of 150k km (ie, the car would be on the road for 15 years).
2. A higher car use driver with 15k km per year. That is a lifetime mileage of 225k km (over 15 years).

The results from the first scenario are shown in Figure 46, which indicate that the EV would be more environmentally friendly than an ICE vehicle after just 7 years from the point of purchase. Undoubtedly, an EV has a lower environmental impact at the point of use than an ICE car. But, the emissions that are generated as a result of its production are circa 57% higher; this higher production environmental gets traded-off with car use over time. The
estimated total lifecycle emissions for the ICE vehicle would be circa 24.3 tonnes CO2e, circa 16% higher than those from an EV (Table 10).

![Figure 46: LCA emissions for a EV vs an ICE. Assumed 150k km lifetime mileage. EV more environmentally friendly after 7.3 years.]

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Estimated emissions in production (tonnes CO2e)</th>
<th>Estimated lifecycle emissions (tonnes CO2e)</th>
<th>Proportion of emissions in production</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>5.6</td>
<td>24.3</td>
<td>23.1%</td>
</tr>
<tr>
<td>EV</td>
<td>8.8</td>
<td>21.0</td>
<td>42.0%</td>
</tr>
</tbody>
</table>

Table 10. Vehicle LCA based upon a 2015 vehicle with a mileage of 10k km/year over 15 years. ICE emissions are based on 124.6 gCO2/km; EV emissions are based on 81gCO2/km as derived from the EV logger trial.

The breakeven time in terms of environmental impact for the second scenario is just under 5 years (Figure 47). This is just a reflection of the higher lifetime mileage which compensates for the disadvantage at the production stage at a much higher rate. The more the car is driven, the higher the relative benefit of the EV over the ICE car. In this case, the estimated total lifetime emissions for the ICE vehicle are 33.6 tonnes CO2e, circa 25% higher than those for the EV (Table 11).
In this section, we demonstrated that the RCN network has already saved 258 tonnes of CO2 in its first 17 month of operation; in addition, we calculated the average EV emission to be 81 gCO2/Km which is significantly lower than the average emissions from the UK car parc and new car registrations. This indicates that EVs are immediately contributing to carbon reduction savings for every Km driven and encouraging their mass uptake would help the UK meet its GHG emissions targets. When an LCA was undertaken and we estimated total lifetime emissions of EV and ICE, we found that the breakeven time in terms of environmental impact when the EV would be more environmentally friendly than an ICE varies between 4.9 and 7.3 years depending on the average mileage driven in a year. Finally, the majority of the RCN participants emphasised the importance of the availability of rapid charging infrastructure to encourage choosing an EV as the next car. This is a particularly important finding that highlights the need to expand the rapid charging infrastructure. Section 3.4 looks at EV sales in the UK and Europe and investigates if the rapid charge network has impacted EV sales. The final section (3.5) in this report considers the feasibility of business models for the operation and expansion of the rapid charging infrastructure.
3.4 EV SALES

3.4.1 EV uptake in the UK and Europe
This section provides a brief review of the EV market in the UK, Ireland and, more widely, around Western Europe in order to set the scene for private investment in rapid charging infrastructure. The business case of a rapid charging infrastructure is described in Section 3.5.

3.4.1.1 ULEV9 market in the UK
Since September 2014 the ULEV market in the UK has experienced significant growth, both in terms of vehicles sold and its market penetration as a proportion of new car registrations. Although coming from relatively low figures, the latest figures from the SMMT (November 2015) show a circa 50.1% growth in BEVs year-to-date sales [22]. The UK government has been actively encouraging ULEV adoption through its Plug-in Car Grant (PiCG), which incentivises purchases of EVs with a 35% discount of the purchase value, capped at £5k[23]. Future planned changes to those incentives are likely to have an effect on future sales.

![Figure 48](image)

Figure 48. Sales and ULEV market share of ULEVs (as a percentage of new car sales) in the UK[24].

As can be seen in the time series shown in Figure 48, the ULEV sales market suffers from the same seasonality effects found in the conventional ICE market, with the highest yearly number of new registrations seen during the months of March and September each year due to the introduction of the new number plates. Additionally, there has been a considerable increase in ULEV sales since September 2014; this has contributed to a spike in ULEV penetration

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9 Defined by the UK Government as vehicles with pure electric engines, plug-in hybrid engines or, more generally, cars with tailpipe CO₂ emissions below 75 gCO₂/km and registered in the United Kingdom.
which, for the first time ever in October 2014, surpassed the 1% barrier. The uptake has consistently remained above that mark for most of the subsequent periods up to July 2015.

Whereas the majority of ULEVs sold in the UK up to the end of 2013 were BEVs, the trend has started to reverse from 2014, when approximately both types of ULEVs had an equal market share, Figure 49. Throughout 2015 and up to end of September, PHEVs sales have continued to outperform BEVs sales and represent approximately 2 of every 3 ULEVs sold. However this trend is likely to change again as a result of the new Vehicle Excise Duty rules announced by the UK Government in its 2015 Summer Budget and which financially disadvantage PHEVs in terms of car-tax levels.[25]

3.4.1.2 EV uptake comparison in Western Europe[10]

As shown in Figure 50, the biggest success story in terms of EV penetration in Western Europe is Norway where EV sales are growing very rapidly; the Norwegian EV market share stood at around 5% at the end of 2013 but it is now just short of 20% (June 2015). Norway is followed in second place, although for quite a considerable margin, by the Netherlands where market share has dropped from circa 5% in December 2013 to 3% in June 2015 (the Dutch Government withdrew registration tax incentives for EV sales as of January 1, 2014. Prior to that date, BEVs were fully exempted for the registration tax (known as BPM tax in the Netherlands); other vehicles, included PHEVs, were also exempted if they emitted up to a maximum of 88 gCO₂/km for diesel or 95 gCO₂/km for petrol vehicles.[26]). These two leading

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[10] Includes the following countries where full datasets are available: Austria, Belgium, Denmark, Finland, France, Greece, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK.
countries are followed by Sweden and Switzerland, which had a market share of around 2% at the end of June 2015. The majority of the remaining countries analyzed have a market inferior to the 1% mark.

![Figure 50](image_url) - EV sales as a % of total passenger vehicle sales[26].

### 3.4.1.3 EV stock (Western Europe)

At the end of June 2015, total stock of EV stood (passenger cars) at around 270,000 vehicles in the 16 Western European markets considered. Yearly growth rates have been very healthy but unequal and stood around 130% both in 2012 and 2013, around 80% in 2014 and 40% for the first six months of 2015 (with respect the full year in 2014).

A snapshot of how these figures are distributed by countries is provided in Figure 51 (top panel). As expected from the previous discussion, Norway and the Netherlands lead in terms of existing EV inventory. In terms of EV stock per unit of population, at the end of June 2015 Norway had almost 10 EVs per 1000 habitants, followed by the Netherlands with around 3. As shown in the bottom panel of Figure 51, most of the countries have less than 1 EV per 1000 inhabitants on their roads.
Assessing the impact of RCN on EV sales

One of the requirements of the study was to assess if a rapid charge network will have an impact on EV sales and this will be investigated in the following sections.

3.4.2.1 Impact of RCN on EV Uptake

In addition to providing an increased range and greater ease of mind for existing EV users, the creation of a wide ranging rapid charge network could lead to an increased uptake in EV usage/purchase (Figure 26) as consumers both perceive the benefits to have increased (in terms of ease of use) and the disincentives (potentially reduced range) to have decreased.

To assign an uptake in EV sales to the RCN it is not enough to simply observe an increase in EV sales. There could be multiple reasons behind an increase in EV sales (such as improvements in technology, government incentives) which are not being driven by an increase in the number of rapid charge network points. However, if the number of RCN points
within a local area is correlated with the level of EV growth then it may be presumed that there is a relationship between the charge point provision and the local uptake of EVs.

However, it is also the case that the charge point installation could be driven by the number of EVs within the area, which would lead to a spurious correlation between charge point installations and EV uptake. To alleviate this, the data was constructed such that each data point for EV growth was taken from a time period after the installation of the rapid chargers.

To numerically investigate this, an exploratory linear regression model was constructed to investigate the relationship between the local uptake of EVs compared to the local provision of RCN. Two sets of data were used to construct the model. The first model was constructed with the data from all the local authorities, the second model was constructed just with the data from the local authorities within 60 km of an RCN charge point.

The theory behind constructing two models is to remove the large number of local authorities which are not within the typical EV range. These local authorities would skew the model by decreasing the potential impact of the variables we are interested in.

3.4.2.2 Data Used Within the Model
The dependent variable within the model is derived from the growth in quarterly numbers for licensed plug-in cars/vans aggregated across local authorities. The data was obtained from the DfT produced statistical table VEH0131 “Plug-in-grant eligible cars and vans licensed at the end of quarter, UK, by location of registered keeper” [27].

The independent variables used to construct the model were obtained from a wide variety of different sources, ranging from existing datasets supplied through the government’s statistical websites through to the direct RCN data obtained through this project. The following variables were used:

1. The number of registered cars/EVs by local authority. This was supplied through the DfT data used to produce statistical table VEH0105 “Licensed vehicles by body type, by local authority, Great Britain, annually from 2010” [28].

2. Mean/median income and number of jobs by local authority. This value was assumed to be constant (or at least minimally varying) through the time frame investigated. This was supplied through Table 8 of Annual Survey of Hours and Earnings (ASHE) published by The Office for National Statistics [29].

3. Local flow levels on interurban roads. Each road within the interurban road network provides 15 minute updates on the traffic levels, using this it is possible to derive the total levels of traffic flow on local interurban routes. This is supplied through the www.data.gov.uk website using data supplied by the DfT [30].
4. Position and installation dates of RCN chargers. This data was supplied through the RCN project and contains both the RCN chargers within the project but also additional fast and rapid chargers. The position and installation dates were used to create a variable for the number of RCN points within 30km and within 60km at the specific data points. In addition to constructing a linear regression model, the decision was made to also use a Random Forest model. This was due to the increased predictive capability of the Random Forest model when compared to the more basic regression models. The linear regression models

3.4.2.3 Data Used Within the Model
The linear regression model for all sites produced a prediction with an $R^2$ of 0.38 whilst the linear regression model for the sites in close proximity to the RCN sites produced an $R^2$ of 0.51, indicating that both models need either an increase in the number of explanatory variables or an improvement in the functional form of the variables if they are to work as a predictive model. However, in both cases the significant variables for producing the regression were the car, EV and job numbers within the local area. For each of the two linear regression models neither the number of RCN points, nor the number of other charge points were seen to have any significant impact on the level of EV growth.

Using the Random Forest model it was possible to create a model which could predict >65% of the total variance in the EV uptake. However, as in the linear regression models, the majority of the explanatory power came from the local vehicle ownership statistics, rather than the presence of charge points.

Despite the comparative lack of explanatory power for the two linear regression models, the complete lack of significance for the charge point statistics indicates that the level of charge point provision, and more specifically, RCN charge point provision does not affect the level of EV uptake. Although it would be possible to improve the model through the use of more variables (such as the level of second vehicle ownership) the lack of any interaction between the RCN network and EV uptake leads to the conclusion that the RCN network has had no detectable impact on the purchase of Electric Vehicles within the UK.
3.5 Rapid Charging Infrastructure Business Models

The question we are addressing in this section is whether a proposed capital investment in rapid-charging infrastructure and its associated expenditures can be recovered over time in addition to making a return on the capital 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 with similar capabilities as those installed by RCN. The only revenue considered is that coming from the selling of the basic service (electricity). The conclusions are based on the actual costs incurred using a sample of 64 sites both in the UK and Ireland where the rapid chargers were installed during the second half of 2014 and the first half of 2015 by the RCN project.

3.5.1 Additional revenue streams

We are scoping the study to cover only revenue from selling a basic service (electricity). However, there could be other revenue-generating opportunities arising from the installation of multi-standard rapid chargers in terms of exploiting a growing number of consumers with high-disposable incomes and spare time. Figure 52, extracted from our business questionnaire, is a reflection of this statement; the drivers surveyed have said that, on average, they spent circa £8.5 while they are waiting for their EVs to be recharged.

![Figure 52. Additional driver expenditure at adjacent retailing facilities](image)

3.5.2 Fixed capital investment

Prospective investors interested in rapid charging infrastructure will incur, as a minimum, initial costs in the following areas:

1. **Charger purchase & delivery.** These costs refer to the multi-standard chargers used in RCN, which are compatible with all mainstream rapid charging capable EV brands. They incorporate 3 outlets: 43kW AC, 44kW DC CHAdeMO and 44kW DC.
2. **Installation & commissioning project management**, which include all costs related to managing the sites and subcontractors in order to complete all installation and commissioning activities successfully, including site surveys, planning permission and building warrants.

3. **DNO power connections**, which will be incurred whenever a new power connection of the premises to the local distribution infrastructure is required. It encompasses both management and civil and electrical works required for the connection. These costs are location-dependent and vary proportionally with the length of the cable being laid out and any increased capacity transformer requirements. A DNO connection has been required in circa 25% of the RCN sites.

4. **Site preparation works**. All civil and electrical engineering work required prior to physically putting the charger in place, including excavation, cabling, plinths, feeder pillars, associated switchgear and metering equipment, bay marking, signage etc.

5. **Commissioning**, which accounts for all costs related to connecting the device to the power, charger communications, limited functionality checks and safety checks.

<table>
<thead>
<tr>
<th></th>
<th>Charger purchase &amp; delivery</th>
<th>Installation &amp; commissioning management</th>
<th>DNO power connections</th>
<th>Site preparation works</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (all sites)</td>
<td>54.9%</td>
<td>7.9%</td>
<td>3.7%</td>
<td>30.7%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Average (without DNO)</td>
<td>57.0%</td>
<td>8.2%</td>
<td>0.0%</td>
<td>31.8%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Average (with DNO)</td>
<td>49.4%</td>
<td>7.1%</td>
<td>13.2%</td>
<td>27.6%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

Table 12: Costs breakdown as a percentage of the average initial FCI.

On average, the investor is expected to find circa £40k for this initial investment outlay. As a reference, the magnitude of each of these cost expenditures as a percentage of the FCI is shown in Table 12. The first row is an average which includes all sites for which costs are available. The second and third rows consider, respectively, only the sites which did or did not require a DNO connection.

3.5.3 **Annual operating cost**
The annual operating expenses can be broken down as follows:

1. **Raw material cost**, i.e. the cost of the energy used by the chargers and delivered to EV users.
2. **Site rent**. All chargers in the RCN have been placed in sites where facilities were available with no land purchases required. Hence, this is the cost associated with renting the land in those business premises.
3. **Back office running costs**. These include all the expenses related to management of the charger and user-related costs: user registration, issuing of customers smart cards, provision of real-time information regarding location and status of charge points, support for customer billing, provision of online user account capabilities and customer support in general. Likewise, it also includes any other maintenance fee in relation to software provision. All this functionality can be normally outsourced.
4. **Maintenance costs**, which cover any insurance required in case of charger breakdown.
3.5.4 Modelling assumptions
For the purpose of this study a number of assumptions have been made to model the business opportunity from an investors’ perspective:

1. Investment horizon. The charger has a *useful life* of 10 years\(^\text{11}\), which will also be the investment horizon. The charger is installed in 2015 (year 0) and will be generating revenue between 2016 and 2030.

2. Salvage value. At the end of its operational life, the charger will have a *salvage value* of 5% of its total purchase price.

3. Energy costs. In 2004, an UK non-domestic user (medium size in terms of energy consumption) paid 3.5 pence per KWh of electricity whereas in 2014, that same customer was paying 9.4 pence[31]. This change represents an annual compound growth rate of 10.4%. The assumption made in this business case is that in the next 10 years UK users will see an annual energy-cost growth rate which is half of the historical rate, i.e. 5.2%.

4. MARR (*discount rate*). A 5% rate is assumed to be acceptable.

5. Annual inflation rate. All annual operating costs are assumed to increase at a 2%. Energy costs are assumed to growth at the aforementioned 5.2%.

6. Rapid charger usability factor. This relates to the amount of time we can expect the charger to be working continuously during a day which we have capped at 65%; this implies that, providing there is enough demand, the charger could be in use for circa 16 hours a day.

3.5.5 ULEV growth scenarios
The Central CO\(_2\) abatement scenario for transport set out by the Committee on Climate Change in its Fifth Carbon Budget, if the UK is to meet its legally binding target for reducing GHG emissions by 80% (compared to 1990), relies on ULEVs reaching a market share of 60% by 2030[3]. Based on literature projections, that target translates into 2.1 million EVs sold out of a total of 3.5 million vehicle sales by 2030[32].

Our business case for rapid chargers hinges around those projections. In other words, if ULEV sales are to reach a 60% market share of total sales by 2030, the annual growth in sales required (from 2015 levels) will be circa 33% (Case 3, Table 13). Implicitly, we are also assuming that the energy demand at the rapid charging stations will grow at the same rate as vehicle sales. In recognising that there is an argument as to whether a 60% ULEV market share by 2030 is achievable (as the CCC acknowledges in its Fifth Carbon Budget report), we have considered additional growth scenarios as set out in Table 13:

1. Case 1, or Low ULEV uptake; under this scenario, EV sales would be circa 350k by 2030, giving ULEVs a market share of 10%.

\(^{11}\) DBT, personal communication.
2. Case 2, or Medium ULEV uptake, which relies on electric vehicles sales reaching a market share of 37% by 2030. This figure is the lower level of the projection interval for EV uptake in Europe, informed by a review of existing projections, made by Cambridge Economics [33].

3. Case 3. This is the CCC's Central scenario with ULEVs reaching a market share of 60% by 2030.

4. Case 4, or very high EV uptake, which although it may be unachievable, would result in a market where ICE sales have been wiped out completely. The growth rate in ULEV sales to reach that goal would be 37.7%.

<table>
<thead>
<tr>
<th>Case</th>
<th>EV uptake scenarios</th>
<th>Annual sales growth</th>
<th>Projected ULEV sales, EOY 2030</th>
<th>ULEV market share (% total sales)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>18.1%</td>
<td>349,986</td>
<td>10.0%</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>28.8%</td>
<td>1,294,994</td>
<td>37.0%</td>
</tr>
<tr>
<td>3</td>
<td>CCC's Central</td>
<td>33.0%</td>
<td>2,100,000</td>
<td>60.0%</td>
</tr>
<tr>
<td>4</td>
<td>Very high</td>
<td>37.7%</td>
<td>3,500,000</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 13. EV market share growth scenarios.

In what follows, we provide a detailed description of what profitability an investor can expect under the CCC's Central growth scenario and under two different pricing strategies; finally, we also compare the results of that Central scenario against the rest of ULEV uptake cases.

3.5.6 Revenue generation
As we have mentioned, the only revenue stream we consider is that coming from selling a recharging service; as such, business income will be dictated both by the volume of energy (or recharging services) sold and its pricing. The purpose of the analysis that follows is to investigate the sensitivity of any profitability measures to the pricing strategy adopted for a given energy growth scenario.

We have considered two different pricing scenarios:

a. Scenario 1. Although the energy may need to be sold as a recharging service, at the most basic level what the EV user is buying is electricity. Users’ preferences are leaned towards a clear pricing structure where they are charged by the amount of kWh they consume. Taking these considerations into account, this scenario sets the price of every recharging service as a variable amount, proportional to the amount of energy drawn from the charging unit; we refer to that variable price using a multiple of the purchase price the rapid charger operator has paid to the energy company. As an example, by using a multiple of three, we mean that the investor would be selling the recharging service (kWh of energy) at three times its acquisition price.

b. Scenario 2. The energy is sold by a fixed charge irrespective of how much energy users consume or time they occupy the charging bay.

12 As found in the RCN business questionnaire, more than 65% of the users prefer to be charged by the energy they consume, in kWh.
In order to rank the profitability of these pricing scenarios, we use two different measures, namely the Internal Rate of Return and the (discounted) payback time. The annual energy volume growth assumed is 33%, in line with the CCC’s Central ULEV uptake scenario\textsuperscript{13}.

**Scenario 1: variable price per charge (kWh used)**

This pricing structure is the most transparent to the user and is directly related to the product sold, i.e. energy transferred during the charging transaction.

Under our modelling assumptions, the site operator needs to sell the recharging service at a level of 2.1 times the purchase price\textsuperscript{14} if they are to break even, Table 14 (IRR=5%). At these price levels, they would recover their investment at the end of 10 years. As prices progressively increase to a multiple of 4.6, the discounted payback time reduces from 10 years to 6 years (assuming the demand stays the same) as shown in Table 14.

<table>
<thead>
<tr>
<th>Energy price multiple</th>
<th>IRR</th>
<th>Payback year</th>
<th>Discounted payback time, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>5.0%</td>
<td>2025</td>
<td>10</td>
</tr>
<tr>
<td>2.5</td>
<td>10.8%</td>
<td>2024</td>
<td>9</td>
</tr>
<tr>
<td>2.8</td>
<td>14.2%</td>
<td>2024</td>
<td>9</td>
</tr>
<tr>
<td>3.1</td>
<td>17.2%</td>
<td>2023</td>
<td>8</td>
</tr>
<tr>
<td>3.4</td>
<td>19.8%</td>
<td>2023</td>
<td>8</td>
</tr>
<tr>
<td>3.7</td>
<td>22.3%</td>
<td>2022</td>
<td>7</td>
</tr>
<tr>
<td>4.0</td>
<td>24.5%</td>
<td>2022</td>
<td>7</td>
</tr>
<tr>
<td>4.3</td>
<td>26.6%</td>
<td>2022</td>
<td>7</td>
</tr>
<tr>
<td>4.6</td>
<td>28.6%</td>
<td>2021</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 14. Profitability measures when energy is sold as a recharging service with a variable price. Investment horizon: 10 years and 33% annual energy volume growth at charging unit.

**Scenario 2: fixed price per charge**

The purpose of second scenario, is to show stakeholders how they could implement a different pricing\textsuperscript{15} strategy in order to try and maximize their return for their investment. If they decided to charge a fixed amount every time users draw energy from the rapid charger, they would need to set the pricing at a minimum level of £3.3 per charge\textsuperscript{16}. At that level, they would recover all their investment in 10 years.

\textsuperscript{13} With this growth rate, chargers will be working at full capacity (16 hours per day) only in 2025.

\textsuperscript{14} As an indication, we would expect the site operator to pay, on average, circa 10 pence/kWh in 2016; hence they would need to sell their recharging service at circa 21 pence/kWh to break even.

\textsuperscript{15} Any pricing strategy can be shown to be equivalent to the first scenario where users are charged per kWh.

\textsuperscript{16} This price is set at year 0 (2015) and updated at a rate of 2% for subsequent years. The assumption made is that, on average, an EV user would be taking 13.0 kWh per charge, which is 40% higher than the average value across all the sites in the RCN network up to the end of September 2015.
Profitability measures for other pricing levels are shown in Table 15. For example, a price of £5 *per charge*, which is in the middle of range of the pricing levels considered, would achieve an IRR of circa 18%, with the initial investment fully recovered during 2023.

<table>
<thead>
<tr>
<th>£ per charge</th>
<th>IRR</th>
<th>Payback year</th>
<th>Discounted payback time, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>5.0%</td>
<td>2025</td>
<td>10</td>
</tr>
<tr>
<td>3.5</td>
<td>6.5%</td>
<td>2025</td>
<td>10</td>
</tr>
<tr>
<td>4.0</td>
<td>11.0%</td>
<td>2024</td>
<td>9</td>
</tr>
<tr>
<td>4.5</td>
<td>14.7%</td>
<td>2023</td>
<td>8</td>
</tr>
<tr>
<td>5.0</td>
<td>17.9%</td>
<td>2023</td>
<td>8</td>
</tr>
<tr>
<td>5.5</td>
<td>20.8%</td>
<td>2022</td>
<td>7</td>
</tr>
<tr>
<td>6.0</td>
<td>23.4%</td>
<td>2022</td>
<td>7</td>
</tr>
<tr>
<td>6.5</td>
<td>25.9%</td>
<td>2021</td>
<td>6</td>
</tr>
<tr>
<td>7.0</td>
<td>28.1%</td>
<td>2021</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 15. Profitability measure when energy is sold at a fixed price per charge. Investment horizon: 10 years and 33% annual energy volume growth at charging unit.

As a final comment with regards to these pricing structures, Figure 53 shows graphically the speed at which the investment would be recovered for two, middle of the range pricing levels under each of the scenarios discussed.

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1.1.1. **Comparison of profitability measures under different ULEV uptake levels**

If the projected ULEV uptake under the CCC’s Central scenario were not to be met, investors will need to adjust their pricing structures in order to achieve an acceptable return for their investment. In general and as expected, the lower the projected ULEV market share in 2030 is, the higher the prices for the recharging service will need to be.
For example, if the yearly growth in ULEV sales was more consistent with a situation where the ULEV uptake in 2030 was low (case 1, Table 13):

1. The variable price for the recharging service will have to be set as a minimum of 3.5 times the purchase price to break even. To achieve a higher return, IRR of 15%, over the 10 years' period, prices would need to be set at a multiple of circa 5 times as shown in Figure 54 for every ULEV scenario displayed in Table 13.

2. The minimum fixed price per charge will need to be circa £5.5. For a higher return (15%), the price must be higher at £7.8 per charge as illustrated in Figure 55.

As a final commentary, there are both other marketing strategies (or pricing structures) that site owners can explore in order to maximize their return as well as other revenue streams, as we have commented in Section 3.5.1, that can add value to the business case for rapid chargers.
4 CONCLUSION AND 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 chargers in GB are operated by Ecotricity and fully integrated into Ecotricity’s Electric Highway whereas ESB ecars operates the RCN sites in Ireland and Northern Ireland. The RCN charging stations are multi-standard, equipped with three charging outlets supporting the charging protocols 44kW DC CHAdeMO, 44kW CCS and 43 kW AC. These chargers have been manufactured by DBT-CEV and can provide an 80% charge in less than 30 minutes.

Activity 6 of the RCN project (The Study) is responsible for all aspects of understanding the usage and impact of the RCN charging infrastructure installed. The key areas of the study include the EV drivers’ usage, attitudes and needs towards a rapid charge network; a predictive analysis of future network use; 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; the environmental impact and the business case feasibility of a rapid charge network.

Key to meet the study objectives is EV user engagement. Following some initial publicity from the project and a request for EV drivers to consider getting involved in the project, over 200 EV drivers expressed their interest in participating in the RCN project and took part by either completing online questionnaires, granting access to their EV electronic data which was provided by the vehicle manufacturers or by volunteering to have a logger installed in their EV.

In addition, data provided by Ecotricity and ESB on the charging network usage was analysed. Over 500 survey entries were analysed, these were collected from 3 online questionnaires with 299 unique individuals participating in total. 40 electric vehicles of users who live close to the RCN network were fitted with data loggers. These loggers collect high resolution spatial and temporal data on driving and charging behaviour. 35 loggers were installed with private individuals and 5 were installed as part of British Gas EV fleet. Data was collected between February and December 2015 and over 51,000 driving events and 11,500 charging events were captured. These equated to over 521,000 Km driven and 97 MWh of energy transferred.

Over 47,000 RCN network transactions were processed from 51 charging stations between July 2014 and November 2015; 33,000 events were successful with around 300 MWh of energy delivered.

The results show that people perceive the rapid chargers as a means to extend their journeys and would naturally want them placed in locations associated with undertaking long journeys.
(e.g. Motorway service stations). As new sites have become live the usage of the network has experienced a steady growth with energy drawn on a per charger basis also showing growth (Figure 14). The CHAdeMO outlet has been the most used delivering just over 72% of the energy (Figure 18) 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 (Figure 19). 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 (Figure 15).

It is clear that there is a popular window of usage reflected in the highest usage being recorded between 12:00 and 18:00 (Figure 20). This is significant when trying to develop a business case as revenue generation is reduced and cannot be assumed to be 24hrs. 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 (Figure 21). 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. As with the case of all equipment exposed to the elements (the rapid chargers are all outdoors) in multiple use, and in some cases misuse, together with technical problems there is down time. As such, 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 which will provide a level of certainty. It is suggested that these ‘EV fuel station’ be explored in any follow up project.

In summary, people expressed the importance of operating and available charging posts (i.e. decrease down time; reliable connection to validate the cards, 24/7 availability, enforce charging time restrictions, eliminate ICE vehicles blocking the posts; eliminate slow charging
Charge point usage prediction work confirmed that the highest levels of predicted rapid charging infrastructure usage are in areas with a higher car/EV density combined with a higher interurban flow. The prediction work used the RCN real world data of rapid charge events to create a statistical model for charge point usage, which then allows each individual point to be compared to the predicted result. Additional datasets used include local EV density, local flow density, total number of charging sites and number of cars in a local region.

The data logger trial captured the complete and detailed charging and driving behaviour of a selected number of EV users who live close to the RCN network. The users rely on home charging with over 70% of the charging energy delivered at home; however, when charging in public locations their preference is for rapid chargers. 15.9% of their total energy is transferred at rapid chargers and 3.5% is transferred at other public charging locations (Figure 29). 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 (Figure 30). Long daily driving events that are above the driving range of an EV were collected (Figure 32). 5% of the daily events collected where 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 (Figure 33, Figure 34 and Figure 35). Finally, the yearly average driving distance in the UK is 10,000km 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.

In the environmental study, we investigated the CO₂ emissions associated with the electricity production to charge the EVs and emissions at point of use (zero) and provided a simplified life cycle assessment between and ICE and an EV. This work is necessary to quantify the levels of emissions associated with EVs in order to accurately measure the contribution that EVs make towards meeting the CO₂ emission reduction targets. We calculated an EV average emission figure of 81gCO₂/km by taking into consideration electricity generation. When comparing with UK car emission figures, an EV is saving 75.6 gCO₂ per km driven when it replaces a car from the UK car parc and 43.6gCO₂/km when it replaces a new vehicle. The EV emission figure is calculated based on the electricity generation mix of 2015 which still
predominately consists of gas and coal. If the UK is to meet its emission reduction targets, carbon emission sources in the generation mix will be replaced by less carbon intensive sources and renewables which would further reduce the emissions associated with EVs. On a similar note, Ecotricity is a Green Energy company and the majority of the electricity delivered on the RCN network has been generated from all-green sources. This means that the EV emissions associated with the charging events on the RCN network are close to 0 gCO₂/km. The RCN network delivered around 300 MWh of energy that equates to 1.65 million electric km driven. As a result, the RCN network has saved 205 tonnes of CO₂ when compared against the emissions which could have been produced by a new registered car and 257.8 tonnes of CO₂ saved when compared against the UK car parc, Table 9. The life cycle assessment between an ICE and an EV considered the emissions related to vehicle manufacture, fuel preparation (i.e. electricity generation in the case of BEVs) and vehicle use. According to data extracted from the literature, BEVs have currently a higher environmental impact at the production stage; however, we found that an ICE vehicle has circa a 25% higher environmental impact than a BEV over its lifetime (using 225k km lifetime mileage), Table 11. The business case feasibility for rapid chargers was undertaken based on the findings from RCN. On average, the RCN multi-standard rapid charger cost account for 55% of the Fixed Capital Investment (FCI). The second largest expenditure related to site preparation works which accounts for circa 31% of the FCI. New DNO power connections have added, on average, 15% to the initial investment costs but only one in every four sites in RCN have required them (Table 12). We have considered four different ULEV growth scenarios which hinge around the CCC’s central scenario of a 60% ULEV market share by 2030 in the UK (Table 13). Under the lowest, most conservative growth scenario, investors could either sell the recharging service at a minimum variable price of 3.5 times their kWh purchase price or at 5.5GBP per charge. They would recover their investment in 10 years. Setting their price levels at either 5 times their energy purchase price or at 7.8GBP per charge will achieve a return of 15% and pay back the investment costs in circa 8 years. Under the CCC’s central scenario for ULEV uptake, a price multiple of 2.9 times the purchase price or a 4.5 GBP per charge will achieve a 15% return. The only revenue stream on consideration in this study is that from selling a recharging service. There are other opportunities for income generation which will add value to the investment. The findings from this study presented in this report will inform and support the expansion of existing rapid charging networks and the development of new networks across Europe.
REFERENCES

Industry Partners

NISSAN
BMW
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RENAULT
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Supporting Partners

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www.rapidchargenetwork.com

Contact: Myriam Neaimeh, Newcastle University: myriam.neaimeh@newcastle.ac.uk